13th International Conference on Development of Drylands

Converting Dryland Areas from Grey into Green

February 11-14, 2019

Proceedings

Organised by

International Dryland Development Commission

and

Arid Zone Research Association of India

ICAR-Central Arid Zone Research Institute, Jodhpur, INDIA

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International
Dryland Development Commission
2019

Organisers and Host

International Dryland Development Commission (IDDC)

The International Dryland Development Commission (IDDC), an autonomous non-governmental non-profit organization established in 1978 by the individuals and institutions interested in and concerned about the sustainable development of dry areas, is promoting all aspects of dryland studies by fostering cooperation, collaboration and networking between various international, regional and national organizations.

One of the important modus operandi of the networking of IDDC has been to hold a major scientific conference at periodic intervals to provide the opportunity to participants from around the world to exchange research results and experiences in dryland development and combating desertification. So far twelve such conferences have been organized in last 40 years, in countries which have large areas under drylands. The 13th International Conference on Development of Drylands, with the theme “Converting Dryland Areas from Grey into Green”, was organized by IDDC, from 11-14 February 2019, in collaboration with Arid Zone Research Association of India (AZRAI) and hosted by ICAR-Central Arid Zone Research Institute (CAZRI) at Jodhpur, India with an objective to share technical knowledge and innovations emerging from recent research and development efforts of various institutions and organizations around the world.

Arid Zone Research Association of India (AZRAI)

AZRAI was established in 1962, especially as conduit for scientific dialogue with arid land researchers in different parts of the world. The Association brought out its first biennial Journal, "Annals of Arid Zone" in 1963, which was later converted into a quarterly Journal. Apart from research articles, the Journal also publishes special issues on topical themes with contributions from eminent researchers worldwide.

AZRAI also periodically organizes National and International Conferences to provide a forum to dryland scientists to exchange and share their research results and experiences. The Association has so far organized 3 International and 7 National Conferences. AZRAI is playing a pivotal role in bringing scientists, planners, administrators and the public on a platform to discuss the issues of common interests.

ICAR-Central Arid Zone Research Institute (CAZRI)

The conference is hosted by CAZRI, Jodhpur which is a premier research Institute of its own kind that was established in October 1959 by Government of India on the recommendations of a UNESCO expert, Dr. C.S. Christian of CSIRO, Australia, to promote sustainable development of the Indian Arid Zone. The Institute is an integral part of the National Agricultural Research System of India under Indian Council of Agricultural Research, Department of Agricultural Research and Education, Government of India. The Institute has entered into 60th year of its establishment and this conference was organized as part of its Diamond Jubilee celebration.

During sixty years of its existence, CAZRI has provided a better understanding of the arid environment and its resources and has developed several technologies that have positively influenced the land-use and livelihood options improving the overall productivity of this fragile agro-climatic region. Located at Jodhpur, in the Thar Desert, CAZRI has been at the forefront of mobilizing scientific, technical and policy-related expertise to improve the livelihood and living conditions of the desert dwellers with a focus on improved agriculture and environmental sustainability.

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Contents

Foreword

Drylands cover about 41% of earth's land area and are home to ~38% of world population. Majority of the people of this ecosystem live in developing countries. Characterized by a fragile natural resource base, this region faces a great challenge in achieving food security. With the threat of climate change in addition, the livelihoods of more than 2.5 billion people - nearly 33% of the world population - living in these areas is at great risk. The efforts of research and development community and policy makers dealing with dry areas and aiming at sustainable management of natural resources have to be boosted in order to optimize adaptive mechanism and risk aversion elements for the dryland communities.

An approach of integrated natural resources management, customized to different dryland ecosystems, to meet the needs of dryland communities, is key for this development. Such an approach would, however, require developing intensive knowledge and understanding of the coping mechanisms to deal with drought risk, managing and restoring ecological functions, sustainably using biodiversity, and diversifying production system and livelihoods. Supporting policies and institutional options would also be needed. This integrated approach only can enable us to realize the various components included in the SDGs. Fast sharing of knowledge and capacity building of all the stakeholders in dryland is essential. Institutional reforms at the ecosystem level to bridge the divide in governance of different natural resources, including precious water, coupled with global commitment for greater coordination in legal, policy and management issues can pave the path for sustainable livelihood security in drylands and in converting dryland areas from grey to green.

The Thirteenth International Conference on Dryland Development (ICDD), with the theme "Converting Dryland Areas from Grey into Green", was organized by the International Dryland Development Commission (IDDC), from 11-14 February 2019, in collaboration with the Arid Zone Research Association of India (AZRAI), at the ICAR-Central Zone Research Institute (CAZRI), Jodhpur, India on the occasion of the Diamond Jubilee celebration of CAZRI. The objective of the Conference was to share technical knowledge and innovations emerging from recent research and development efforts of various institutions and organizations around the world. The aim was to prepare a roadmap for sustainable development of drylands areas in the face of changing climates and contribute to achieving sustainable development goals (SDGs).

The Conference provided a forum for informed discussion on these issues. Presentations made in six plenary sessions, two specialized evening lectures, eleven concurrent technical sessions and a series of posters, covering nine themes of program of this Conference, constitute the body of this volume.

Manuscripts of some presentations were unfortunately not available, but they had very valuable information. Hence, their extended summaries have been included so that those interested in getting more information on those topics and/or interested in forgoing research collaboration might contact the concerned authors.

It is hoped that the information contained in this volume would help promote research and development activities targeted to dry areas and contribute to enhancing the resilience of the dryland communities to cope with the adverse effects of changing climates. It is further hoped that it would promote, in some measures, a rational use of the fragile natural resource base of the drylands and contribute to achieving sustainable development goals.

Adel El-Beltagy
Mohan C Saxena
OP Yadav
NR Panwar
Editors

Plenary Lectures

Navigating through uncertainties: Agro-ecosystems affected by dynamic impact of climate change

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Abstract

The world population, already 7.7 billion, is expected to reach around 10 billion by 2050. This will increase global food demand by nearly 75%. Despite this grave reality, the political action remains elusive in implementing the Paris Agreement, Sendai Framework for Disaster Risk Reduction and Sustainable Development Goals (SDGs). The Sixth Assessment Report of the Intergovernmental Panel on Climate Change has examined the scenarios of rise in global temperature by 1.5ºC and 2ºC by 2050. The system transitions under changing climate are expected to be unprecedented in scale and appropriate measures are highly required to avoid them. The implementation of land-based mitigation options would require overcoming socio-economic, institutional, technological, financing and environmental barriers that differ across regions. The anticipation that climate change will have major impacts on agro-ecosystems requires continuous assessments on the local level, where the major action of adaptation will have to be taken. Avoiding the climate change impact on sustainable development, eradication of poverty and reducing inequalities will require system transition that enables increased adaptation and mitigation investments, policy instruments, the acceleration of technological innovation and behavior changes. Advanced ICT tools are being developed for research and innovation, policy modeling, prediction of desasters, development of new governance models for R&D policy initiatives, and simulation of the impact of climate change. Increasing investment in physical and social infrastructure is a key enabling condition to enhance resilience and the adaptive capacities of societies. The importance of international cooperation would increase with increasing global warming and climate uncertainty. Climate change could unite the international community, recognizing climate change as a threat to human kind. We, in dry areas, are concerned about the future of 2.5 billion people living in these areas, if temperatures were to exceed 2 ℃ as this will cause high risk for their livelihood. We need to work together as time is running out.

Introduction

The current world population is already 7.7 billion and it is expected to reach around 10 billion by 2050. This expected rise in the population would increase the global demand for food by nearly 75%. Production in the developing countries will need to be almost doubled in the face of the changing climate due to anthropological factors. In addition, 1/3 of the food produced globally is wasted every year (i.e. 45% roots, tubers, fruits, and vegetables; 25% cereals; 20% dairy, meat; 35% fish and sea food). At the same time, about 805 million people go hungry every year. It is anticipated that 4°C increase in temperature will reduce production of food (crops, fish and animals) by 50%, by the end of the century (Fig. 1).

Global yield losses of rice, maize and wheat are projected to increase by 10-25% per degree of global mean surface warming (Zhaoa *et al.,* 2017; Iizumi *et al.,* 2017). Crop losses will be most acute in areas where warming increases both population growth and metabolic rate of insects and vector-borne diseases (Curtis *et al*., 2018; Wilcox *et al.*, 2019). In spite of this grave reality, the political action remains elusive in implementing the Paris Agreement, Sendai Framework for Disaster Risk Reduction and Sustainable Development Goals (SDGs) (El-Beltagy, 2017).

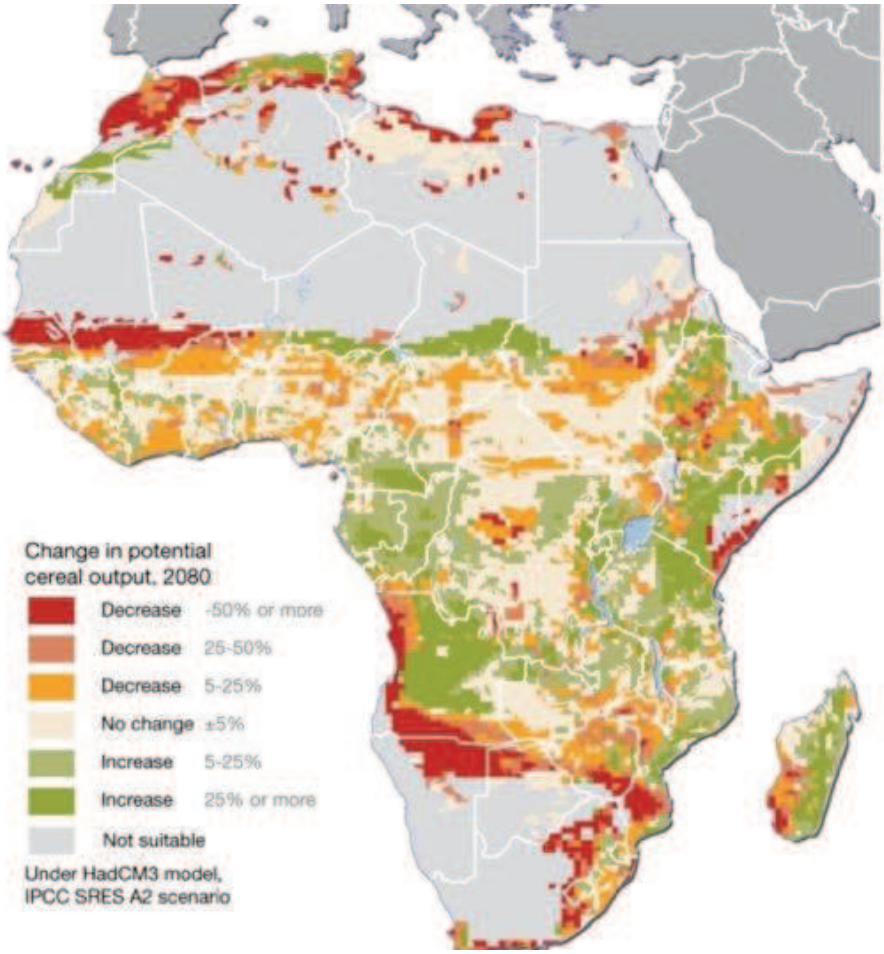

Figure 1. *Projection of global yield losses of rice, maize and wheat in Africa.*

Impact of climate change

The sixth assessment report of the Intergovernmental Panel on Climate Change (IPCC) has examined the scenarios of rise in global temperature by1.5ºC and 2ºC by 2050 (IPPC, 2018b) and measures are highly required to avoid it. Climate change (CC) will have a major impact on agro-ecosystems and hence the geographical distribution of species of terrestrial and marine organisms. This will impact bioclimatic drivers that regulate the geospatial distribution of dryland agro-ecological classes (AECs). Climate models used to assess geospatial shifts of AECs under current production practices project that CC will cause greater cropping system uncertainty, and potentially could lead to less cropping system flexibility. These projections by IPCC are counter to cropping system goals of increasing intensification, diversification and productivity (Kaur *et al.,* 2017).

The systems transitions under changing climate are expected to be unprecedented in scale, and would cut across different ecosystems (Hillel and Rosenzweig, 2010). Land use transitions under increase of temperature by 1.5ºC will be similar to the one observed in the model that projects a rise of 2ºC. Such large transition poses profound challenges for sustainable management of various demands on land for human settlements, food, livestock feed, fiber, bioenergy, carbon storage, biodiversity and other ecosystem services. The implementation of land-based mitigation options would require overcoming socio-economic, institutional, technological, financing and environmental barriers that differ across regions (IPPC, 2018a).

The real problem we need to solve in order to truly understand how earth's environment may change is that of cumulative impacts. Sometimes the science of cumulative impact is straight forward - for example, connecting habitats to provide migration corridors in response to sea level rise brought in by climate change. But even clear-cut cases require extra work, more partnerships, and more time to address. Tackling problems of cumulative dimensions is a priority if we are to find viable solutions to the real environment crises of coming decades (McNutt, 2013).

Enhancing coping capabilities through adaptation to CC

Enhancing coping capacities of the communities will require appropriate adaptation mechanism. Developing these measures would require new tools of science and technology in the fields of remote sensing and GIS/GPS; biotechnology and genetic engineering; functional breeding; simulation modeling; information technology; renewable energy; new energy-saving techniques for desalination and transportation of sea water; nanotechnology; molecular machines and devices.

Adaptation will require an intensive knowledge in the field of the following:

A. New genetic makeup:
   - Genetic engineering / Genome editing, e.g. for developing:
     - C4 rice
     - Nitrogen-fixing wheat
     - Enhanced photosynthetic pathways
     - Biotic and abiotic resistant crop varieties through functional breeding (Fig. 2 and 3).

B. New agro-management techniques related to on-farm irrigation and nutrition management; integrated pest management; Conservation Agriculture etc.:
   - Precision agriculture:
     - Moisture sensors (to conserve water)
     - Optimizing use of fertilizer nutrients
     - Remote sensing
     - Simulation modeling
     - Artificial intelligence
     - Cloud computing

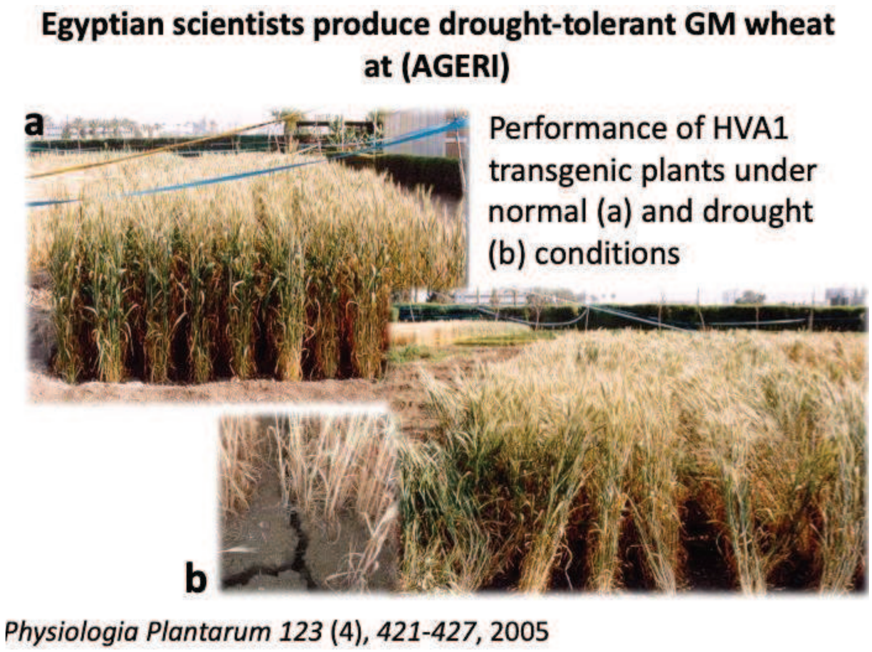

Figure 2. *Genetically modified wheat performance under normal and drought conditions.*

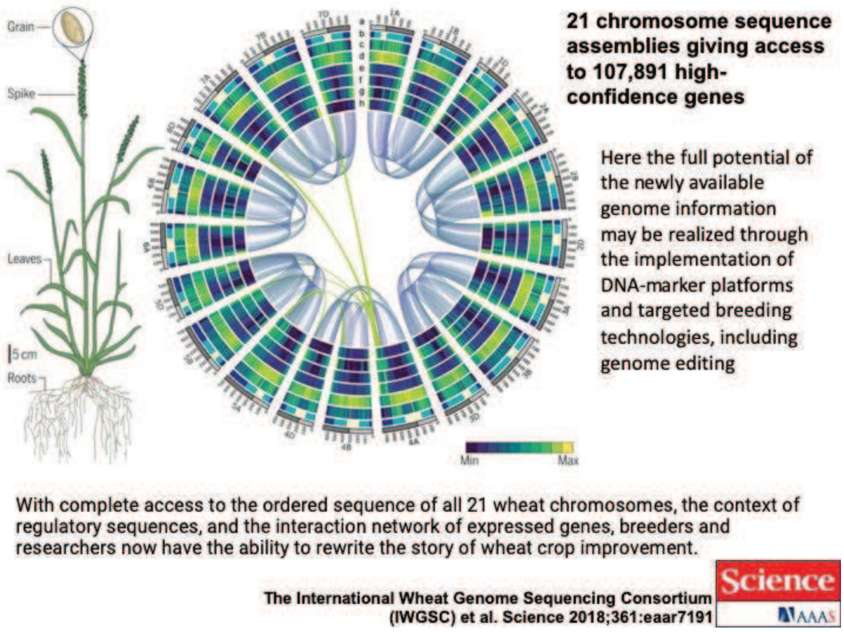

Figure 3. *A complete access to the ordered sequence of all 21 wheat chromosomes (IWGSC et al., 2018).*

Advanced ICT tools, including artificial intelligence (AI), are being developed for research and innovation, policy modeling, prediction, development of new governance models for R&D policy initiatives and simulation of their impact (Ahrweiler *et al.,* 2015). Farming 4.0 could hold the key to "produce more with less" with high yields and protection of the environment. Precision and smart agriculture will depend on AI, including machine learning, image processing, neural networks, IoT, block chain, bioinformatics, remote sensing, and modeling. Farm management through texting animals, farming data, smart tractors, survey drones for field monitoring, fleet of Agribots (robots) will be needed (Coomes e*t al.,* 2019; PAD, 2019). The importance of international cooperation would increase with increasing global warming and climate uncertainty. More interactions will be needed to ensure stable cooperation among symmetric and asymmetric players (Zhang and Hennlock, 2018).

We need to double our food production by 2050, and it is anticipated that 70% of this food would come from efficiency improved technology. Strategic themes related to these aspects include: synthetic biology; product diversification and innovation; novel drying and dehydration techniques; advance food processing technology to minimize food wastage and improve production efficiency; bio-processing (utilizing organisms, tissues, cells or their molecular components from both plant and animal product as a means to produce safe food products).

Need for local assessment of impact for developing appropriate adaptation measures

The anticipation that climate change will have major impacts on agro-ecosystems requires continuous dynamic assessments, globally, regionally, and at the local level. Failure of global assessment to support regional or local communities to cope with the predicted risk of CC impact is well known. This calls for continuous assessments on the local level, where the major action of adaptation would have to occur. Coping with uncertainty will require recognizing the fact that there will be shift in baseline as further assessment of climate change is done. This assessment will require international cooperation and national capacity building in different ecological zones. Monitoring climate variation will require the establishment of advanced national meteorological network in different local ecological zones. The continuous assessment of the impact of CC on the local level will require the introduction of different suitable crop rotation. The dynamic changes in cropping pattern and animals will have to be supported by GIS and bio-modeling to optimize performance (Fig. 4).

Avoiding the climate change impact on sustainable development, eradication of poverty and reducing inequalities will require system transitions that enable increased adaptation and mitigation investments, policy instruments, the acceleration of technological innovation and behavior changes. The value of such transition would be greater if global warming were limited to 1.5ºC rather than 2ºC (IPCC, 2018a).

Adaptation to CC and sustainable development goals (SDG)

Adaptation options that reduce vulnerability of human and natural systems, if well managed, have many synergies with sustainable development, such as ensuring food and water security, reducing disaster risks, improving health conditions, maintaining ecosystem services and reducing poverty and inequality. Increasing investment in physical and social infrastructure is a key enabling condition to enhance resilience and the adaptive capacities of societies. These benefits can occur in most regions with adaptation targeting 1.5ºC of global warming (Fig. 5).

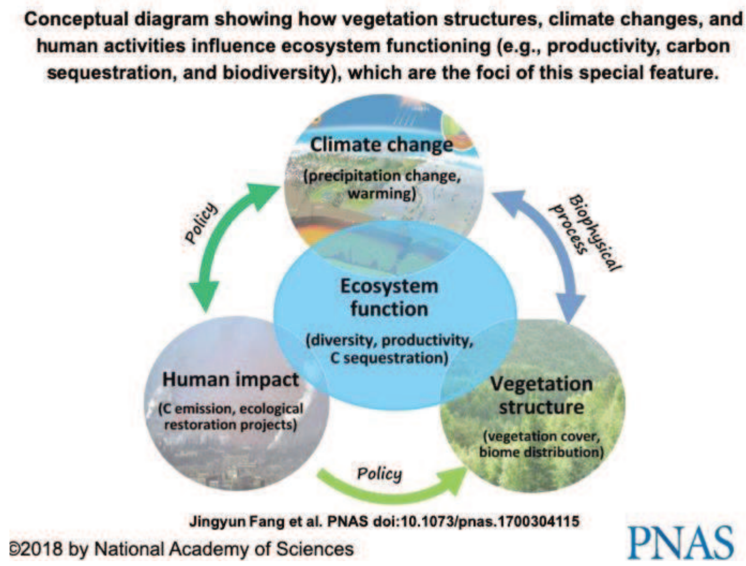

Figure 4. *Conceptual diagram showing how vegetation structures, climate change, and human activities influence ecosystem functioning.*

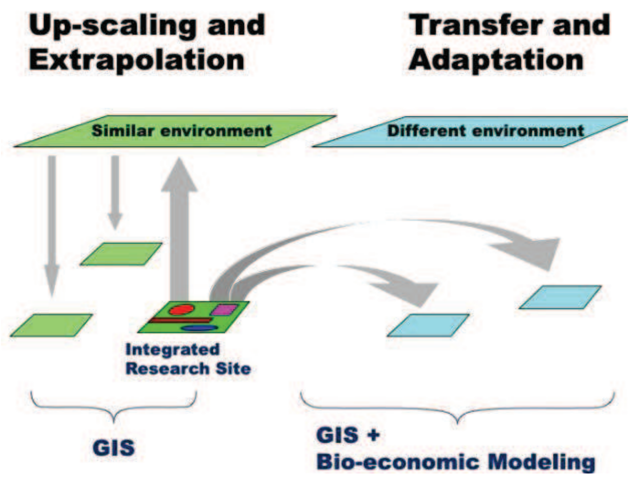

Figure 5. *GIS and bio-economic modeling for up and out scaling innovations.*

Sustainable development supports, and often enables, the fundamental societal and systems transitions and transformations that could help limiting global warming to 1.5ºC. Such changes facilitate the pursuit of climate resilient development pathways that achieve ambitious mitigation and adaptation in conjunction with poverty eradication and efforts to reduce inequalities (El-Beltagy, 2017).

Strengthening the capacities for climate action of national and sub-national authorities, civil societies, the private sector, indigenous peoples and local communities can support implementation of ambitious actions plans that would limit global warming to 1.5ºC. International cooperation is a critical enabler for developing countries and vulnerable regions to strengthen their action for the implementation of 1.5ºC - consistent climate responses, including through enhancing access to finance and technology and enhancing domestic capacities, taking into account national and local circumstances and needs.

Collective efforts at all levels, in ways that reflect different circumstances and capabilities, in the pursuit of limiting global warming to 1.5ºC, taking into account equity as well as effectiveness, can facilitate strengthening the global response to climate change, achieving SDG (United Nations, 2015) (Fig. 6).

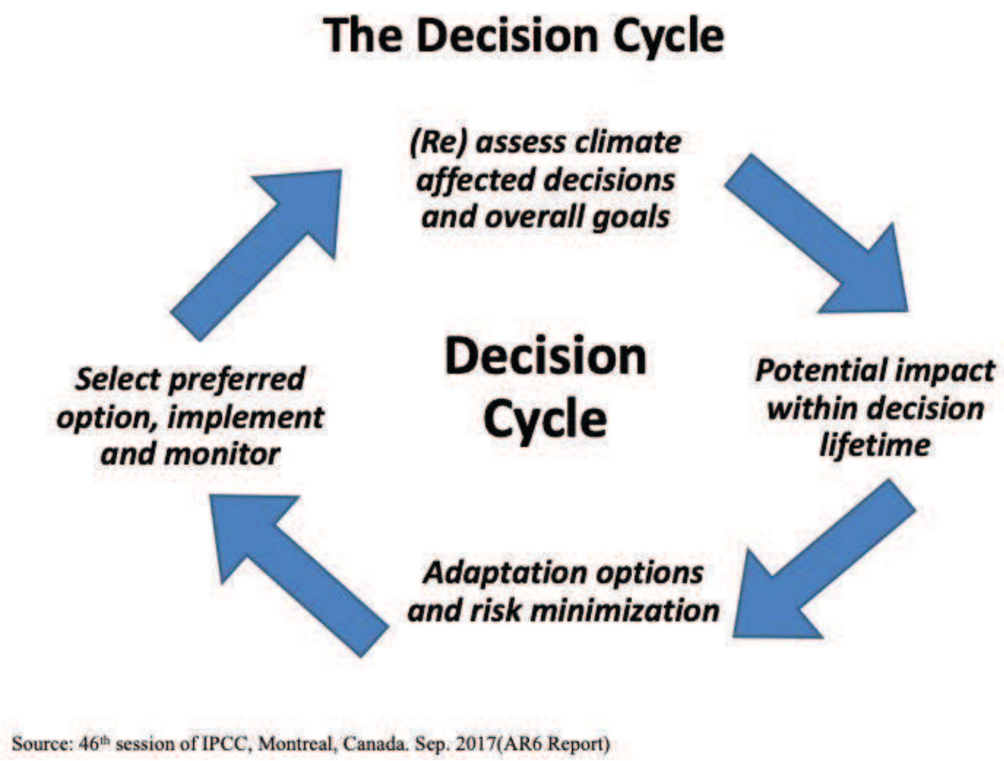

Figure 6. *The decision cycle (Source: 46th session of IPCC, Montreal, Canada. Sep. 2017, AR6 Report)*

Action-oriented knowledge networks for dealing with CC

There is an urgent need for establishing an action-oriented knowledge network to accelerate and enhance the effort to develop local assessment of the impact of climate change and facilitate more precise prediction of agro-ecosystem sustainability and future change. An attempt to create knowledge network is being noticeable in US, Europe, Asia and other regions. A group of concerned scientists and experts started a Regional Action in Climate Change (RACC) in 2009, which has been established within the context of the Science and Technology for Society (STS) Forum. The group created an adjunct session to the STS Forum in Kyoto, Japan to discuss the challenges CC poses for governments, organizations and regions as they develop adaptation strategies (STS Forum, 2018).

RACC is based on 'Knowledge Action Networks' to connect the global science, technology, and policy communities to realize locally applicable solutions. These are sponsored social networks connecting the generators of pertinent knowledge with local actors and decision makers. Every region has knowledge leaders who can forge relationships with local decision-makers, but often there aren't enough of them. The critical mass sufficient to characterize the multiple impacts of climate change and communicate them to decision makers is often lacking. The objectives of the RACC are: (1) Learning from each other's experiences, issues, problems and solution approaches, and from the integration of local and traditional knowledge with newest advances in science and technology; (2) Creating a growing community of individuals across societal institutions and disciplines who talk the same language; (3) Developing templates based on local cases for successful solutions in CC adaptation; and (4) Building capacities around the globe for dealing efficiently with local challenges for successful CC adaptation. RACC, in its 10th meeting in October 2018, agreed to mobilize the effort for harnessing the synergy between the existing and newly established network. The link with 'Future Earth' initiative is helping to enhance this process.

International cooperation a key to enhance resilience to CC

Climate change could unite the international community, recognizing climate change as a threat to human kind. The International Monetary Fund has called on developed nations to take urgent measures to help climate-vulnerable developing countries better cope with the impacts of climate change. Such measures include financing targeted infrastructure projects and mechanisms to share risk.

Following COP24 (Katowice, Poland 2018), it is now confirmed that it is impossible to reach the objectives of the Paris Agreement regarding the reduction of carbon emissions. As demonstrated by most recent analysis of the IPCC, and many other reliable sources, the planet is on the way to a global temperature increase of about 3°C, inevitably leading to upheavals and a global climatic collapse. UN Secretary General emphasized this in September 2018 by stating that "If we do not change course by 2020, we risk missing the point where we can avoid runaway climate change, with disastrous consequences for people and all the natural systems that sustain us". It is projected that IPCC AR6 Synthesis Report will be finalized by the first half of 2022. Therefore, the time is running and action is highly needed. The lack of political will lead to a disaster.

We, in the dry areas, are concerned about the future of 2.5 billion people living in these areas, if the temperatures were to exceed 2°C, causing high risk for the livelihood of this section of the global population. We aspire for a shift of consciousness on the part of the 'have' and the 'have not', and a new understanding of oneness of humanity.

References

Ahrweiler, P., M. Schilperoord, A. Pyka and N. Gilbert. 2015. Modeling research policy: Ex-Ante evaluation of complex policy instruments. *Journal of Artificial Societies and Social Simulation* 18(4): 5.

Coomes, O.T., B.L. Barham, G.K. MacDonald, N. Ramankutty and J. Chavas. 2019. Leveraging total factor productivity growth for sustainable and resilient farming. *Nature Sustainability* 2: 22-28.

Curtis, P.G., C.M. Slay, N.L. Harris, A. Tyukavina and M.C. Hansen. 2018. Classifying drivers of global forest loss. *Science* 361(6407): 1108-1111.

El-Beltagy, A.S. 2017. Achieving sustainable development goals (SDG) in the dry areas - a myth or real possibility. In: Proceedings Sustainable Development of Drylands in the Post 2015 World (El-Beltagy, A.S. and Mohan C. Saxena (eds.)). Twelfth

International Dryland Development Conference, 21-24 August 2016, Alexandria, Egypt. International Dryland Development Commission. pp 13-22.

Hillel, D. and C. Rosenzweig (eds). 2010. Handbook of Climate Change and Agroecosystems: Impacts, Adaptation, and Mitigation. ICP Series on Climate Change Impacts, Adaptation, and Mitigation Vol. 1. Imperial College Press.

IPCC. 2018a. Final report of 48th Meeting, Korea, Oct. Earth Negotiations Bulletin. A Reporting Service for Environment and Development Negotiations. Vol. 12 No. 734. 9 Oct. 2018. Online at: http://enb.iisd.org/climate/ipcc48/

IPCC. 2018b. Summary for Policymakers. *In*: Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [V. Masson-Delmotte, P. Zhai, H.O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, T. Waterfield (eds.)].

Iizumi, T., J. Furuya, Z. Shen, W. Kim, M. Okada, S. Fujimori, T. Hasegawa and M. Nishimori. 2017. Responses of crop yield growth to global temperature and socioeconomic changes. *Scientific reports* 7: 7800. DOI:10.1038/s41598-017-08214-4.

IWGSC (International Wheat Genome Sequencing Consortium) *et al.* 2018. Shifting the limits in wheat research and breeding using a fully annotated reference genome. *Science* 2018 Aug 17; 361 (6403). pii:eaar7191.doi: 10.1126.aar7191.Epub 2018 Aug 16.

Kaur, H., D.R. Huggins, R.A. Rupp, J.T. Abatzoglou, C.O. Stöckle and J.P. Reganold. 2017. Agro-ecological class stability decreases in response to climate change. Projections for the Pacific Northwest, USA. *Frontiers in Ecology and Evolution* 5: 74. doi: 10.3389/fevo.2017.00074

McNutt, Marcia. 2013. Climate change impacts. *Science* 341(6145): 435.

PAD (Precision Agriculture for Development). 2019. PAD Q2 Report. 32 Atlantic Avenue, Pilot House - Lewis Wharf, Boston, MA 02110 USA.

STS Forum. 2018. Science and Technology for the Future of Humankind. STS Forum 2018: 15th Annual Meeting, Kyoto International Conference Center, October 7, 2018, (www.stsforum.org).

United Nations. 2015. Transforming our World: the 2030 Agenda for Sustainable Development. Resolution adopted by the General Assembly on 25 September 2015. Report no. A/RES/70/1.

Wilcox, B.A., P. Echaubard, M. de Garine-Wichatitsky and B. Ramirez. 2019. Vector-borne disease and climate change adaptation in African dryland social-ecological systems. *Infectious Diseases of Poverty* 8:36. https://doi.org/10.1186/s40249-019-0539-3

Zhang, Xiao-Bing and Magnus Hennlock 2018. The benefits of international cooperation under climate uncertainty: a dynamic game analysis. *Environment and Development Economics* 23(4): 452-477.

Zhaoa, C., B. Liub, S. Piaoa, X. Wanga, D.B. Lobelli, Y. Huangj, M. Huanga, Y. Yaoa, S. Bassuk, P. Ciaisl, J. Durandm, J. Elliottn, F. Ewertp, I.A. Janssensr, T. Lis, E. Lint, Q. Liua, P. Martreu, C. Müllerv, S. Penga, J. Peñuelasw, A.C. Ruaney, D. Wallachz, T. Wangg, D. Wua, Z. Liua, Y. Zhub, Z. Zhua, and S. Assengf. 2017. Temperature increase reduces global yields of major crops in four independent estimates. *PNAS* 114: 35.

Maize and wheat science for alleviating the pressure on natural resources in drylands

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Extended Summary

Two of the world's most important staple grains, maize and wheat, account for a quarter of the total crop area harvested globally (OECD-FAO, 2014) and provide 19% of the total calories available (FAO, 2015). Research on maize, wheat and rice agri-food systems lies at the heart of the solution to feeding more than 9 billion people by 2050.

Today's challenging times mirror the Green Revolution of the 1960s. We face growing demand for cereals, including maize and wheat, due to the rising worldwide population with changing dietary preferences whilst having to alleviate the pressure that agriculture places on our planet.

We have reached the limits of cultivated areas. Aquifers are being depleted. Climate change related drought and heat stresses and disease and insect-pest outbreaks are causing massive crop failures especially in the tropics. At the same time, nearly 815 million people still go to bed hungry (WFP, 2017).

Although sometimes criticized for its environmental impact, without the Green Revolution and the long-term increase in food crop productivity and lower food prices it brought, the world would have experienced "a human welfare crisis" (Evenson and Gollin, 2003). The high-yielding wheat varieties and improved farming practices developed by Norman Borlaug and his team in Mexico during the 1950s and introduced into South Asia in the 1960s saved hundreds of millions of people from starvation and helped to promote science-based agriculture in developing countries to produce more from less and reduce pressure on natural resources.

Today, high-yielding, abiotic stress tolerant and disease-resistant wheat varieties based on the pioneering efforts of Borlaug and generations of scientists following his footprints are sown on 70 million hectares worldwide. Around 50% of all the improved wheat varieties grown today in the developed and developing countries are based on CIMMYT lines or have significant contributions from CIMMYT wheat germplasm.

CIMMYT's Maize Program in Asia focuses on enhancing maize yields in the tropics by incorporating tolerance to key abiotic stresses (drought, heat, water logging) and resistance to major diseases, without compromising on grain yields under optimal conditions. Selected stress-resilient hybrids with combination of traits relevant for Asian smallholders have been developed and licensed to public sector and seed company partners in the region for deployment and scale-out to help smallholder farmers in vulnerable ecologies of South Asia.

The Fall Armyworm (FAW, *Spodoptera frugiperda*), a highly destructive insect-pest indigenous to the Americas, was reported in Africa in January 2016, and since then has spread to more than 40 countries. While the pest is capable of feeding on more than 80 plant

species, it prefers maize, a staple food for more than 200 million people in sub-Saharan Africa. FAW was reported for the first time in India in July 2018 in the southern state of Karnataka. CIMMYT is playing a key role in the fight against FAW in Africa with international and national partners through an integrated pest management strategy (Prasanna *et al.*, 2018). The team is also intensively screening maize germplasm for native genetic resistance to FAW in screen houses in Kiboko, Kenya. Together with IITA, under the CGIAR Research Program MAIZE, CIMMYT has established a FAW R4D International Consortium, which brings together more than 35 diverse institutions in public and private sectors to explore ways to work on solutions to tackle FAW in parts of the world where it is prevalent (Fig. 1).

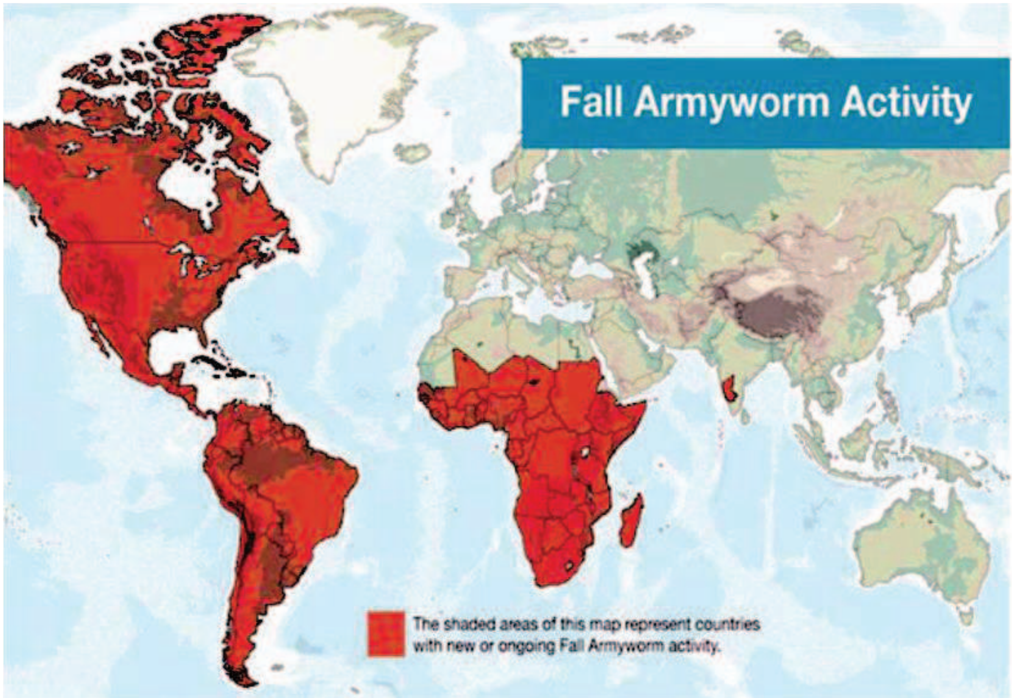

Figure 1. *Global Fall Armyworm activity in 2018. (Credit: CIMMYT)*

As experts of the UNCCD warn in the 2017 *Global Land Outlook*, maximizing the productivity of land without undermining its ecosystem services, often referred to as sustainable intensification, is one of the greatest challenges of the 21st century. It seems that farming overall has become more productive but less sustainable in the last few decades, and is now exceeding acceptable limits for stressors such as nitrogen levels in the ecosystem (DeWitt, 2009; Rockstrom *et al.*, 2009).

Appropriate mechanization can support the sustainable intensification of agri-food systems, helping to improve resource (soil, labor, water) use and providing social benefits like increased income, employment, food security, and less drudgery. Adoption of agricultural mechanization in Africa, Asia, and Latin America has reaped many benefits. For example, farmers in many parts of Africa and Asia are saving up to 45 days of labor with direct-seed machinery in conservation agriculture systems, compared to conventional methods (Fig. 2).

Figure 2. *Appropriate mechanization can support the sustainable intensification of agri-food systems, helping to improve resource use and providing social benefits. (Credit: CIMMYT)*

In Bangladesh, CIMMYT's work with partners (Krupnik *et al.*, 2017) showed that by switching to surface water irrigation, farmers can greatly increase crop production, even in the face of soil and water salinity constraints. A recent study identified over 121,000 hectares of currently fallow and rainfed cropland that could be placed under irrigation.

Laser-assisted land leveling introduced in India in 2001 (CIMMYT-IRRI-NARS collaboration) in rice-wheat systems of the Indo-Gangetic Plains is a major success story. Adopted on over 5 million ha, the technology is potentially saving 10 km^3 water and benefiting millions of resource-constrained farmers (Jat *et al.*, 2016). This saved water is being used for sustainable intensification to produce more from same or less land in irrigated areas, thereby limiting horizontal expansion of cultivated land, which essentially comes from dryland/rainfed areas.

From the 1990s, CIMMYT scientists have worked with national agricultural research system partners and advanced research institutes in India, Nepal, Bangladesh and Pakistan to test and promote a resource-conserving approach of sowing wheat seed directly into untilled soil and rice residues in a single tractor pass, also called zero tillage. Its environmental benefits - now used on as much as 1.8 m ha in India - include healthier soils, significant water savings and a 90 kg ha^{-1} reduction in greenhouse gas emissions. In India, for smallholder precision nutrient management, decision support tools (Nutrient Expert™), calibration curve for GreenSeeker™ sensor (Variable Rate Technology) and Android phone-based app to support GreenSeeker™ calibration have been developed and validated through large on-station and on-farm participatory validation trial wheat-based systems. Recent research on sub-surface drip irrigation and fertigation, layered with conservation agriculture based management, have shown game changing pathways for future food security while conserving critical natural resources (water, soil) with minimal environmental footprints.

Achieving sustainable intensification requires further massive efforts including use of climate-resilient crop varieties, improved agronomic practices, enabling policies, and institutional innovations. Crops like maize and wheat have to be viewed as components of complex farming systems that may also include livestock, trees and off-farm employment. Stronger partnerships are required to tackle production constraints in wider social, economic and environmental contexts.

References

DeWitt, Calvin B. 2009. Unsustainable agriculture and land use: restoring stewardship for biospheric integrity. In: *Crisis in Creation* (Robert S. White, FRS ed.) Cambridge University, London: SPCK publishers, pp.137-156.

Evenson, R.E. and Gollin, D. 2003. Assessing the impact of the Green Revolution, 1960 to 2000. *Science* 300: 758-762.

FAO 2015. FAO Statistical Pocketbook World food and Agriculture. pp 231.

Krupnik, T.J., Schulthess, U., Ahmed, Z.U. and McDonald, A.J. 2017. Sustainable crop intensification through surface water irrigation in Bangladesh? A geospatial assessment of landscape-scale production potential. *Land Use Policy* 60: 206-222.

OECD/Food and Agriculture Organization of the United Nations 2014. OECD-FAO Agricultural Outlook 2014, OECD Publishing. http://dx.doi.org/10.1787/agr_outlook-2014-en

Parasanna, B.M., Huesing, J.E., Eddy, R. and Peschke, V.M. 2018. Fall armyworm in Africa: *A guide for integrated pest management*. VII, II. México, CIMMYT, USAID. pp 109.

Rockström, J., Steffen, W., Noone, K., Persson, A., Chapin, F.S., Lambin, E.F., Lenton, T.M., Scheffer, M., Folke, C., Schellnhuber, H.J., Nykvist, B., de Wit, C.A., Hughes, T., van der Leeuw, S., Rodhe, H., Sörlin, S., Snyder, P.K., Costanza, R., Svedin, U., Falkenmark, M., Karlberg, L., Corell, R.W., Fabry, V.J., Hansen, J., Walker, B., Liverman, D., Richardson, K., Crutzen, P. and Foley, J.A. 2009. A safe operating space for humanity. *Nature* 461: 472-475. http://dx oi.org/10.1038/461472a.

WFP 2015. Hungry Map 2015. World Food Programme. https://www.acww.org.uk/ assets/ wfp275057.pdf

Role of traditional knowledge combined with innovative technologies and systems approaches in achieving livelihood resilience in dry areas in the face of climate change

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Extended Summary

Climate change is a reality and its adverse effects are more pronounced in drylands, leading to vulnerable, unsustainable and unpredictable farming due to a range of changed edapho-climatic factors arising from variability and evolution of climate, diet and demography. Drylands, delineated into rainfed, irrigated, agro-pastoral and desert farming, cover more than one third of planet's land and are home to more than one-third of the population. Without access to information and technology, farming in these lands can greatly suffer during dry seasons and face catastrophic losses during periodic droughts. Over the decades and centuries, the farming techniques have changed from traditional, where most of farm operations used to be done manually, to modern farming which is more productive in term of land and labour but highly dependent on industrial and financial inputs. However, by 2050, we expect a population of 9 billion that will cause a "perfect storm" of food, energy and water shortages as demand for fresh water, food and energy will climb by 30%, 70% and 100%, respectively. Therefore, a paradigm shift is needed to produce more nutritious food from less land, water, and inputs without further pressure on the declining natural resources. ICARDA and its national and international partners aim to develop this new paradigm for the drylands with a smart combination of traditional knowledge and new technologies, using multicriteria and multiscale systems methodologies to build resilient and sustainable agroecosystems.

The value of traditional knowledge

The traditional practice and knowledge still have great relevance and contribution to dryland farming, more significantly in the developing world. In Africa and Asia a lot of ancestral techniques and land races of dryland crops are still in use for crop production, water conservation, soil health management, animal feeding, grain storing and value addition of plant and animal products. For example, farmers have a long history of experience on water harvesting, retention and use for feed and food production. This includes prevention of soil erosion on flat farms mounding the land into long furrows and traps water around the plants; furrows of bunds along contour lines or terraces to limit soil erosion and allow rainwater to infiltrate into the soil and terraces; soil cover with organic mulch to prevent evaporation; land fallowing to store moisture in the soil for the following crop. These all emanate from farmers' experience, which has been transmitted from generation after generation.

Most of these traditional farming techniques developed prior to modern agro-technological revolution, in a period of true conservation agriculture (CA), a time during which farmers developed thousands of crop varieties and animal breeds over centuries. They accomplished CA through natural crossing and the selection of appropriate crops and varieties, which are adapted to local soil and biotic, climatic (drought, heat, flood, storms) and socio-economic conditions. Farmers in this era restored soil fertility through periodic addition of natural materials such as household wastes, composts and manures, and adopting practices such as crop rotation especially with N-fixing legumes and mixed cropping. Farmers replanted their own seeds and exchanged their seeds and animal breeds with others, thereby spreading new technologies far and wide while coincidentally preserving biodiversity on farmlands.

Almost unaware of the scientific breakthroughs, debates and discussion over climate change and its impact on dryland production systems, the traditional agrarian practices of indigenous communities in Asia and Africa have evolved but integrated some resilience based on crop/livestock diversity and soil fertility. Along with low-cost technologies, those traditional farmers grow variety of crops (rice, millets, legumes, sorghum, leafy and other vegetables, medicinal plants, tubers) throughout the year, thus ensuring that their food and nutritional requirements are met. In many farming communities, as many as 80 different crops are grown for household needs. Farmers also practice mixed-cropping and inter-cropping to be resilient against total crop loss due to climatic variability, pests and diseases. For example intercropping and agroforestry are contributing to the conservation of prey-predators as a means of biological control (birds, spiders, flies) instead to using insecticides. Today some farmers of South Asia (most particularly the indigenous and hilly area tribes) are going back to farming as they used to do before introduction of high-yielding crop varieties, hybrid seeds, synthetic fertilizers and pesticides.

The limitations of traditional knowledge

Modernization of agriculture during the green revolution took a different pathway and focused on a limited number of crops and varieties, field mechanization and the use of synthetic input (fertilizers, herbicides and pesticides) as well as water for irrigation. These cropping systems are now seriously contested in a 'One Health' approach of nature and human health. However, this paradigm shift was also essential to increase total factor productivity in order to meet the rapidly increasing food demand and the globalization of markets for most staple crops.

This trend is likely to accelerate in the future and any new paradigm for ecological intensification of agriculture should keep it as a baseline component. In this context, the traditional knowledge of farmers faces several limitations, which need to be addressed by research-for-development institutions like ICARDA:

- Replacing synthetic input by soil and ecosystems natural processes makes any solution site-specific for a proper matching, for example of the nutrient crop requirements and soil organic matter mineralization, both processes being highly sensitive to climate (rainfall, temperature). Replacing "knowledge embedded" technologies like mineral fertilizers by ecosystem-based production of nutrients makes farming a more 'knowledge intensive' and 'site-specific' business. This is one of the challenges today for researchers, advisors, farmers, and policy makers. Capacity development of stakeholders becomes key in this context.

- Use of traditional knowledge for the design of modern sustainable farming systems is facing a serious discrepancy between the data availability (mostly on production) and the need for multicriteria (biodiversity, water, energy, product quality and safety) and multi-scale analysis (farm, supply chain, landscape) required to design the agriculture of tomorrow. Similarly, gender and youth consideration has not necessarily been taken into account in the traditional farming systems but cannot be ignored today.
- Agro-ecological practices have been developed by farmers over long periods with a trial-error approach, which can impair innovation in face of an uncertain climate and with the high risk aversion of smallholder farmers. In face of global changes (climate, economy) this approach has to be re-visited in order to address the design of farming systems on a short term (few years) and taking into account potential risks and impacts.

The role of research-for-development organizations

The above-mentioned three limitations are taken into account by ICARDA and its partners in their research and capacity development activities. This can be described along the four outcomes of our R&D projects.

Improvement of technologies and crops

There are many examples (e.g. www.icarda.org) of traditional practices, which have been refined and made more efficient with modern scientific innovations: cultivars with improved resistance to pest and disease, drought and heat resistance, grain quality; rainwater harvesting at field and basin levels, etc. This approach aims to improve one of the components of the farming system (that we call “component research”). It has contributed substantially to improve biophysical and economic productivity of water, land and labour in the drylands.

Innovation is sometimes also derived from the modernization of traditional crops. For example, smallholder farmers in semi-arid environments have limited resources to improve the supply of animal feeds. Cactus pear (*Opuntia ficus-indica*) is an ideal candidate that can grow in degraded land with minimum inputs.

The yield improvement must be done in a multicriteria analysis, in order to combine it with biophysical and economic productivity of water and fertilizers in face of soil and climate variability. This can be done with crop models, properly calibrated and then applied for simulating scenarios of fertilizer and irrigation application using long term weather datasets.

Capacity development of farmers

The above example also illustrates how research can provide access to farmers and advisors on quantitative analysis of input-output relationships in crops, empowering farmers with a better knowledge of the system they manage and allowing them to conduct risk analysis of implementing a new variety or a new technique in an uncertain climate and market. Applications in this domain are rapidly expanding and we are working to allow farmers and advisors to access with their smartphone knowledge on crops and varieties, pest and disease, input, markets and climate (www.icarda.org).

Systemic design and management of cropping systems

As shown above the improvement of sustainability and resilience of farming systems cannot rely on individual technologies (characterized above as "component research") and their application in a wide range of agro-ecologies. This is why ICARDA is also conducting a "system-based research" where the innovation is grounded in the smart management of interactions (Genotype x Environment x Management) between the components (soil, crops, livestock, trees, water) of the farming systems in specific agro-ecologies and socio-economic contexts.

Integration of improved varieties of pulses in the existing crop-livestock systems can drive more efficiency, productivity and resilience in drylands of India, provided they are also properly integrated into added-value chain in the food system. Smallholder farmers in South Asia can increase the intensity and diversity of 'rice-fallow' systems with specific varieties of pulses adapted to soil type and residual moisture.

Digital augmentation for precision decisions

Digitization of the agro-ecosystems (e.g., geo-tagging, agro-tagging, farm-typology) becomes the most essential entry point for any sustainable developmental entity whether it is breeding site- specific varieties, crop diversification and intensification, efficient use of farm inputs, agronomic practices, stable economic return, or ecosystem-services management. Ongoing efforts in big-data driven digital augmentation aim at quantifying functional production dynamics and drivers to target site-specific sustainable developmental interventions and scaling the ecological intensification such as integration of pulses in rice fallows, adoption of conservation agriculture, bridging the yield gaps, geo-localization of the research and impact reporting (www.icarda.org).

These technologies, combined with a quantitative and systemic analysis of innovation in dryland farming systems, can support out-scaling, up-scaling and foresight approaches, which are required by policy makers, investors and research institutions to prioritize and guide their interventions. This is the aim of the 'Dry Arc Interface' that ICARDA is developing in partnership with three other CGIAR centers (ICRISAT, IFPRI and IWMI).

It is a fact that traditional knowledge and its application in dryland farming can have a great contribution to todays' agriculture for resilience in the context of climate change and other socio-economic considerations. Many of the traditional practices are still being nurtured by farming communities. However, the use of scientific breakthroughs and innovative agro-technologies (machineries, geo-informatics, biotechnology, nano-technology, new knowledge, etc.) is needed to meet food, feed and fiber requirements of a growing population under changing climate. This synergy among traditional practices and modern innovative technologies is one of the key pillars of ICARDA research-for-development strategy.

Gene editing for adaptation of dryland crops to changing climate

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Abstract

Genetic engineering in plants is not a new technology. The main tools for introducing heterologous DNA into plants, Agrobacterium tumefaciens-mediated transformation and biolistics, were invented in the 1980s. All transgenic crops that are currently commercially grown were produced using these methods. However, the random nature of gene insertions can have undesirable effects, and these methods are not favorable for making large concerted changes, such as adding an entire metabolic pathway in a plant. Plant-genome editing, using a host of new tools, including Zinc-Finger Nucleases (ZFNs), Transcription Activator-Like Effector Nucleases (TALENs) and Clustered Regularly Interspaced Short Palindromic Repeats (CRISPRs), is poised to have the greatest effect on precisely changing DNA sequences in crops in novel ways. CRISPR can be used to introduce new genetic material. CRISPR can make precise mutations by substituting existing DNA sequences with desired ones. It can disable whole genes by snipping them out or via imprecise repairs that knock out gene function. The Cas9 enzyme itself can be manipulated to enhance or suppress gene expression. If we want to design crops suited for special ecosystems (e.g. abiotic stress and climate change) CRISPR is a transformative technology that can offer immediate solutions to grand challenges in agriculture. However, gene editing and synthetic biology can possibly face some biosafety concerns. Therefore, some governmental biosafety regulations will need to be devised to allow stakeholders to benefit from this innovation.

Introduction

Genetic engineering in plants is not a new technology; it is now more than 35 years old. The main tools for introducing heterologous DNA into plants, *Agrobacterium tumefaciens* mediated transformation and biolistics, were invented in the 1980s. All transgenic crops that are currently commercially grown were produced using these methods. Genetic engineering directly manipulates the genome of an organism either by the introduction of one or several new genes and regulatory elements, or by decreasing the expression of endogenous genes. For either of these end points, a DNA construct is inserted into one or more chromosomes in a random manner and into one or more *loci*. This approach has been effective in cases in which simple traits, such as herbicide tolerance and insect resistance, have been added to plants. However, the random nature of gene insertions can have undesirable effects, and these methods are not favorable for making large concerted changes, such as adding an entire metabolic pathway in a plant.

Plant-genome editing, using a host of new tools, including zinc-finger nucleases (ZFNs), transcription activator-like effector nucleases (TALENs) (Cermak *et al*., 2011) and clustered regularly interspaced short palindromic repeats (CRISPRs), is poised to have the greatest effect on precisely changing DNA sequences in crops in novel ways (Gaj *et al*. 2013; Du *et al.*, 2016). CRISPR can be used to introduce new genetic material, providing a big boost to an emerging technology known as "gene drive" (Miller *et al.*, 2007; Sander *et al.,* 2011). Various applications are possible due to the many types of editing that CRISPR enables. CRISPR can make precise mutations by substituting existing DNA sequences with desired ones. It can disable whole genes by snipping them out or via imprecise repairs that knock out gene function. The Cas9 enzyme itself can be manipulated to enhance or suppress gene expression (Feng *et al.,* 2013; Jansing *et al.,* 2019).

Since its 2013 demonstration as a genome-editing tool in Arabidopsis and tobacco, CRISPR has been tested in crops, including wheat, rice, soybean, potato, sorghum, orange and tomato. By the end of 2014, research into agricultural uses for CRISPR included a spectrum of applications, from crop resistance to pests to reducing the toll of livestock disease (Govindan and Ramalingam, 2016; Doyon *et al*., 2011).

Table 1. *Traits that may be delivered using gene editing technologies*

Input traits:

- Stacked herbicide resistance
- Carbon Fixation:
    - Improved rubisco
    - C4 photosynthesis in C3 grasses
    - CAM in C4 plants
- Phosphorus-use efficiency
- Nitrogen fixation (cereals)
- Biotic stress resistance
- Microbial resistance
- Insect resistance-
- Abiotic stress tolerance:
  - Drought tolerance
  - Water-use efficiency
  - Cold/Heat tolerance
  - Salt tolerance

Output traits:

Enhanced nutritional content (micronutrients, vitamins, amino acids)

- Food safety (lower aflatoxins, reduced acrylamide formation)
- Forage quality (digestibility, nitrogen protection)
- Biofuels and industrial products (improved biodiesel properties).

CRISPR and food production

There are several examples of use of CRISPER for improving specific traits of some major food crops. Some are given below:

Bananas: The Cavendish banana, the most common type, is on the verge of extinction due to a fungal disease. However, Korean researchers are attempting to save it, using CRISPR to snip out the receptor that the fungus uses (ISAAA, 2018).

Table 2. *Plant genes that can be edited by the CRISPR/Cas9 technology to improve plant tolerance to abiotic stresses (Jaganathan et al., 2018)*

Crop	Gene	Trait
Cassava	*MeKUP*	salt, cold and drought resistance
Cassava	*MeMAPKKK*	drought resistance
Cotton	*GhPIN1-3*	drought resistance
Cotton	*GhRDL1*	drought resistance
Date palm	*Pdpcs/ Pdmt*	Cd, Cr resistance
Date palm	*Pdpcs/ Pdmt*	metals resistance
Papaya	*CpDreb2*	drought, heat and cold) resistance
Papaya	*CpRap2.4*	heat and cold resistance
Sugarcane	*ScAPX6*	ABA, methyl jasmonate and Cu stress resistance
Sugarcane	*ScGluD2*	smut and salt and heavy metal resistance
Sugarcane	*ScNsLTP*	drought and chilling resistance
Banana	*MaAPSI and MaAPL3*	cold and salt resistance

Peanuts: In Ireland, researchers at Aranex Biotech are working on a hypoallergenic peanut. Their use of CRISPR to remove genes that contain allergens may be the most promising attempt yet to create a new crop of allergy-free peanuts (ISAAA, 2018).

Tomato: Scientists from University of Nottingham, UK, used CRISPR-Cas9 to edit genes PL, PG2a, and TBG4, which are related to fruit ripening, flavor and shelf life in tomato (ISAAA, 2018).

Rice: Glutinous cytoplasmic male sterile (CMS) line is vital for the selection of hybrid glutinous rice combination with high yield and quality. Xin Wang and team knocked out the granule-bound starch synthase OsWaxy with low amylose content in 209B using CRISPR-Cas9-mediated genome editing technology and successfully obtained a glutinous maintainer line WX209B (ISAAA 2018).

Ethics in the use of CRISPR/Cas9 technology

Oversight for CRISPR is difficult because the technology is evolving so quickly. There is no global (or national) consensus on what should or should not be done with CRISPR. Decisions about CRISPR are made by experts, often with little input from the general public, religious community, social scientists, biosafety professionals etc. This situation creates fear of CRISPR misuse on purpose or by accident. However, gene editing and synthetic biology can possibly face some biosafety concerns, as increasingly greater amounts of DNA and proteins are being manipulated into crops (Jaganathan *et al.,* 2018; Grohmann *et al.,* 2019).

Potential advantages and disadvantages of gene editing

The positive side of the use of gene editing includes the following:

- The ease and low cost may make genome editing a viable option for smaller, specialty crops, as well as animals.

- The method could eventually be used to tweak almost everything we eat, allowing researchers to select traits that make agriculture more sustainable and productive and our food more nutritious.

The possible disadvantages and concerns associated with gene editing are as follows:

- Mentality that "as long as it works, we don't have to understand how it works."
- With gene editing, it will be hard to detect whether something has been mutated conventionally or genetically engineered.
- There could be "Off-Target Effects"
- The genes used will only work well in certain genetic backgrounds and environments.
- By editing plant genes, companies can avoid regulation.
- Critics warn that the industry is repeating the mistakes made by promoting GMOs (Benjamin, 2017).

How to promote responsible use?

If we want to design crops suited for special ecosystems (e.g. abiotic stress and climate change) CRISPR is a transformative technology that can offer immediate solutions to grand challenges in agriculture. This technology will reshape the future of agriculture. However, some governmental biosafety regulations will need to be devised to allow stakeholders to benefit from this innovation. There is an urgent need to accompany gene editing and CRISPR development with a policy framework that responds to the concerns of the public when technologies migrate from the laboratory to the market. Transparency, through provision of adequate societal oversight of risks, trade-offs and opportunity costs of CRISPR engineering will be needed. It will hinge on the involvement of everyday people - not just scientists or companies - in decision making about altering the food system.

References

Benjamin, D. 2017. Real Food Seminars.com. Montpelier, Vermont.

Cermak, T., E.L. Doyle, M. Christian, L. Wang, Y. Zhang, C. Schmidt, J.A. Baller, N.V. Somia, A.J. Bogdanove and D.V. Voytas. 2011. Efficient design and assembly of custom TALEN and other TAL effector-based constructs for DNA targeting. *Nucleic Acids Research* 39: e82. doi: 10.1093/nar/gkr218

Doyon, Y., T.D. Vo, M.C. Mendel, S.G. Greenberg, J. Wang, D.F. Xia, J.C. Miller, F.D. Urnov, P.D. Gregory and M.C. Holmes. 2011. Enhancing zinc-finger-nuclease activity with improved obligate heterodimeric architectures. *Nat. Method.*8: 74-79.

Du, H., X. Zeng, M. Zhao, X. Cui, Q. Wang and H. Yang. 2016. Efficient targeted mutagenesis in soybean by TALENs and CRISPR/Cas 9. *Journal of Biotechnology* 217: 90-97.

Feng, Z., B. Zhang, W. Ding, X. Liu, D.L. Yang and P. Wei. 2013. Efficient genome editing in plants using a CRISPR/Cas system. *Cell Research* 23: 1229-1232.

Gaj, T., C.A. Gersbach and C.F. Barbas. 2013. ZFN, TALEN, and CRISPR/Cas-based methods for genome engineering. *Trends in Biotechnology* 31: 397-405.

Govindan, G. and S. Ramalingam. 2016. Programmable site-specific nucleases for targeted genome engineering in higher eukaryotes. *Journal of Cellular Physiology* 231: 2380-2392.

Grohmann, L., J. Keilwagen, N. Duensing, E. Dagand, F. Hartung, R. Wilhelm, J. Bendiek and T. Sprink. 2019. Detection and identification of genome editing in plants: Challenges and opportunities. *Frontiers in Plant Science* 10: 236.

ISAAA. 2018. Crop Biotech Update. http://www.isaaa.org/kc/cropbiotechupdate/

Jaganathan, D., K. Ramasamy, G. Sellamuthu, S. Jayabalan and G. Venkataraman. 2018. CRISPR for crop improvement: An update review. *Frontiers in Plant Science* 9: 617.

Jansing, J., A. Schiermeyer, S. Schillberg, R. Fischer and L. Bortesi. 2019. Genome editing in agriculture: Technical and practical considerations. *International Journal of Molecular Sciences* 20: 2888. https://doi.org/10.3390/ijms20122888.

Miller, J.C., M.C. Holmes, J. Wang, D.Y. Guschin, Y.L. Lee, I. Rupniewski, C.M. Beausejour, A.J. Waite, N.S. Wang and K.A. Kim. 2007. An improved zinc-finger nuclease architecture for highly specific genome editing. *Nature Biotechnology* 25: 778-785.

Sander, J.D., E.J. Dahlborg, M.J. Goodwin, L. Cade, F. Zhang, D. Cifuentes, S.J. Curtin, J.S. Blackburn, S. Thibodeau-Beganny and Y. Qi. 2011. Selection-free zinc-finger-nuclease engineering by context-dependent assembly (CoDA). *Nature Method* 8: 67-69.

Sustainable intensification and diversification in drylands: Role of protected agriculture and arid horticulture

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Extended Summary

Sustainable agricultural intensification has been defined as an increase in the output of the unite area or unit volume of water used, while reducing the external inputs, thereby minimizing the negative impact on environment (Pretty, 1997). Sustainable intensification was linked, originally in 1990s, with the smallholder agriculture in Africa, where low productivity was associated with degradation of natural resources. Later on, several reports of major public and private institutions (www.fao.org/docrep/meeting/024/md300e.pdf) have endorsed sustainable intensification as a mainstream concept and one of the key components to achieve sustainable development.

Sustainable intensification

The World should increase food production while maintaining productivity of arable land base and conserve the natural resources. Intensification of agriculture without harming the environment is essential to meet the needs of expected increase in population and the rising level of food consumption (Tilman *et al.*, 2011; Alexandratos and Bruinsma, 2012). The challenge of access to food, in a scenario with no assurance that higher levels of production will result in food security for more people, would be increasing unless distributional, political and economic issues in the food system are appropriately addressed (Allen *et al.*, 2006).

Several arguments criticize the narrow definition of sustainability that is currently being used. Intensification could be achieved by intensive use of chemical inputs and biotechnology, with no concerns for environment. Sustainability may also neglect some socio-economical factors. The incentives for growers or private sector to adopt the concept of intensification are not clear; this means that public sector or governments will bear the cost of improvement.

About 30% of food produced in the world is lost or wasted during production, harvest, post-harvest and marketing. The pattern of nutritional consumption results in increasing the number of overweight to about two billion people and the number of obese to 600 million worldwide. This raises the issue of the importance of addressing the access, consumption and waste of food to prevent more degradation of natural resources. Improving pre and post-harvest agricultural practices will effectively address the issue of production losses and waste, especially when it is coupled with a well-established modern marketing system. Linking farmer to markets will reduce losses and also address the socio-economical issues of increasing farmers' income.

Protected agriculture

Adopting the technologies of protected cultivation using modern greenhouses and hydroponics is an effective way of intensifying and diversifying arid land agriculture. This will increase land and water productivity and farmers' income. By increasing the water use efficiency and avoiding water losses associated with irrigated agriculture in dry areas, protected agriculture will lead to conservation of scarce water resources in arid zones (El-Shinawy *et al.*, 1996).

Protected cultivation is a system that grows crops using hydroponic with re-circulated nutrient solution. It does not have any negative effect on the soil structure or composition. As the chemicals used in the nutrient solution are much less than the amount of fertilizers used for soil cultivation, protected agriculture reduces pollution of soil and water, and hence, reduces adverse impact of crop production on environment. Further, using insect-proof nets to protect plants from insects reduces the need for insecticides.

Growing green fodder for intensive animal production in arid lands requires large areas of fertile agricultural land and huge amounts of water for irrigation. Greenhouses offer a solution through the technique of growing sprouts on hydroponic trays. Such technique provides a continuous supply of green biomass from relatively low area and limited amount of water.

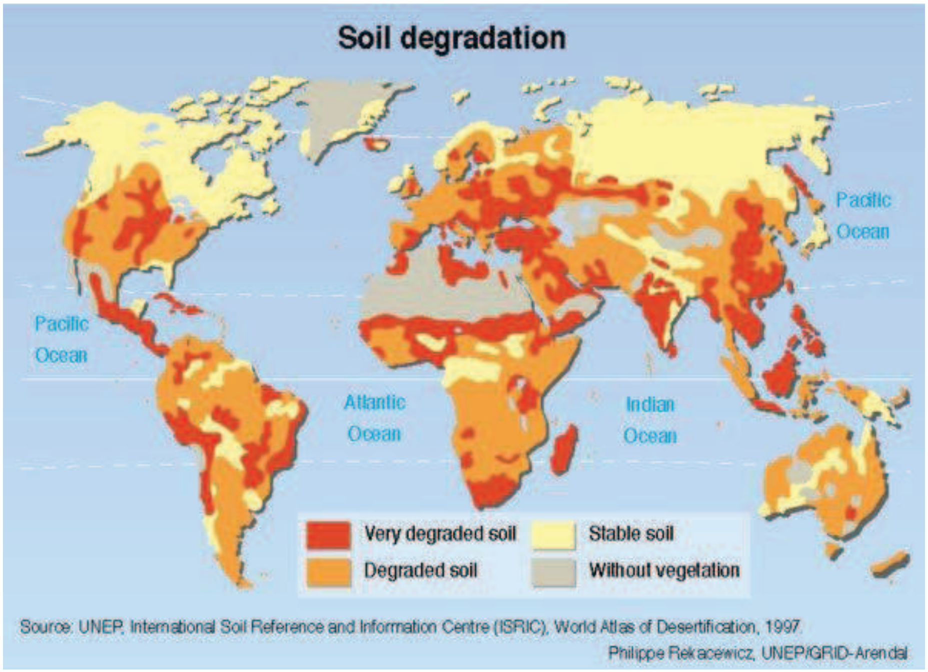

Figure 1. *UNEP soil degradation map of the World.*

A remarkable example of the efficient use of water resources is the use of substrates in soilless culture for better vegetable quality and as a means for improving water use efficiency (Abou-Hadid, 2013). Soilless culture is a modern technique in the protected agriculture that has been investigated for the arid areas using different rooting media and re-circulated nutrient solution (Abou-Hadid *et al.*, 1987). The technology of soilless culture or hydroponic system under greenhouses will be more advantageous to conserve the environment and add more income for the grower. For example in Egypt, the yield of field-grown tomato was 3 kg m^{-3} of water; plastic house soil-grown tomato 17 kg m^{-3}, and of tomato grown in soil-less culture in plastic house conditions was 45 kg m^{-3}.

Arid lands are located in areas where the solar radiation is at its maximum. The use of such renewable energy to operate greenhouses will reduce the fossil fuel utilization, and hence, reduce the emission of greenhouse gases.

Arid horticulture

The soils of almost all the arid areas of the world range from very degraded to degraded, as shown in Fig. 1 (IAASTD, 2008). The scope of intensive crop-based agriculture is therefore not very promising for the arid areas because of soil degradation and scarcity of water for intensive irrigation. Intensive field crop cultivation will accentuate stress on the limited soil and water resources. Arid horticulture will be another more promising method of diversifying arid agriculture as it will allow soil conservation through management of the soil without disturbing soil structure and production of high value fruits adapted to arid environment. Adding value to their products would not only enhance use efficiency of limited water resources but would also improve farm income and the resilience of farmers to adverse environmental conditions, particularly drought. Several good examples of successful introduction of arid horticultural crops in the drylands are available from China, Egypt, India, Mexico and the USA.

References

Abou-Hadid, A.F. 2013. Protected cultivation for improving water-use efficiency of vegetable crops in the NENA region. FAO Plant Production and Protection Paper 217- Good Agricultural Practices for greenhouse vegetable crops - Principles for Mediterranean climate areas.

Abou-Hadid, A.F., Adel S. El-Beltagy and S.W. Burrage. 1987. Comparison of Hydroponic Systems for Tomato Production in Egypt. *Egyptian Journal of Horticulture* 14(2): 119-130.

Alexandratos, N. and J. Bruinsma. 2012. World Agriculture: Towards 2030/2050 - the 2012 revision. FAO, Rome.

Allen, L., B. de Benoist, O. Dary and R. Hurrell (eds). 2006. Guidelines on food fortification with micronutrients. World Health Organization, Geneva and FAO, Rome. https://www.who.int/nutrition/publications/guide_food_fortification_micronutrients.pdf

El-Shinawy M.Z., M. A. Medany, A.F. Abou-Hadid, E.M. Soliman and A.S. El-Beltagy. 1996. Comparative Water Use Efficiency of Lettuce plants Grown in Different production Systems. *Acta Horticulture* 434: 53-57.

IAASTD. 2008. UNEP soil degradation map. *In* "Figures of the Global Summary for Decision Makers of the International Assessment of Agricultural Science and Technology for Development".

Pretty, J. 1997. The sustainable intensification of agriculture. *Natural Resources Forum* 21(4): 247-256.

Tilman, D., C. Balzer, J. Hill and B.L. Befort. 2011. Global food demand and the sustainable intensification of agriculture. *Proceedings of the National Academy of Sciences of the United States of America* 108: 20260-20264. https://doi.org/10.1073/pnas.1116437108

No till-based sustainable production systems for converting dryland areas from grey into green: The experience of AAPRESID

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Extended Summary

'No Tillage' (NT) is a crucial tool to convert drylands into productive lands. As it also recovers, maintains and improves soil conditions, it is conceived as a production system and not only as a conservationist practice or an agricultural alternative. NT has revolutionized agriculture. Its arrival meant a true paradigm shift, eliminating tillage as an historical basic tool for agriculture. Non removal of crop residues, and thus leaving soils covered with stubbles, generates a change in the soil environment by improving its structure, increasing soil organic matter and water availability for crops, modifying the biological activity and therefore, nutrients dynamics. Initially, immediate results are observed on physical and chemical properties of soil, with improved and stabilized soil structure, increase in macro-porosity, and improved water and air dynamics.

The extensive cover of the soil surface by organic residues and stubbles greatly reduces the amount and severity of water run-off, increases water infiltration and decreases direct evaporation from the surface. It also protects soil from water and wind erosion. Although the extra water stored is important in all regions, it is even more critical in marginal sub-humid to semi-arid areas, where soil water holding capacity and rainfall are lower than in areas with better soils and climate. Under rain-fed crop conditions, the extra rainfall captured by the NT system is critical insurance to achieve some level of yields, even when rains are delayed. Better and higher water storage in the soil improves not only water-use efficiency but also permits intensification of crop rotation, which, in turn, contributes to return of different quantities and quality of the residues. Subsequent decomposition of residues leads to accumulation of soil carbon in the topsoil.

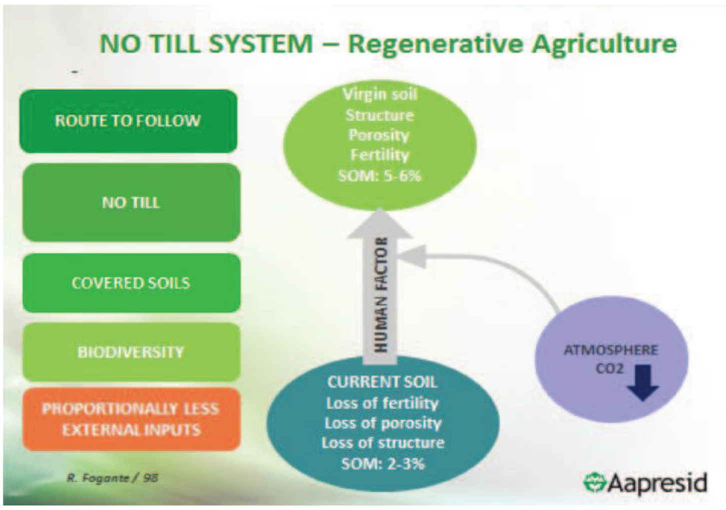

Figure 1. *'No Till', a regenerative agriculture system.*

No-till system is the basis of regenerative agriculture (Fig. 1) that allows carbon sequestration in the soil, GHG emission reduction, development of healthy soils, biodiversity conservation, enhanced resilience of production system to climate change, in addition to higher production of nutritious food. Nutrient dynamics is modified, which offers opportunity for a strategic management of nutrients in the system with little adverse affect on environment.

Water availability is as crucial factor in the global production of food, particularly in the dry areas. It is a challenge as to how climate, soil, plant improvement and cultural management can be combined to increase water use efficiency. Beltramo (2008) studied the role of adequate fertilization in enhancing the water use efficiency of maize (Table 1) and soybean (Table 2) in a 'maize-soybean' rotation under no-till production system. The results indicated a better water use efficiency and yields with improved nutrition and, sustainable intensification model, the nutrient replacement treatment being the most efficient.

Table 1. *Water use and use efficiency (WUE) of maize under different fertilization treatments (Beltramo, 2008)*

	Control			**S Treatment**			**NP Treatment**			**NPS Treatment**			**NPS Replacement**		
Phenological stages	**S**	**Fl**	**MF**	**S**	**Fl**	**MF**	**S**	**Fl**	**MF**	**S**	**Fl**	**MF**	**S**	**Fl**	**MF**
Total available water (mm)	278	58	34	276	52	31	270	54	81	259	40	30	271	43	60
Rainfall*#	*During the period from planting to maturity **274 mm**														
Available water at planting (mm)	278			276			270			259			271		
Consumption by crop (mm)	518			519			463			503			485		
Yield (kg ha^{-1})	4,640			6,222			5,656			7,947			8,497		
WUE (kg of grain mm^{-1})	9			12			12			16			18		

#Rainfall 15 days before flowering 16 mm

Table 2. *Water use and use efficiency of soybean (second crop) under different fertilization treatments (Beltramo, 2008)*

	Control			**S Treatment**			**NP Treatment**			**NPS Treatment**			**NPS Replacement**		
Phenological stages	**S**	**Fl**	**MF**	**S**	**Fl**	**MF**	**S**	**Fl**	**MF**	**S**	**Fl**	**MF**	**S**	**Fl**	**MF**
Total available water (mm)	134	185	330	107	186	276	82	211	318	41	220	277	10	186	293
Rainfall*	*During the period from planting to maturity **793 mm**														
Available water at planting (mm)	134			107			82			41			10		
Consumption by crop (mm)	597			624			557			557			510		
Yield (kg ha^{-1})	2,684			4,253			2,596			4,266			4,499		
WUE (kg of grain mm^{-1})	4			7			5			8			9		

Under the NT system, a much richer and more favorable soil biological environment is created, promoting larger amounts and diversity of microorganisms, and presence of meso- and macro-fauna. They generate and control some of the critical ecosystem functions, encouraging good soil health, including soil carbon storage and nutrient cycling. They are also important in promoting larger and more stable soil aggregates, as well as networks of soil "bio-pores", thereby improving water infiltration and storage. Many of them are involved in the decomposition processes of organic matter and nutrient cycling, although others can be harmful to crops as pathogens.

The adoption of NT associated with crop rotation, cover crops, integrated management of pests, weeds and diseases, with responsible use of phyto-sanitary products, is known as the concept of Good Agricultural Practices (GAP). Argentine No Till Farmers Association (AAPRESID) initiated a PPP multidisciplinary research initiative, BIOSPAS, with the goal of building soil quality indicators with a biological basis to characterize good agricultural practices (GAPs). In a study under BIOSPAS project, a meta-genomics analysis of the bacterial fraction of the soil revealed that the bacterial diversity in plots under GAP remained at a level equivalent to natural environment while under the non-sustainable practice of monoculture it decreased.

Within the research of some groups of bacteria communities, in the framework of the BIOSPAS project, isolates have been obtained with interesting properties such as phosphorus solubilization capacity, plant growth promotion and control of soil-borne plant pathogens.

Regarding soil biology, four new research areas are foreseen: (i) interpretation of the biological processes that occur in soil and their impact on productivity; (ii) the impact of soil pathogens causing diseases; (iii) use of biological soil variables as indicators of environmental performance; and (iv) use of microorganisms with specific agronomic applications. Soil biology can offer innovative solutions to the current conflict inherent in increasing food production at the same time and taking care of the sustainability of the environment, providing opportunities for new productivity leap and sustainable environmental management.

The sustainable agriculture production system, based on NT, certainly improves the conservation of soil and water resources as compared to the conventional tillage production system (Marelli, 1995). Therefore, in Argentina, as in other regions in South America, the adoption of NT is massive. The adoption of NT innovative technologies and others GAPs has led to 5-6 times growth in total production, from around 20 million tons annually in the 1970s to between 100 and 120 million tons now, with only a twofold expansion of the cultivated area. The NT has provided benefit spread over all kinds and sizes of farming systems, from large holdings to small-scale, also subsistence operations.

Currently, nearly 160-170 mha of global agricultural land is being managed under NT (Derpsch *et al.*, 2015). Although the NT worldwide expansion has been impressive, it still represents only about 10-12% of the global cultivated area, and remains limited to North and South America and Australia. Therefore, much remains to be done for promoting adaption of this model to the agro-ecological, geopolitical, economical and culture diversity around the world. The integration of NT in different productions provides an interesting opportunity to increase the buffering capacity of the agro-ecosystem against variations in the climate and socio-economic conditions in the changing world.

References

Beltramo, G. 2008. Balance de agua útil en parcelas con diferente criterio de fertilización para la secuencia maíz-trigo/soja en siembra directa. Revista Fertilidad y Fertilizantes, AAPRESID. Argentan.

Derpsch, R., A.J. Franzluebbers, S.W. Duiker, D.C. Reicosky, K. Koeller, T. Friedrich, W.G. Sturny, J.C.M. Sa and K. Weiss. 2014. Why do we need to standardize no-tillage research? *Soil & Tillage Resarch* 137: 16-22.

Marelli, H.J. 1995. La Siembra Directa en Argentina. In: Proceedings of the IICA/PROCISUR Conference, Avances en Siembra Directa, August 8-10, 1994, Asunción, Paraguay.

Conservation agriculture for sustainable intensification for dry areas

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Extended Summary

Since the 1950s, the massive increases in food supplies, which were essential to feed burgeoning populations and avert famines, were produced at critical cost to the natural resources, for example diminished soil health and depleted aquifers. Fortunately, there is an alternative to historic intensification approaches, namely, Conservation Agriculture (CA) - also known as Zero-till (ZT) or No-till (NT) in many countries - which is one of the few proven sustainable agricultural intensification practices.

The drylands are a natural home for CA because CA fosters infiltration of water in the soil, reduces runoff, evaporation and soil erosion and reduces production risk while boosting farm income. There is strong evidence of increased soil organic carbon on many soil types after several years of CA. The retention of crop residues on the soil surface not only improves soil health but also increases green water use efficiency. Another signature principle is zero-tillage or the direct sowing into unplowed land through the stubble of the previous crop. Direct sowing reduces labour input and ground preparation requirements, and thus augments farm income and returns to family labour and often can improve the timeliness of planting in dryland farming where the onset of planting rains is uncertain. In addition, crop rotations often contribute to soil health and disease control.

During the past decade CA was adopted at an annual rate of about 10 m ha on smallholders and large commercial farmers worldwide. Now more than 180 m ha of cropland is under CA, distributed across all regions of the world and it is spreading rapidly in the agro-pastoral and sub-humid farming systems of the drylands. For example, most rainfed cereal production in Australia occurs under CA - a greater proportion than any other country in the world.

With the experience in diverse agroecological and policy environments, researchers and development practitioners have realised that the principles of CA are most readily adopted and perform best when complemented by good farming practices from the 'Sustainable Intensification' approach, which seeks to increase output while maintaining or enhancing the natural resource base. While some researchers work on station focused on the original principles of CA, researchers working on-farm and development practitioners focused on adoption and scaling recognised the need for broadening the CA approach. FAO now promotes CA in farming systems or agroecosystem contexts.

In this presentation, the combined approach of Sustainable Intensification and CA is termed Conservation Agriculture based Sustainable Intensification (CASI), incorporating the advantages of both parent approaches. For example, integrating good soil and crop management practices from sustainable intensification (e.g., improved nutrient management, drought tolerant cultivars, good plant populations and weed, disease and pest control) with

CA principles reinforces the sustainability and resilience dividends whilst boosting intensification and farm income outcomes.

Thus, well-designed CASI can address the multiple policy objectives and wide range of negative externalities (e.g., dust storms) often observed in the drylands, while improving the adoptability by and benefit streams for agropastoralists. In the farming systems or agroecosystem context, CASI naturally includes local institutions and market access, forage and livestock improvements and agroforestry and directly addresses policy priorities on household food security and livelihoods in the mixed crop and livestock farming systems of the drylands. In fact, CASI can also be viewed as one form of climate smart agriculture.

The complexity and uncertainty of dryland farming systems demands the use of multi-disciplinary teams and inter-disciplinary (or trans-disciplinary) research and scaling methods. Such approaches call for emphasis on economic, environmental and social sustainability outcomes at multiple scales, in contrast to focused disciplinary or organisational mandates, and practices which connect innovation from communities to national institutions. This is ideal- it is widely recognised- but implementation has been challenging without strong policy and science leadership and budget, or a well-supported results-oriented task force approach.

Such R&D methods also need to take a dynamic approach to processes of adoption, experimentation and learning by agro-pastoralists. There are a wide variety of modern inter-disciplinary R&D methods that foster knowledge and accelerated scaling, which could be applied to CASI in the drylands. For example, various types of multi-stakeholder innovation platforms have demonstrated the value of farmer experimentation, community learning and linkages with government agencies and private sector. At the other end of the spectrum, continuous monitoring and capture by sensors combined with crop and climate modelling will have a major role in drylands R&D.

Systematic targeting of R&D is an essential part of effective CASI R&D. The FAO/World Bank classification of farming systems in low income regions is one framework. Many countries including India have agroclimatic and/or farming systems frameworks which offer an efficient basis for the organisation of field research, the consolidation and spillover of CASI knowledge and the monitoring of adoption and impacts. Clearly, monitoring metrics should include not only field level soil health, but also productivity, whole farm and landscape metrics - to correspond to the broader drylands CASI R&D agendas. Experience in Brazil, India and Australia shows how farmer groups can play a major role in research, often in close cooperation with scientists, and monitoring, in cooperation with extension and local officials.

As particular types of dryland farming systems extend over many countries and often share similar CASI research questions and development challenges, there is enormous value in sharing CASI knowledge between scientists and policy makers across countries. One such example is the CASI platform for sharing knowledge across South Asian countries that could be a model for other regions. By extension, mechanisms for bridging CASI knowledge sharing across regions are also valuable to support future efficient research, knowledge sharing and scaling - and thus sustainable agricultural intensification and achievement of national development priorities, e.g., doubling farm income, and the SDGs.

Note: Practical experiences with CASI approaches were explored in a Master Class on 'Systems Approaches to Land Restoration' convened in Jodhpur during 15-17 February 2019 imediately following the 13th ICDD.

Water security and sustainable growth in drylands

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Extended Summary

Water is a finite and renewable resource that is fundamental to human well being. It is especially critical in drylands, which occupy 41% of the earth's surface, encompass over 100 countries and are home to one-third of the world's population - yet possess only 8% of the global renewable water supply. Most prevalent in Africa and Asia, drylands sustain both rural and urban communities and are home to the poorest and most marginalized people in the world (United Nations, 2011; Pedrick *et al.*, 2012). Drylands account for 44% of the world's cultivated area, and are centers of origin and diversity for vital staple food crops, including wheat, maize, potatoes, lentils, beans, millets and sorghum, though much of this diversity remains untapped (CGIAR, 2018). Rangelands account for 65% of the global dryland area, supporting 50% of the world's livestock (Davies *et al.*, 2016; CGIAR, 2018). Despite their aridity, drylands include many major watersheds, supplying water to billions of people (United Nations, 2011). Given the importance of drylands, it is essential to understand and address their water-related challenges, with the aim of achieving sustainable growth.

Dryland challenges

Drylands face a wide range of pressures, including high levels of climate uncertainty, persistent water scarcity, water-related risks (droughts and floods), environmental degradation, desertification, biodiversity loss, rapid population growth and urbanization. About 6 million km^2 of drylands (10%) are already degraded, costing developing countries an estimated 4-8% of their national gross domestic product each year (Pedrick *et al.*, 2012). Floods, droughts, water pollution, overuse of aquifers and other water-related hazards in drylands pose serious risks for food systems, rural livelihoods and the ecosystems on which they depend. With food demand predicted to increase 50% by 2030, demand for water will certainly increase. In response, water use in arid regions must become more efficient.

Drylands are, by definition, water scarce, and this is the common denominator of many of the problems they experience. In addition to water scarcity, drylands are characterized by erratic rainfall with substantial inter-annual variability (Davies *et al.*, 2016). This makes water management a challenging task, requiring heavy reliance on water 'banks', such as rainwater harvesting tanks and groundwater. In many regions, however, over-abstraction of groundwater reserves has caused a steady decline in the availability of this resource during recent decades (United Nations, 2011). Climate change is expected to exacerbate these problems, leading to more frequent and severe extreme weather events. Water scarcity is often the key limiting factor in food production, and in many dryland countries, conditions for crop growth are predicted to become even more difficult as a result of climate change, with the poorest and most marginalized people suffering the most (Pedrick *et al.*, 2012; Cervigni *et al.*, 2016).

Dryland areas have generally achieved only limited progress in realizing their potential for sustainable transformation. Crop yields, for example, show large gaps between potential and actual performance in many places (Pedrick *et al.*, 2012), and on poorly managed land, the share of water available to plants can be as low as 40-50% of rainfall. There are significant opportunities to increase crop yields and water-use efficiency.

Solutions and ways forward

A key step forward in drylands entails policies and other measures to speed the adoption of water-saving technologies and integrated approaches for boosting water productivity in agriculture, leading to greater food security and employment. Policies should also aim to increase the availability to small-scale farmers of information, knowledge and finance for investment in water-saving technologies.

Among the most promising solutions are:

1. Sustainable intensification of agriculture together with water-smart agriculture for smallholders in Asia and Africa. This involves better capture, storage and conservation of water through small-scale irrigation systems, participatory groundwater management and 'green' solutions, including rainwater harvesting and integrated watershed management.

2. Water productivity innovations:

- Crop varieties that use less water.
- Water technologies, such as drip irrigation (Fig. 1) that increase water-use efficiency.
- Increased investment coupled with enabling policies, institutions and incentives at different levels (household, community, national and global).

Figure 1. *A farmer checks the drip irrigation system at his rice field in Govindapuram, Tamil Nadu, India.*

3. Improved management of uncertainty and enhanced resilience:

- Innovative approaches for early drought/flood warning as well as index-based weather and crop insurance to reduce the economic impacts of such shocks.
- Novel use of ICT tools, the internet of things and last-mile connectivity with smart phone apps.

4. Institutional and policy measures that promote inclusive access to water, with special emphasis on gender equality.

5. Sustainably managed solar irrigation systems, which show great promise in dryland areas, given their high solar potential (Fig. 2).

6. More effective policy making, based on reliable data, requiring more systematic information gathering, improved access to data and careful analysis. For this purpose, both small-scale, ground-based technologies, like mobile weather stations, and large-scale, web-based information systems and geo-spatial tools can be useful.

7. Traditional systems for water harvesting and conservation as well as managed aquifer recharge to conserve the last drop of available moisture.

Figure 2. *Sprinkler system energized through a submerged solar pump.*

Researchers, development professionals and policy makers must work together with rural people to examine options that are suited to diverse contexts and generate multiple benefits across scales to ensure enhanced water availability and improved resilience through efficient and sustainable use of limited water resources in drylands.

References

Cervigni, R. and M. Morris, (eds). 2016. Confronting Drought in Africa's Drylands: Opportunities for Enhancing Resilience. The World Bank.

CGIAR Program on Dryland Systems. 2018. Infographic. www.drylandsystems.cgiar.org

Davies, J., S. Barchiesi, C.J. Ogali, R. Welling, J. Dalton and P. Laban (eds). 2016. Water in drylands : Adapting to scarcity through integrated management. IUCN International Union for Conservation of Nature. https://doi.org/10.2305 /IUCN.CH.2016.06.en

Pedrick, C., M. Devlin and T. Timmermann. 2012. Strategies for Combating Climate Change in Drylands Agriculture. *In*: Synthesis of Dialogues and Evidence. Presented at the International Conference on Food Security in Dry Lands, Doha, Qatar, November, 2012. CGIAR CCAFS, ICARDA. p. 36.

United Nations. 2011. Global Drylands: A UN system-wide response.

Development of innovative germplasm for wheat breeding for dry and heat-prone agro-environment of Sub-Saharan Africa

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Extended Summary

Sub-Saharan Africa is the region where food shortage is expected to increase in the future. Due to economic development and urbanization in the region, demand for wheat is increasing. However, wheat production is not keeping pace with the demand due to the unsuitability of agro-environment (high temperature and drought) for wheat production. This area is predicted to be hotter in the future, and thus it is an urgent task for breeders to develop varieties well adapted to the dry conditions and higher-temperature.

Bread wheat (*Triticum aestivum*, genome AABBDD) originated through a few events of natural hybridization between durum wheat (*T. durum*, AABB) and *Aegilops tauschii* (DD), wild species. Because these events involved a few progenitors, the genetic diversity of durum wheat and *A. tauschii* is not fully represented in the current bread wheat germplasm. This narrow genetic diversity limits the availability of genes useful for wheat breeding. One approach to widen wheat diversity is to use the germplasms of wheat progenitors. Since the 1980s, about 1200 hybrids between durum wheat and *A. tauschii* have been developed at CIMMYT (Van Ginkel and Ogbonnaya, 2007), and the hybrids, designated as 'primary synthetic' (PS), were used to capture the considerable genetic diversity of the progenitor genomes (Zhang *et al.*, 2005).

The current approach to use the genetic diversity is first to evaluate PS lines and then to cross the limited numbers of the selected PS lines with elite cultivars. However, the expected traits of PS may not always appear in the genetic background of the elite cultivars due to the large genetic difference between the backgrounds. Thus, a new approach and platform for efficient exploration, harnessing, and utilization of this tremendous genetic diversity is needed (Gorafi *et al.*, 2018).

We, in our work, have used 43 PS wheat lines as donors and a bread wheat cultivar 'Norin 61' (N61) as a recipient. The PS lines were made by crosses between the durum wheat cultivar 'Langdon' and 43 accessions of *A. tauschii.* These accessions cover the entire intraspecific diversity of the species (Matsuoka and Nasuda, 2004). We crossed N61 with each of the 43 PS lines and produced 43 F_1 plants in 2011. We crossed these 43 F_1 plants with N61 and produced 43 BC_1F_1 seeds in 2012. We cultivated them and obtained BC_1F_2 seeds from individual plants in 2013. We took ten seeds from every 10 BC_1F_1 plant in the 43 lineages and mixed all the seeds to produce a bulk of 4300 seeds. The mixed population was maintained till BC_1F_6.

First, we grew the BC_1F_3 population in the experimental field of Agricultural Research Corporation (ARC) in Wad Medani, Sudan, in 2014/2015 season. The MSD population showed various phenotypes in spike, leaf, and plant traits at maturity time. We selected six plants showing vigorous growth and retaining green leaves at maturity compared to the adjacent plants, which were completely dry. These six lines were named as MNH1 to MNH6 (MNH: MSD-Norin 61-Heat). In the next season, we phenotyped the MNH lines together with N61 as a control in two sowing dates, optimum and late, to insure the exposure of the plants to heat stress during flowering and grain filling. Also, we evaluated the physiological traits, such as photosynthesis rate and stomatal conductance, of the same lines in controlled optimum and heat-stress conditions using growth chambers at the Arid Land Research Center (ALRC), Tottori, Japan. The results revealed that MNH lines had different responses to heat stress, longer peduncle (all MNH lines except MNH3), increased photosynthesis rate (MNH2 and MNH5), and increased biomass and grain yield (MNH2 and MNH5) than N61 (Elbashir *et al.*, 2017a).

In the next study, to validate the suitability of the MSD population as germplasm for heat-stress tolerance breeding, we cultivated randomly selected 400 plants from the BC_1F_5 population in the two locations in Sudan (Dongola and Wad Medani), in an augmented randomized complete block design with N61, the genetic background of the population, and 'Imam' and 'Goumria', heat-tolerant Sudanese varieties, as checks. Wad Medani is warmer than Dongola, and in Wad Medani we did seeding in late sowing time, in addition to normal sowing time. We calculated heat tolerance efficiency (HTE) of each line as HTE = 100 (Ysi/Ypi), where Ysi is grain yield under a higher temperature, and Ypi is that under lower temperature. The results again showed that the MSD population includes a large diversity of yield attributes and heat tolerance capacity. We found many MSD lines that showed better yield performance than check lines (N61 and two adapted Sudanese cultivars) under normal condition and some lines showed higher heat tolerance than the checks with good yield potential (Elbashir *et al.*, 2017b).

We further genotyped these 400 lines by 47,994 dominant silico-DArT (SD) markers and 20,046 co-dominant SNP markers. Out of these, 8,822 SD and 6,794 SNP markers with known genetic positions were allocated on the 21 wheat chromosomes. The molecular markers revealed some QTLs (quantitative trait loci) for heat tolerance and other morphological traits by modified genome-wide association analysis (Gorafi *et al.*, 2018; Gorafi *et al.*, unpub.). We have already crossed the selected materials from the MSD population with some Sudanese varieties and started a breeding program using the selected lines as genetic resources for dry and heat-prone agro-environment of Sub-Saharan Africa.

References

Elbashir, A.A.E., Y.S.A. Gorafi, I.S.A. Tahir, A.M.A Elhashimi, M.G.A. Abdalla and H. Tsujimoto. 2017a. Genetic variation in heat tolerance-related traits in a population of wheat multiple synthetic derivative. *Breeding Science* 67: 483-492.

Elbashir, A.A.E., Y.S.A. Gorafi, I.S.A. Tahir, J-S. Kim, and H. Tsujimoto. 2017b. Wheat multiple synthetic derivatives: a new source for heat stress tolerance adaptive traits. *Breeding Science* 67: 248-256.

Gorafi, Y.S.A., J-S. Kim, A.A.E. Elbashir, and H. Tsujimoto. 2018. A population of wheat multiple synthetic derivatives: an effective platform to explore, harness and utilize genetic diversity of *Aegilops tauschii* for wheat improvement *Theoretical and Applied Genetics* 131: 1615-1626.

Matsuoka, Y. and S. Nasuda. 2004. Durum wheat as a candidate for the unknown female progenitor of bread wheat: an emperical study with a highly fertile F1 hybrid with Aegilops tauschii Coss. *Theoretical and Applied Genetics* 109: 1710-1717.

Van Ginkel, M. and F. Ogbonnaya. 2007. Novel genetic diversity from synthetic wheats in breeding cultivars for changing production conditions. *Fields Crop Research* 104: 86-94.

Zhang, P., S. Dreisigacker, A.E. Melchinger, J.C. Reif, A. Mujeeb Kazi, M. Van Ginkel, D. Hoisington and M.L. Warburton. 2005. Quantifying novel sequence variation and selective advantage in sunthetic hexaploid wheats and their backcross-derived lines using SSR markers. *Molecular Breeding* 15: 1-10.

The Agrobiodiversity Index: How is agrobiodiversity faring in drylands?

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Extended Summary

The way we currently consume and produce our food is one of the greatest health and environmental challenges of the 21st century. More than 820 million people have insufficient food and many more consume an unhealthy diet that contributes to premature death and disease. Moreover, global food production is the human activity that is placing the most pressure on earth, threatening local ecosystems and the stability of the Earth system. While transformations in global agri-food value chains have made a greater variety of food commodities available to consumers in many countries around the globe, they have also led to greater homogeneity in national food supplies. The newly published report from EAT-LANCET Commission on healthy diets from sustainable food systems (Willet *et al.*, 2019) underlines that "production needs to focus on a diverse range of nutritious food from biodiversity-enhancing food production systems rather than the increased volume of a few crops". Agrobiodiversity is the foundation of sustainable food systems. Scientific evidence shows that it boosts nutrition in diets. It increases resilience, soil health and water quality, and reduces the need for costly artificial inputs such as fertilizers and pesticides in food production systems. Farming systems high in agrobiodiversity produce less greenhouse emissions than less biodiverse farms.

Around a third of populations living in drylands depend on agriculture for their food security and livelihoods, and many of them live in chronic poverty. Understanding the uses of biodiversity for agriculture in dry areas will be crucial to manage an increasingly scarce natural resource base in a sustainable way and to ensure that enough nutritious food is available for all. To do so, we need information about how different species, varieties and techniques will affect our food and agricultural production and the environment.

Using two examples from dryland systems, evidence is presented that shows how biodiversity-based approaches can provide a diet that is essential for human health and at the same time increase the resilience of food production systems, for example, to adapt to changing climates. Also presented is 'Agrobiodiversity Index' - a tool to measure agricultural biodiversity in a given food system, that empowers governments, investors and companies to ensure that food systems are sustainable.

Millets

Millets are genetically diverse and adapted to a range of marginal growing conditions, including drought. Traditionally a staple of diets in many parts of the world, including India, they are high in a range of micronutrients, including calcium, iron and dietary fibre. Yet, their cultivation, consumption and marketing remain underdeveloped compared to other crops. Bioversity International has been working with partners for 15 years in India to promote millet production and consumption. Activities include creating markets for small-scale producers, including empowering women entrepreneurs through the creation of millet-based snacks for urban markets, and adding millets to school lunch menus.

Seeds for Needs

Drylands cover almost 40% of the world's surface. Rainfall is often less than 250 mm a year and there is limited access to other water sources for agricultural and consumption needs. In India, 15,000 farmers across five states participated in crowdsourcing trials assessing different varieties of rice and wheat on their farms. Linking to local gene banks, scientists and farmers evaluated a broad selection of crop diversity, including traditional varieties, modern varieties and obsolete varieties. Trials resulted in the adoption of 39 varieties of rice and 43 varieties of wheat. As a result, their agricultural systems should be more resilient to climate change and rural communities are now better able to use adapted genetic materials through an improved local seed system network.

Agrobiodiversity Index

Bioversity International's Agrobiodiversity Index is the tool that governments, companies and investors need to measure the status of agrobiodiversity in a selected area and assess if their actions and commitments are contributing or not to a sustainable use of agrobiodiversity.

The Agrobiodiversity Index measures agrobiodiversity across three dimensions:

- Diets and markets: to what extent and how companies, countries and projects contribute to ensure food biodiversity for healthy diets.
- Production systems: to what extent and how companies, countries and projects contribute to agrobiodiversity for sustainable production.
- Genetic resources: to what extent and how companies, countries and projects contribute to diverse genetic resources for current and future options.

One of the objectives behind the Agrobiodiversity Index is to support countries to use the information generated through the tool to guide their action for improved agrobiodiversity. Using an 'if/then' scenario in a targeted area or value chain, the Index assesses the agrobiodiversity performance of a country at local, regional or national level.

With the Index prototype now in place and 'Use Cases' conducted at the country, company and project level, the Agrobiodiversity Index team is preparing to roll out the Index. The Methodology Report has recently been published (Bioversity International, 2019) and the first-round scoring is about to start.

Among other uses, the Agrobiodiversity Index can work as: 1) a reference for issuing green bonds; 2) an impact assessment mechanism for blended finance and social impact bonds; 3) an allocation driver for equity funds; 4) a tool to support policy design and corporate management decisions. By measuring diversity in food and agricultural supply chains, the Agrobiodiversity Index helps investors screen their portfolios for companies and governments that promote agrobiodiversity, as a proxy for operational and reputational risks related to climate change and unsustainable production. For instance, with almost USD 162.5

billion green bonds issued in 2017, the world is getting serious about climate-smart finance. But climate finance needs a tool to rate bonds and listed equities in the agricultural and food sector against their impact on the environment. The Index allows corporate and government issuers to demonstrate the value for money of their agrobiodiversity-themed green bonds, anticipating their product's positive impact on agrobiodiversity status or reduction in agrobiodiversity-related risks.

Call to Action

Putting agrobiodiversity back into our diets and into our food production systems is critical to deliver healthy foods from a healthy planet. To do this, we need to be able to measure it.

References

Bioversity International. 2019. Agrobiodiversity Index Report 2019: Risk and Resilience. Rome (Italy): Bioversity International 182 p. ISBN: 978-92-9255-125-4.

Willet, W., J. Rockstroem, B. Locken, *et al.* 2019. Food in Anthropocene: The EAT-LANCET Commission on Healthy Diets from Sustainable Food Systems. (https://doi.org/10.1016/S0140-6736(18)31788)

How can we restore hundreds of millions of hectares of degraded land - and get the biggest bang for the buck?

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Extended Summary

Land restoration has climbed to the top of the global agenda. The world now recognizes the dangers and costs of neglecting this critical aspect of human development. Nevertheless, the financial resources to address the problem remain woefully inadequate. So, we have to get smart about how to restore vast areas of degrading land with simple, practical and highly cost-effective practices. We need to create new ways of bringing the strengths of government, the private sector, and the non-governmental community together to synergize their efforts.

The Bonn Challenge - a global effort to bring 150 m ha of deforested and degraded land into restoration by 2020 and 350 m ha by 2030 (www.bonnchallenge.org) - has been the overarching umbrella for land restoration globally. But in recent years, regional initiatives have proven to be exceptionally effective in mobilizing national commitments, technical resources, and financial commitments. This has been particularly the case in Africa, where the African Forest Landscape Restoration Initiative (AFR100) was launched in 2015 (https://afr100.org). During the past few years, 28 countries have voluntarily embraced the initiative. Each of them has now set its own national target to restore degraded land. These targets now exceed 112 m ha.

AFR100 is an audacious enterprise: A huge stretch goal to achieve by 2030. One good outcome of this approach has been to challenge nations and organizations to get real about focusing like a laser on mobilizing to scale-up those practices that can be successfully applied over vast areas of degraded farmlands, forestlands, and rangelands. This commitment ensures that all involved really bear down on getting biggest restoration bang for the buck.

Fortunately, there are now inspiring examples of successful land restoration on a vast scale that provide a model for enormous further expansion. The most notable of these has been the natural regeneration of hundreds of millions of useful trees across seven million hectares of farm and community lands in Niger, a dryland country in the Sahel on the edge of the Sahara. What is so remarkable about this example is that it was accomplished solely through the efforts of millions of poor farm households. They spread the technique from farm-to-farm and village-to-village without any external assistance, other than some modest support for farmer-based extension. This phenomenon has been recognized as the greatest positive land restoration success ever achieved on the continent.

The success of farmer-managed natural regeneration (FMNR) has now spread to the other countries of the Sahel. Recent studies have shown that tree cover on farmlands in the region has reached 16%. FMNR has also been successful on a major scale in Malawi and other countries in southern and eastern Africa.

Ethiopia has developed another type of successful and low-cost model for massive land restoration. The country's exclosure program has assisted villages surrounding degraded watersheds to apply the principles of assisted natural regeneration (ANR). Whole catchments are restored to productive natural tree and grass cover on millions of hectares. The same ANR principle has been applied in north-western Tanzania to restore healthy household and community silvo-pastoral systems. ANR has also been a basis for thousands of communities in India and in many other Asian countries to restore the productivity of their community forest and grazing lands.

Institutional innovations have also been an important feature of applying cost-effective land restoration. In Kenya, a community conservancy approach has evolved during the past 15 years. It fosters successful governance mechanisms for the sustainable management of vast areas of grazing lands. There are now more than 100 community conservancies in Kenya and Tanzania, and about 70 conservancies are also operating in Namibia.

Another institutional innovation that has arisen recently is the development of the 'EverGreening Global Alliance'. This platform has enabled dozens of international, national and local development and conservation NGOs to connect their deep technical capacities, and their extensive on-the-ground program footprints; and to unite their efforts in massive, multi-country land restoration scaling-up initiatives, in coordination with governments and development donors (www.evergreening.org).

Dryland farming in a future of hotter temperatures and more frequent and severe droughts requires a total rethink of the role of trees in agricultural systems. The Alliance is pursuing a bold vision to create an evergreen agriculture that incorporates trees and shrubs directly into cropping systems. This builds on the growing evidence base that woody perennials can be profitably combined with crops. The trees buffer the crops from climatic stresses, increase their yields, restore the health of the land, and provide additional high-value products for greater income and farm assets.

We foresee that evergreen agricultural systems will be a major driver to achieve success in land restoration at a very large scale in the coming years. The many examples of its major successes, such as those outlined above, provide the inspiration and direction for adapting it to local conditions across the tropical world.

Of course, such a concept and approach to land restoration is highly unconventional when viewed from the standpoint of current mainstream agricultural science and extension. But the science and practice of evergreen agriculture is expanding rapidly. This new paradigm for agriculture is gaining momentum because of its demonstrated success, and its enormous potential to addressing the serious challenges that agriculture is now facing.

The EverGreening Global Alliance is also pursuing the tremendous scope for the cross-fertilization of lessons in land restoration among regions, particularly between Africa and India/South Asia. The massive land restoration successes out of Africa can stimulate applications for the Indian subcontinent. For example, there is an agroecological analogue between the *Faidherbia albida* FMNR systems of Africa and the *khejri* (*Prosopis cineraria*) systems of dryland India. Likewise, there are many lessons from India's agroforestry and land restoration experiences that can be a great value to Africa. One example is the success of the Indian national agroforestry policy. It has enabled many stimulatory effects for expanded smallholder tree production systems. We need much more cross-regional exchange of lessons and experience between South Asia and Africa.

Note: Building a cross-regional bridge through a new community of practice was the theme of a Master Class on this topic convened in Jodhpur during 15-17 February, 2019 immediately following the 13th IDDC.

Sustainable Land Management to convert areas from grey into green

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Abstract

Sustainable Land Management (SLM) plays an essential role in achieving a land degradation-neutral world through converting dryland areas from grey into green. SLM is defined as a knowledge-based combination of technologies, policies and practices that integrate land, water, biodiversity, and environmental concerns to meet rising food and fiber demands while sustaining ecosystem services and livelihoods. We are now proposing a framework for next-generation SLM in Ethiopia, incorporating effects such as enhanced prevention of soil erosion, improvement of land productivity and increasing local residents' income. Research sites were set up in three different areas (highland, midland and lowland) in the Upper Blue Nile Basin, which suffers from serious soil erosion caused by rainfall, so as to develop practices and technologies for improving land productivity by reducing soil erosion and introducing crop-livestock production systems as well as linking such efforts to improving the livelihoods of local residents. Various SLM practices targeted to fight desertification have been implemented in many areas of the world, but their sustainability and effectiveness are being questioned. Hence, this project aims to develop improved SLM technologies and approach that could address the major limitations of the currently implemented SLM practices.

Introduction

Sustainable Land Management (SLM) is defined as a knowledge-based combination of technologies, policies and practices that integrate land, water, biodiversity, and environmental concerns to meet rising food and fiber demands while sustaining ecosystem services and livelihoods (Liniger *et al*., 2011). Thus, SLM covers not only physical land issues, but SLM also includes other issues such as biodiversity, environment, and people's livelihood and welfare.

We are now conducting a research project in Ethiopia supported by the Science and Technology Research Partnership for Sustainable Development (SATREPS) program. The title is "Development of next-generation Sustainable Land Management (SLM) framework to combat desertification".

Our study area is located in the upper Blue Nile basin, Ethiopia. The upper Blue Nile basin is one of the areas of severest water erosion. Soil erosion is one of the most important issues in Ethiopia. Soil erosion has two different effects. One is onsite effect, for example, land destruction by gully and decrease in soil fertility by sheet erosion. Another is offsite effect, for example, soil is eroded at farm lands, then the sediment comes through river with water pollution, and dam function declines because of the sedimentation. To tackle those problems, soil and water conservation (SWC) measures are introduced in Ethiopia such as stone bund and trench. Those measures are being introduced by SLM projects in Ethiopia (Haregeweyn *et al*., 2015). There are a number of SLM projects being carried out in Ethiopia, however, the effects of measures had never been evaluated by scientists, particularly in Amhara Region of the Upper Blue Nile basin. Thus, we started from basic research to provide scientific evaluation about the effects of those measures.

Effects of SLM interventions

Haregeweyn *et al.* (2017) estimated the effects of SLM interventions in upper Blue Nile basin using a combination of different numerical models; the total sediment yield from the basin could be reduced by ~61.4%, when appropriate soil and water conservation practices targeted ca. 79% of the area with moderate to severe erosion (>15 t ha^{-1} yr^{-1}) (Fig. 1).

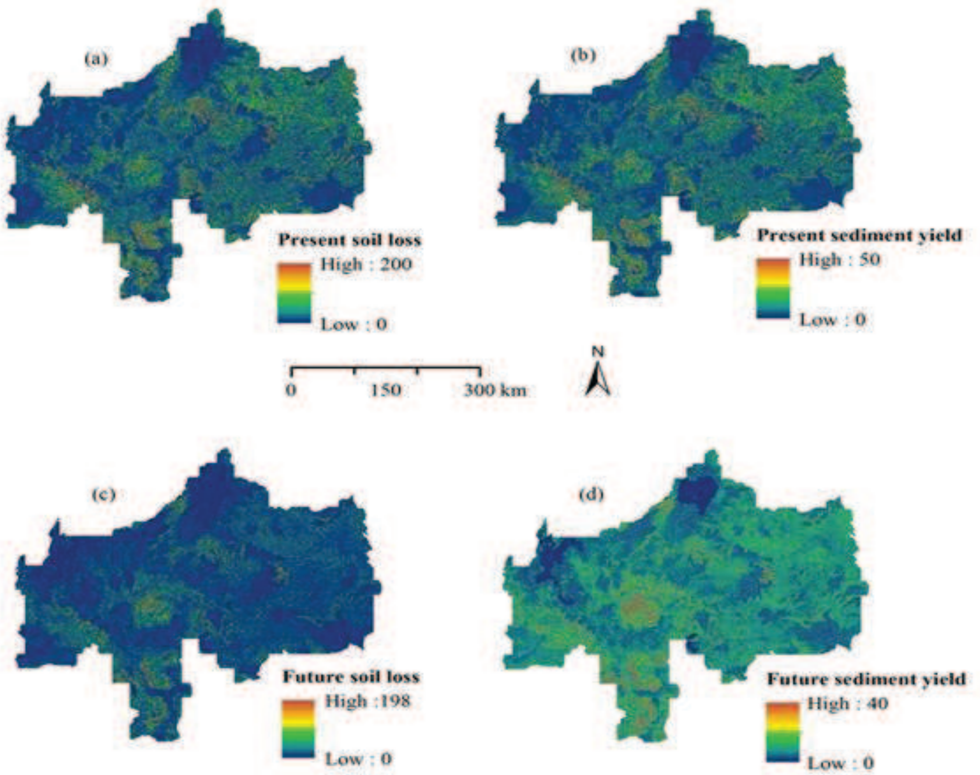

Figure 1. *Soil loss and sediment yield (t ha^{-1} yr^{-1}) maps of the Upper Blue Nile River basin: (a) present (2016) soil loss; (b) present sediment yield; (c), future (2025) soil loss and (d) future sediment yield. (Haregeweyn et al., 2017).*

On the other hand, Ebabu *et al.* (2019) tried to clarify the effects of SLM interventions through field plot experiments. We selected three paired-watersheds, one was the watershed treated with soil and water conservation measures, and the other was without any such measures. We also set experimental plots, and are measuring runoff and sediment yield at watershed as well as plot level. We evaluated the effectiveness of different SLM practices through monitoring runoff and sediment from 42 runoff plots (30 m × 6 m) in the three study sites. On average, seasonal runoff was reduced by 11% to 68% and soil loss by 38% to 94% in SLM plots. Soil bund with grass in croplands and exclosure with trenches in non-croplands were found to be the most effective SLM practices for reducing runoff and soil loss (Fig. 2).

Actually, in the first year, trench was very effective, but in the second year, with the growth of grass, soil bund with grass proved more effective.

Changing village life

According to our preliminary survey, the annual income in our study siteswas about 500 USD per household; however, their agricultural income was less than half of their income, and non-agricultural income and remittance from family members who live in cities accounted for the major portion. Thus, even in such villages with very low incomes, they are now less dependent on local biological production than before.

The situation surrounding those villages has been changing. World economy and globalization are surging even to rural villages. According to the final report of the Millennium Development Goals (UN DESA, 2016), extreme poverty has declined significantly from 47% in 1990 to 14% in 2015. However, due to spread of radio, TV and cell-phones to rural villages, it may be natural that villagers come to desire much more for goods and they are eager for urban life style. They are now able to move more easily than before from villages to cities due to mobility enhancement, and it may cause social destabilization. At the same time, global environment is changing because of climate change, land degradation/desertification and so on. Therefore, the relationship between nature and human is now changing. It is big challenge for villages to achieve land sustainability under changing environment and increasing human needs?

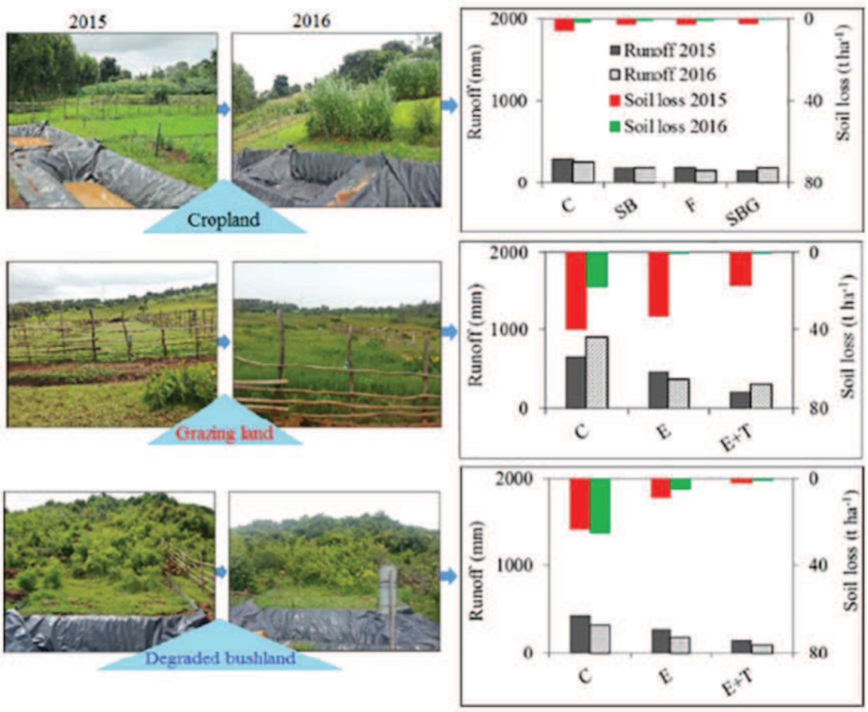

Figure 2. *Effects of land use and management practices on runoff and soil loss at the Aba Gerima site: changes in vegetation cover between the 2015 and 2016 following the implementation of SLM practices (photos, left), and corresponding seasonal runoff and soil loss amounts for different treatments (graphs, right), where C: control, SB: soil bund, F: Fanya juu, SBG: soil bund reinforced with elephant grass, E: exclosure, E + T: exclosure with trenches. (Ebabu et al., 2019).*

Challenges for sustainable rural regime

According to Cumming *et al.* (2014), a 'red trap' occurs when people over-consume and cannot change in response to ecological declines, although level of household wealth is high. On the other hand, a 'green trap' occurs with inadequate food production, although level of ecological degradation is low, and both are leading to socioeconomic collapse and famine.

As illustrated by Xu and Wu (2016), focusing on social-ecological transformations of Inner Mongolia, it may be possible to assume old steady state maintained by low population, low level needs and high ecosystem potential. However, people in rural villages are now facing a transition stage because of increased desire for higher standard for life and goods, and changing environment. There is rapid growth in population, with increasing needs and lowered ecosystem potential.

The target stage should be stable and sustainable, which will have a feature of high but steady population, higher levels of needs and sustainable ecosystem potential. This stage should be realized by avoiding both 'red trap' and 'green trap'. In other words, we have to find a solution to avoid collapse of nature and society. This is a challenge for which researchers have to propose appropriate sustainable land management options, based on scientific evidence.

References

Cumming, G.S., A. Buerkert, E.M. Hoffmann, E. Schlecht, von Cramon-Taubadel, and T. Tscharntke. 2014. Implications of agricultural transitions and urbanization for ecosystem services. *Nature* 515: 50-57.

Ebabu, K., A. Tsunekawa, N. Haregeweynd, E. Adgo, D.T. Meshesha, D. Aklog, T. Masunaga, M. Tsubo, D. Sultan, A.A. Fenta, and M. Yibeltal. 2019. Effects of land use and sustainable land management practices on runoff and soil loss in the Upper Blue Nile basin, Ethiopia. *Science of the Total Environment* 648: 1462-1475.

Haregeweyn, N., A. Tsunekawa, J. Nyssen, J. Poesen, M. Tsubo, D.T. Meshesha, B. Schütt, E. Adgo, and F. Tegegne. 2015. Soil erosion and conservation in Ethiopia: A review. *Progress in Physical Geography* 39(6): 750-774.

Haregeweyn, N., A. Tsunekawa, J. Poesen, M. Tsubo, D.T. Meshesha, A.A. Fenta, J. Nyssen and E. Adgo. 2017. Comprehensive assessment of soil erosion risk for better land use planning in river basins: Case study of the Upper Blue Nile River. *Science of the Total Environment* 574: 95-108.

Liniger, H.P., R. Mekdaschi Studer, C. Hauert, and M. Gurtner. 2011. Sustainable Land Management in Practice? Guidelines and Best Practices for Sub-Saharan Africa. TerrAfrica, WOCAT and FAO. pp. 14. http://www.fao.org/3/i1861e/i1861e00.pdf

UN DESA. 2016. The Millennium Development Goals Report 2015, UN, New York, https://doi.org/10.18356/6cd11401-en.

Xu, G., and J. Wu. 2016. Social-ecological transformations of Inner Mongolia: a sustainability perspective. *Ecological Processes* 5: Article No. 23.

Science and policy interacted for combating desertification in China

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Extended Summary

Since the beginning of 1950s some research and development projects for combating desertification/land degradation in China were operating, but they did not meet the needs at the national to local levels. In 1958, the Central Government therefore convened a National Conference on Combating Desertification and encouraged all efforts to combat desertification in China. Meanwhile, the Chinese Academy of Science (CAS) established the Institute of Desert Research for better understanding of the process and extent of damage from the desert/desertification and for proposing the strategy and tactics to solve the problem and guide national policy and projects.

China, as one of the UNCCD signatory countries, promulgated the Law of the People's Republic of China on Prevention and Control of Desertification in 2001, which came into effect in 2002. Scientists contributed a lot to the formulation of the law, based on the results of research on desertification related to the environmental background, main causes, dynamic monitoring and assessment of development/combating processes, methods and techniques. They made proposals on policy and project formulation, etc. to the national government for combating desertification.

An example is the case of aeolian desertification in northern China. We define aeolian desertification as land degradation through wind erosion, mainly resulting from the human impacts in arid, semiarid and sub-humid regions of northern China. The key point in the definition, based on our study for 4 decades, is that the aeolian desertification has been caused mainly (more than 80%) by human activity - unreasonable pattern and intensity of landuse - and can be combated by human beings only.

So, our scientific group designed the theory and practice of the “Grain for Green” (GfG) Program and suggested it to the Central Government to implement for combating aeolian desertification in northern China. GfG is considered as the largest Ecological Restoration and Rural Development Program in the World (Delang and Yuan, 2015).

The program pays farmers to revert sloping or marginal farmland to trees or grass with the aim of improving the ecological conditions, and the socio-economic circumstances of hundreds of millions of people. It has been carried out since 1997, and will be over by 2019, with an expenditure of 75 billion Yuan (about 11 billion US$), entirely provided by the national budget. Besides the monitory incentive given to the farmers, they are also provided technical knowledge about the scientific and environmental-friendly technologies to be adopted in their alternate agricultural operations.

In a policy review presented in the International Workshop on ‘Forests for Poverty Reduction: Opportunities with Clean Development Mechanism, Environmental Services and

Biodiversity' in Seoul, Korea, Li Zhiyon (2004) show cased the accomplishments of GfG in reforestation, ecological restoration, and rural development in China. The efforts in the program provided outstanding results as the area under aeolian desertified land started decreasing since the year 2000 (Fig. 1) and the rising mean rate of increase of aeolian desertified land since the period 1958-1975 become negative from the period 2000-2005 (Fig. 2).

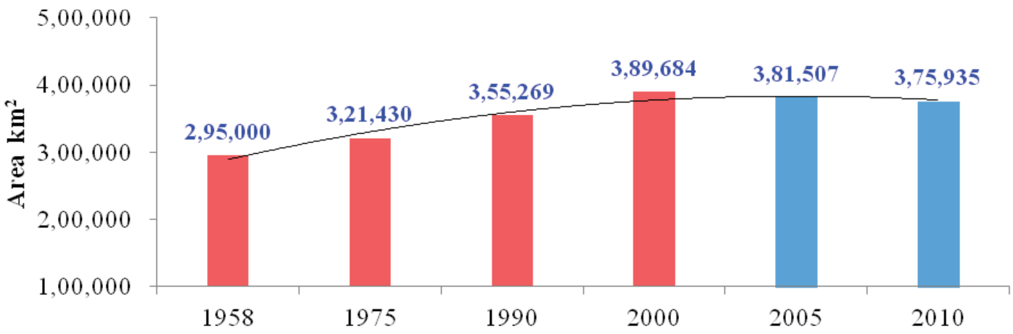

Figure 1. *Change in the area (km2) of aeolian desertified land in northern China.*

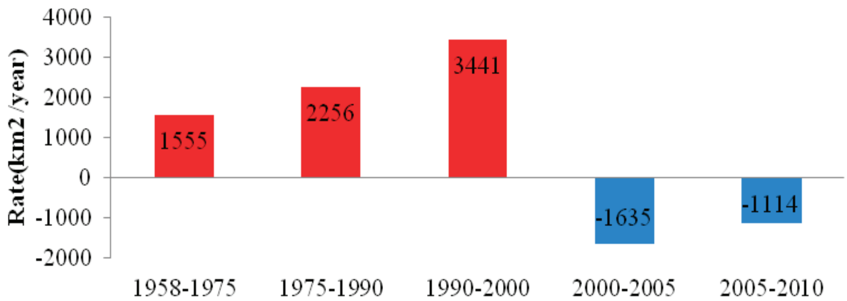

Figure 2. *Rate of increase/decrease in aeolian desertified land (km2 year-1) in northern China in the period 1958-2010.*

Thus, the UNCCD's "Land Degradation Neutrality Target Setting" has been implemented with respect to combating aeolian desertification in northern China since 2000 because of synergistic interaction between science and policy.

References

Delang, Claudio O. and Zhen Yuan. 2015. China's Grain for Green Program - 2015. A Review of the Largest Ecological Restoration and Rural Development Program in the World. Springer, Hong Kong, China.

Zhiyon, Li. 2004. A policy review on watershed protection and poverty alleviation by the Grain for Green Programme in China. Chapter 17. *In:*. Proceedings of the workshop Forests for Poverty Reduction: Opportunities with Clean Development Mechanism, Environmental Services and Biodiversity (Sim, H.C., S. Appanah and Y.C. Youn. eds.) 27-29 August 2003, Seoul, Korea. FAO.

Post-harvest processing, storage and marketing of dried products: Tools for the ‘Dry Chain’

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Extended Summary

Post-harvest losses of dried foodstuffs, grains, pulses, and dried fruits and vegetables are hard to quantify, but are commonly estimated to be higher than 30% in the developing world. Losses include predation by rodents and birds, but most significant are the losses resulting from insect attack and moulds. Moulds result in quality loss, including changes in flavor and color, but more importantly they may produce mycotoxins. Mycotoxins, particularly aflatoxin and fumonisins, have been implicated in a range of pathologies, especially childhood stunting and liver cancer. Surveys of the levels of these toxic compounds in dried foods show that they are frequently present at concentrations above those considered safe.

Fungal infection in the field is an important source of development of mold and mycotoxins, and it can be minimized by early harvest. However this requires additional drying to bring products to a safe dryness. It is well established that proper drying can also prevent mold development and mycotoxin accumulation during product storage. If the ‘water activity’ of the dried food is kept below 0.65, mold growth is prevented. **‘**Water activity’ is the partial vapor pressure of water in a substance divided by the standard state partial vapor pressure of water**.**

Modeled on the ‘Cold Chain’ that is widely regarded as the key to reducing losses of perishable products, the ‘Dry Chain’ concept emphasizes the importance of low water content throughout the handling of dried foods.

In arid and Mediterranean climates, low humidity conditions during the harvest period allow on-plant or open air drying to the water activity required for safe long-term storage. In humid regions, particularly the humid tropics, air drying typically does not adequately dry grains or other foods, and gas-fired dehydrators are not available or economically feasible. We have developed a solar dryer for fruits, vegetables and fish that uses a chimney to draw air through a shallow tunnel containing the food to be dried. This dryer is less expensive and two to three times as efficient as the solar cabinet dryers that are typically used for this purpose. The chimney dryer is not as well suited to drying grains and pulses, since it does not work well with deep beds of products.

A number of ‘low-tech’ dryers have been proposed, including the so-called ‘bubble’ dryer and the cob-fired heated dryer from Purdue, Ind., USA. We recently tested a much more affordable dryer that uses two sheets of plastic, four standard wooden pallets, a sheet of plywood and a solar-powered fan. The pallet dryer is a ‘batch’ dryer and the initial design efficiently dried 150 kg of maize in 1 day under conditions when drying in the open air took more than two days.

A key question for any farmer drying a product and for any trader purchasing it is the dryness of the product. Insufficiently dry product is prone to mold and insect attack; over-drying results in lost income for products sold by weight. Determining moisture content traditionally requires scales and ovens. Measuring water activity (as equilibrium relative humidity, or ERH) requires hygrometers that range in cost from $10 to $2000. Lower cost digital devices may be inaccurate and require careful calibration. Replacing their batteries can be a challenge in developing economies. To overcome these problems, we developed a credit card-sized relative humidity indicator, the DryCard™ using commercially-available cobalt chloride humidity strips. The card is made by local entrepreneurs for about US$0.15 and sells typically for around US$ 1.0. It is reusable and provides a portable and accurate tool for determining water activity of dried products. As the thermometer is used to monitor perishable product temperature in the Cold Chain, the DryCard is used to monitor product dryness in the Dry Chain.

Storage at low water activity is an important link in the Dry Chain, but it also requires attention to the problems caused by insect infestation. Apart from the direct losses in quantity and quality of product resulting from insect predation, the associated damage provides infection sites for mold. Insect metabolism produces water, so water activity in the storage container of infested products may increase sufficiently to allow mold growth. Commercially available hermetic storage containers, whether metal or plastic, have proven to be an effective component of small-scale storage of dried materials without the need for insect control with fumigants or insecticides. Insect respiration in products stored in a well-sealed container rapidly reduces the oxygen in the container to the level that the insects suffocate, essentially killing themselves. This provides the dual benefits of reducing insect damage and reducing the associated fungal growth and mycotoxin contamination.

A special, but critical example of the Dry Chain is the post-harvest handling system for seeds. Germination percentage and vitality of stored seeds are strongly affected by storage conditions. Particularly for smallholder farmers, improper storage results in poor stand establishment and variable vigor and yield. Seeds are best stored at a water activity less than 0.25, a dryness that is difficult for such farmers to achieve and maintain. 'Drying Beads', manufactured from clay minerals with a pore size that specifically adsorbs water, are an effective tool for drying seeds, and have some features that are an improvement on the indicating silica gel that is sometimes used to finish drying and store seeds. An alternative technology is the use of saturated salts with the desired water activity, a technology that may well be more appropriate for small-scale farmers, as such salts are inexpensive and do not require the high regeneration temperatures required for Dry Beads.

Enhancing resilience of arid lands: The Indian experience

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Abstract

Arid regions constitute around 31% of drylands at global level and 18% in India. The agro-climatic conditions in arid regions are very challenging due to scanty rainfall and its highly erratic distribution, low fertility and poor water holding capacity of soils, high evaporative demand and temperature extremes during the year. Existing levels of land degradation and increasing biotic pressure on limited natural resources pose major challenge to farming and livelihood security. Climate change is emerging as an additional challenge since arid regions are more vulnerable. In spite of these limitations, the arid regions in country still support a very large human and livestock population, often adding to degradation of natural resources and overexploitation of ground water. On the other side, arid regions have unique distinct advantages in the form of rich bio-diversity of adapted plant and livestock species and amazing traditional knowledge towards minimizing risk and high solar radiation. Enhancing resilience of arid ecosystem has therefore been a high priority in India through strategically undertaken research and development efforts. This paper synthesizes the important challenges, potential and measures to enhance the resilience of farming in Indian hot arid regions. Our synthesis highlights that diversification of agro-ecosystems through agroforestry (agri-horticulture, silvi-pasoral, horti-pastoral, agri-pastoral), integrated agricultural production (arable crops + trees + grasses + livestock), water harvesting, conservation practices and land management have strengthened the resilience of farming in challenging production environment of these regions. Harnessing the potential of native agro-biodiversity adapted to abiotic stresses and genetic improvement of crops for augmenting drought and thermal stresses are crucial for enhancing resilience of farming. A technology-mediated change, backed up by sound policy for crucial components of farming systems is required for improving profitability and resilience of farming in the region.

Introduction

Drylands, regions having aridity index (AI: the ratio of mean annual precipitation to mean annual potential evapotranspiration) < 0.65, encompassing hyper-arid (AI: < 0.05), arid (AI: 0.05-0.20), semi-arid (AI: 0.20 to 0.50) and dry sub-humid (AI: 0.50 to 0.65) areas, cover about 41.3% of the earth's land surface and are inhabited by ~2.5 billion people (Millennium Ecosystem Assessment, 2005). Globally, the arid, semi-arid and sub-humid areas, respectively, cover 42%, 37% and 21% areas of drylands.

Dryland climate is characterized by low, infrequent and highly variable rainfall and intense solar radiation. The scarcity of water constraints primary productivity and nutrient cycling, both in the natural and the managed ecosystems, thus profoundly affecting livestock and humans living there (Safriel and Adeel, 2005) and hampering the development of the area. Ensuring sustainable livelihood in these regions is threatened by complex and interrelated changes (social, political, economic and environmental) that present significant challenges to researchers and policy makers (Reynolds *et al.,* 2007).

Spread of the Indian arid zone

The arid regions in India occupy 38.7 million ha, comprising 31.7 million ha and 7 million ha under hot region and cold arid region, respectively. Major part (90.1%) of the hot arid region lies in Northwest (NW) India and the rest in geographically isolated pockets in South India. The NW hot arid region extends from 22°30" to 32°50" N and 68°50" to 75°45" E, bounded by Aravalli Hills in the east, Thar desert in the west, the irrigated Indus plain in the north and the alluvial plain of the Sabarmati river in the south. Major part of NW hot arid region lies in western Rajasthan covering 12 districts (196150 km^{2}, 68.66%) followed by northwest Gujarat in six districts (62180 km^{2}, 21.77%), southwest Haryana in five districts (12840 km^{2}, 4.49%), and southwest Punjab in six districts (14510 km^{2}, 5.08%) (Fig. 1). The region is characterized by low rainfall (100 to >400 mm yr^{-1}), that is erratic and highly unpredictable (coefficient of variation, CV = 30 to 70%); high evaporation (1600 to 2000 mm yr^{-1}); extremes of temperatures (-5.7°C to 50°C); frequent droughts (once in 2.5-5.0 years); frequent strong winds (20-50 km h^{-1}) during summer, and short crop growing period (8 to 15 weeks) (Moharana *et al*., 2016). Despite the common characteristics of aridity and extremes of temperatures, there are enormous spatial variations in terms of rainfall pattern, physiography, soils, amount of available surface and ground water, and extent of vegetation cover (Joshi, 2012). Accordingly, the NW hot arid region has been classified in 4 sub-regions, 11 zones and 34 sub zones (Fig. 1) (Faroda *et al.,* 1999).

Figure 1. *Spread of NW hot arid region of India.*

Challenges in arid regions

The agriculture is mainstay of economy and livelihood in the hot arid regions of India, contributing 26-43% to national income. Within agriculture sector, cropping provides 59-71% of the total income while livestock provides 28-42% (CAZRI, 2007). Historically, the NW hot arid region has been a land of low yield and low-value and short duration crops with major dependence on livestock and agroforestry. During post-independence era, introduction of irrigation, new technologies, better infrastructure facilities and the advent of Green Revolution has made drastic changes in agricultural land use in the region and led to improvement in rural economy (Kar, 2014). However, adoption of some faulty land-use practices has led to emergence of several economic, social and environmental problems threatening sustainable agriculture and livelihood in NW hot arid region.

Climatic stresses: Owing to geographical location, sandy terrain, sparse vegetation and low humidity, there is a wide range in the diurnal, seasonal and annual temperatures in NW hot arid region. Summer season (April-June) is the hottest, with air temperatures ranging from 31°C to 42°C (peak values as high as 50°C during May). The temperature declines by 3-5°C during monsoon (rainy) season but again increases slightly during September and October, with the withdrawal of monsoon. During winter season, the mean monthly maximum temperature ranges from 22°C to 29°C and minimum from 4°C to 14°C. Soil temperature follows the diurnal and annual cycles of air temperatures and shoots up to 62°C during May and June (Joshi, 2012). The rainfall is low and erratic with very high spatial, seasonal and annual variability. The mean annual rainfall varies from 100 mm (in extreme western part of Jaisalmer district) to 450 mm (in the eastern fringes along the Aravalli Hills range). Based on 1901-2010 rainfall data, the mean annual rainfall in western Rajasthan and Saurashtra & Kutch met-subdivisions is 291 and 501 mm, respectively. The high inter-annual variability of rainfall (CV= 36 to 65%) is another distinct characteristic (Rao, 2009). Most of the rainfall (88% in western Rajasthan and 94% in Saurashtra & Kutch) is received during south-west monsoon season. The monsoon season is effective only for 2.5-3.0 months (Moharana *et al.*, 2016), and rainy days vary from 8 (at Jaisalmer) to 22 (at Nagaur) (Joshi, 2012).

The region experiences very strong wind regime, peaking in June when average speed varies from 14.6-18.5 km h^{-1}, while during monsoon period it varies from 9-13 km h^{-1}. Peak winds occasionally reach as high a speed as 60-80 km h^{-1} during dust and thunder storm events. The speed decreases sharply from October onwards and remains <7 km h^{-1} during post monsoon season. On an average, the region annually experiences 3-8 dust storms. Very high temperature, low atmospheric humidity and high wind speed result in high evapotranspiration rates, and the annual PET ranges from 1400 mm to >2000 mm in western Rajasthan (Rao, 2009). Length of crop growing period (LGP) varies from 7-14 weeks (Rao *et al.*, 1994).

Drought is a recurring feature of the region with large year to year variation in its location and magnitude. During last century, 47-62% of the years in arid region of Rajasthan experienced droughts of varying intensity and duration (Rao and Singh, 1998). During 1901-2001, Jaisalmer, Barmer, Bikaner and Jodhpur experienced 68, 48, 46 and 43 drought events, respectively (Rao, 2009). Based on district-wise annual rainfall data of 1901-2002, Rathore

(2004) reported that there were droughts of various intensities during almost half of the years in arid districts of Rajasthan. During the drought years, the probability of early-, mid- and late-season drought was 26, 9 and 26%, respectively. Amongst these three categories of drought, the mid- and late season drought caused more reduction in crop yields (72 to 85% in pearl millet and 23 to 61% in pulses) than early season drought (48% in pearl millet and 11% in pulses) (Rao, 2009).

Fragile land and water resources: The soils of NW hot arid region belong to Aridisols and Entisols orders, occupying 41% and 52% area, respectively (Joshi *et al.,* 1998). They are generally loamy sand to sand with 2.0-6.0% clay, 1.5-4.0% silt, 10.0-30.0% coarse sand and 65.0-80.5% fine sand and 1.5 Mg m^{-3} bulk density of surface soil. The range of moisture retention capacity values at 0.1 bar (field capacity) and 15 bars (permanent wilting point) tension is 8.0-10.0% and 2.0-3.0%, respectively. The soils predominantly have macro-porosity and, therefore, there is fast movement of water into and through the soil profile. The initial infiltration rate varies from 15 to 30 cm h^{-1} and saturated HC (hydraulic conductivity) from 5 to 10 cm h^{-1}. There is presence of hard pan at 40-50 cm depth, formed of lime (petrocalcids) or gypsum (petrogypsids), restricting root growth. The soil fertility is low (generally 0.03% N and 0.21% OC content). In the region having $<$300 mm annual rainfall, the OC varies from 0.05 to 0.2, 0.2 to 0.3 and 0.3 to 0.4% in light, medium and heavy textured soils, respectively. As per nutrient index, N status in the soils of arid Rajasthan varies from very low to low; P low to medium and K medium to high (Kathju *et al.,* 1998). Soils are prone to crusting after rains, impeding seedling emergence and accelerating runoff. Sandy soils associated with dunes are dominant formations in ~25% area of western Rajasthan and highly prone to wind erosion. Thus low fertility, less water retention capacity and high erodibility are major edaphic constraints for crop production in the region.

Rainfall is the major source of water in arid regions. Surface water resources are limited due to low and scanty rainfall and poor water yielding efficiency of sandy terrain. The total surface water resources of arid zone of Rajasthan, excluding Indira Gandhi Nahar Pariyojna (IGNP), is 1361 million cubic meters (MCM). The IGNP annually brings 1.72 to 2.91 MCM water to arid Rajasthan. Underground water reserve of the region is 4545 MCM, with 4282 MCM being utilized for irrigation. An analysis of stage of groundwater development under cropped and irrigated area indicated that in six districts of western Rajasthan, the groundwater development has exceeded 100% (Moharana *et al.,* 2016). Overexploitation of groundwater poses serious threats to sustainability of agriculture because most of the aquifers will run dry in the next 20-30 years at the current rate of use, as recharge opportunities are slim and costly. About 80% of the groundwater in Rajasthan has EC $>$2.2 dS m^{-1} and as most of the underground water used for irrigation has EC $>$5 dS m^{-1}, its continuous useleads to development of soil salinity. The canal irrigation in hot arid region triggered considerable development of agriculture, but it also brought problems of water logging and secondary salinization in some areas because of lack of proper drainage, excessive irrigation and seepage from the canals. The average rate of rise in water table in the command areas of Ganga canal, Bhakra canal and IGNP, is 0.53, 0.66 and 0.77 m yr^{-1}, respectively. About 0.208

million ha land is already affected by waterlogging and associated salinity in IGNP command area.

Increasing population pressure: The NW hot arid zone is one of the most densely populated arid regions in the world. The population, both human and animals, is consistently increasing. As per the census of 2011, the human population in the region was 28.15 m (increased by >250% during 1961-2011) and is estimated to reach 41 m in next twenty years. As per the livestock census of 2012, the region harbours 30.18 m livestock (increased by 125.2% during 1956-2012) (CAZRI, 2015). Buffalo registered highest increase (412.5%) followed by goat (266.4%), cattle (57.7%) and sheep (44.8%). The fast increasing population is leading to greater exploitation of natural resources, threatening the sustainability of the ecosystem.

Low yielding and risky agriculture: Most of the crop production in hot arid region is rainfed and therefore yields are low. The common rainfed crops like pearl millet (*Pennisetum glaucum)*, clusterbean (*Cyamopsis tetragonoloba)*, moth bean (*Vigna aconitifolia)*, mung bean (*Vigna radiate)* and *til* (*Sesamum indicum)* are sown both as sole and mixed crops in various proportions. Keeping the land fallow in alternate years is also common, although now on decline. The cropping intensity is therefore below 100%. Wherever water is available for irrigation, groundnut (*Arachis hypogaea)*, cotton (*Gossypium* sp.), wheat (*Triticum aestivum)*, Indian mustard (*Brassica juncea),* chickpea *(Cicer arietinum), isabgol (Plantago ovata)*, and cumin (*Cuminum cyminum)* are grown. Amongst the fruit crops, *ber* (*Ziziphus mauritiana*), *aonla* (*Phyllanthus emblica*), pomegranate, citrus and date palm are cultivated.

The productivity of livestock is also low, the average milk yield per head of cow, buffalo and goat being 4.13, 5.60 and 0.87 l d^{-1}, respectively (Patil *et al*., 2009). Shortage of good quality fodder is major factor responsible for low productivity. The fodder deficit in western Rajasthan was estimated to be about 60% (Pratap Narain and Kar, 2005). The situation gets aggravated in the drought conditions, the deficiency of dry and green fodder reaching 35.9% and 79.9%.

Vulnerability to climate change: Climate change is the greatest challenge, impacting the ecology, economy and society in multiple ways. It has been estimated that because of climate change, the northern part of NW hot arid region may receive 30% less rainfall, while southern and eastern parts may receive 15% higher rainfall, and temperature may gradually increase by 4-5°C everywhere (CAZRI, 2007). Climate change is likely to affect the spatio-temporal distribution, availability and demand for water, and may alter both water availability and crop water requirement significantly as a result of changing temperatures and precipitation. Goyal (2004) projected 14.8% increase in total ET demand with increase in temperature. Climate change will also pose major threat to groundwater resources in future and would add uncertainty to the water supply and exacerbate water scarcity for agricultural production. Land degradation (wind erosion, groundwater depletion and soil salinization) is also projected to increase with increased frequency of droughts, and extreme temperature and rainfall events. Climate change induced heat stress poses formidable challenges to the animal husbandry sector as well by impacting animal productivity and reproduction. Furthermore, the anticipated climate change, coupled with intensification of agriculture, irrigation, industrialization, mining, tourism and urbanization, would adversely affect survival, abundance and distribution of plant species and hence plant biodiversity (Kumar, 2016). Studies have shown that NW hot arid region falls within the areas of highest climate sensitivity, vulnerability and lowest adaptive capacity in India. Climate change is, therefore, likely to make livelihood of inhabitants more vulnerable and less resilient in the region.

Opportunities in hot arid regions

Arid regions, inspite of their marginal resource base, have unique advantage in the form of rich bio-diversity of adapted plant and livestock species, amazing traditional knowledge to minimize risk, and high solar radiation as a potential source for energy. In addition, parts of Indian arid areas have one of the biggest man-made canal systems.

Rich biodiversity - an insurance against risks: With their modest rainfall, arid regions are characterized by relatively fewer species than the better water-endowed biomes (McNeely, 2003). Despite inhospitable and harsh climate, poor soils and anthropogenic pressure, Indian hot arid zone has 682 plant species belonging to 352 genera and 87 families, representing unique blend of trees, shrubs and herbs. These species have typical habitat - plant cover relations resulting in major vegetation types on hills, piedmontes and pediments, alluvial plains, saline flats, river and stream banks, sandy hummocky plains and sand dunes (Kumar, 1998). People in these areas depend mainly on native plant species for their livelihood. Their economic importance is evident from the fact that these species are used in many ways such as vegetables (40), seeds (27), fruits (27), fiber (8), ropes (3), gums and resins (7) and medicinal sources (131) (Kumar, 1998). Many species also provide fuel wood and forage. Thus, native plant diversity is an important source of life support in the arid region. These species possess excellent physio-morphological adaptation to survive under harsh edapho-climatic conditions.

Besides, the domesticated and semi-domesticated plant species have considerable genetic variability. The crops like pearl millet, mothbean, *til* (sesame), clusterbean; grasses like *Lasiurus sindicus*, *Cenhcrus ciliaris* and *C. setigurus*; and shrubs like *Ziziphus, Calligonum, Haloxylon,* having low water requirement, heat tolerance and adaptation to poor soil conditions, have considerable variability.

Similarly, the region is endowed with diverse indigenous livestock breeds (sheep: Marwari, Magra, Nali, Jaisalmeri, Pugal, Chokla, Kheri, Patanwadi; goat: Marwari, Parbatsari, Jhakarana, Kachchhi; cattle: Tharparkar, Kankrej, Nagori, Rathi; camel: Bikaneri, Jaisalmeri, Kachchhi), which have inherent potential for drought and heat resistance. Hence, this rich biodiversity, well adapted to various stresses, needs to be systematically conserved, augmented, and sustainably usedto derive full benefit in the changing climate scenario (CAZRI, 2015).

Rich traditional knowledge: NW hot arid region has thousands of years of cultural heritage backed up by a wealth of traditional wisdom. To evade or minimize the adverse effects of frequent droughts and aberrant weather conditions and for conserving natural resources, the native people have developed many strategies, helping them survive and prosper for millennia. This knowledge has been passed from generation to generation. For instance, to minimize the risk associated with sole crop production, the farmers have developed traditional mixed farming systems, incorporating woody perennials and livestock, to enhance productivity and resource-conservation. Similarly, protection of trees and *orans* (sacred forest/grazing lands attached to temples), construction of water harvesting structure like *kahdin* and *tanka*, adopting long fallow period, etc. have permited sustainable natural resource use. Unfortunately, many of the strategies are presently under severe threat because of technological changes and weakening of societal concern and control. These time-tested techniques and practices need preservation and fine-tuning with scientific and innovative ideas.

Abundant solar radiation: Harnessing renewable energy resources to curtail use of fossil-fuel generated energy is an important strategy to deal with climate change. In this context, solar energy is an attractive option. The NW hot region receives higher amount of solar radiation (5.3 to 6.0 kWh m^{-2} day^{-1}) than rest of the country (<5.5 kWh m^{-2} day^{-1}). It can be used for both domestic and agricultural purposes.

Many solar photo-voltaic and thermal devices have been designed for domestic and agricultural purposes. Photovoltaic-based electricity generation requires land for PV panels which may decrease the area available for crop production. Therefore, agri-voltaic system, with solar panels and crops on the same land area (Dupraz *et al*., 2010), has been advocated, where the crops are cultivated in between and below PV arrays for simultaneous production of food and energy. The studies at CAZRI have indicated that several arable crops (*Vigna radiata, Vigna aconitifolia, Cymopsis tetragonoloba, C. cyminum)* and medicinal plants (*Plantago ovate, Aloe vera, Cassia angustifolia, Convolvulus pluricaulis*) are suitable for agri-voltaic system. It is possible to cultivate 25-50% area of agri-voltaic system for crop production and the yield of crops is only ~10-15% lower than sole crop production but with higher land equivalent ratio (LER: 1.42 to 1.62). Apart from an extra income of about 60,000 ha^{-1} yr^{-1} from cropping, the agri-voltaic systems provide other advantages such as increased overall income from farm land, irrigation with rainwater harvested from and used for cleaning photovoltaic modules, improvement in micro-climate for crops, reduction in dust load on photovoltaic panels, soil moisture conservation by reducing wind speed at ground level and reduction in GHG emission (Santra *et al.,* 2018).

IGNP: One of the largest canals in arid areas: Indira Gandhi Nahar Priyojna (IGNP) is one of the largest irrigation projects in the world. It was conceived to transform Thar Desert into a land of plenty, and had the objectives of "drought proofing, provision of drinking water, industrial and irrigation facilities, creation of employment opportunities, settlement of human population of thinly populated desert areas; improvement of fodder, forage and agriculture facilities, check spread of desert area and improve ecosystem through large-scale afforestation, develop road network and provide requisite opportunities for overall economic development" (IGNB, 2002). The project encompasses the districts of Sri Ganganagar, Hanumangarh, Churu, Bikaner, Jaisalmer, Jodhpur and Barmer with a culturable command area (CCA) of 1.963 million ha. It has enabled farmers to increase crop yields and cropping intensity, stabilized production by providing a buffer against the vagaries of weather, and created employment in rural areas. The transformation in poverty alleviation, improving agricultural productivity, providing livelihood, settling people and providing drinking water has been remarkable (Kavadia and Hooja, 1994). However, the project has also posed several environmental, management and social problems. Rapidly increasing water table by seepage from canal has resulted in water logging and development of secondary soil salinity. The water-use is not very efficient. The system needs to be more efficient and flexible to meet the demands of many sectors (farming, fishing, domestic use and energy supply) and ways have to be found to generate more value from ecosystem services and halt environmental degradation.

Guiding principles to enhance resilience

There are many definitions of resilience most of which suggest that resilience is the capacity of a system to withstand and/or adapt to disturbances over time (Hoddinott, 2014) in order to continue fulfilling its functions and providing its services and desired outcomes (Walker *et al.,* 2006). The resilience and sustainability are complementary concepts (Maleksaedi and Karami, 2013); sustainability implies capacity to achieve today's goal without compromising the future capacity and resilience is dynamic capacity to achieve goals despite disturbances and shocks. Peterson *et al.* (2018) proposed an operational version of resilience in agro-ecosystem that is centred around: (1) productivity, (2) stability, (3) resistance to decline in yield and the supporting mechanisms in the face of disturbances, and (4) rapid recovery to baseline functioning when conditions improve. Thus, a resilient agricultural production system should have ability of high production under normal conditions, sustained provision of ecosystem services and have minimal negative impacts on other services (productivity); minimal variability/fluctuation in yield/profit (stability); minimal losses under disturbances or adverse conditions (resistance); rapid return to baseline productivity after disturbances and maximal positive response to beneficial conditions (recovery). Results of research experiences accumulated over the years have indicated that there are various strategies which increase the resilience of agricultural production systems, and some, with special reference to NW hot arid region, are given in this section.

Building upon traditional knowledge: The traditional wisdom of the native people of arid regions, as mentioned before, has helped them survive the harsh environment for centuries. This is of immense significance to enhance resilience of farming in future as well. For instance, their traditional mixed farming improves resilience by decreasing risk associated with crop failure in sole crop production. There is traditional knowledge regarding suitability of components species (crops, grasses and woody perennials) in accordance with site-specific edapho-climatic conditions.

Various runoff farming systems have been traditionally used for growing crops (Kolarkar and Singh, 1990) to meet the challenge of low rainfall. Among them, *khadin* cultivation is a unique, followed since 15th century in 100-200 mm rainfall zone in Jaisalmer district of western Rajasthan (Parsad *et al.,* 2004). The system comprises suitable highland area having good runoff potential serving as catchment area, and relatively low plains having deep soil in the proximity to receive, collect and store the runoff water for crops. The ratio between cultivated and catchment area varies from 1:15 to 1:56. On withdrawal of monsoon, the accumulated water in *khadin* starts receding due to seepage and evaporation, and the crops are cultivated, depending upon depth of impounded water, starting from upper to lower reaches. During the years of poor rainfall, when accumulated water is less, generally *kharif* crops such as pearl millet and clusterbean are grown. Generally *rabi* season crops like wheat, Indian mustard and chickpea are grown on conserved soil moisture. The cropping intensity varies from 60 to 100% from upper to lower reaches. Study by Parsad *et al.* (2004) showed that average yield of chickpea varied from 1.0 to 1.5 t ha^{-1} and of wheat from 2.0 to 3.0 t ha^{-1}. ICAR-CAZRI has prepared guidelines for sustainable utilization of *khadin* systems (Goyal *et al*., 2018) that include suitable design with provision of spillway, recycling of excess stored water for supplemental irrigation (SI), moisture conservation, soil fertility management, standardization of nutrient schedule for different crops, crop planning for different reaches of *khadin*, and integration of suitable alternative land use systems for better utilization of water and increasing overall productivity and profitability. "*Birani badi*" is another important traditional practice of growing summer season cucurbits (water melon and musk melon) with the use of limited water in the sandy soils of Bikaner district of Rajasthan. Similarly, as indicated before, there are traditions of protecting trees and sacred forest/grazing lands that help conserve phyto-diversity and provide fodder and other economic products.

Integrated farming systems - good for people and planet: Scientific studies across the world suggest that, relative to conventional agricultural production system (particularly specialized agriculture), the integrated farming system (IFS) lowers reliance on external inputs, enhances agro-biodiversity, provides better yields, enhances ecosystem services and promotes resilience in the face of disturbances (e.g. abiotic, biotic and economic). The first and most important attribute of IFS is enhanced agro-biodiversity which not only enhances the desired ecosystem services but promotes resilience. IFS provides opportunities to harness synergies among different agricultural sub-systems and/or enterprises, augmenting productivity and gainful year-round employment, ensuring efficient resource recycling, higher resources use efficiency, improved soil quality, and protaction of natural resources and environment in the arid and semi-arid regions (Rathore e*t al.,* 2018, 2019).

Minimization of risk by increasing on-farm biodiversity: The IFS is less vulnerable to climatic, biotic (pests and diseases) and economic (relative prices of input and output) changes compared to specialized agriculture or a single commodity-based agriculture. Different commodities (crops, livestock, grasses, and woody perennials) have different ability to absorb production and economic risks. Hence, increasing the diversity enhances the risk absorbing capacity of production system. IFS has potential to minimize the production and economic risk associated with sole arable cropping, and decrease the vulnerability of producers to the impacts of aberrant weather conditions. In case of crop failure, the woody perennials provide fodder, fruit or fuel wood. The rainfall-scarcity induced reduction in the yield of crops is more in sole cropping system (SCS) compared to that IFS. Faroda (1998) reported that the yield reduction of mungbean was higher in SCS compared to that in *Ziziphus* based integrated production system under subnormal rainfall conditions (51% less rainfall than long term average of 360 mm yr^{-1}) in hot arid region of Rajasthan. This integrated production system provided a year round supply of fodder for five sheep/goat and fuel wood for a family of four members. Delayed onset of monsoon is a common weather aberration in the region. Studies at ICAR-CAZRI showed that under very delayed onset (first week of August), the IFS (comprising agri-horticulture, agri-pasture, silvi-pasture) fetched higher returns than sole cropping (Tanwar *et al*., 2014). Additionally, IFS gives opportunity to farmer to adjust the allocation of production inputs among the enterprises in response to climate and price fluctuations. For instance, the integrated crop-livestock production system provides an opportunity to producer to convert a grain crop to forage mid-season during low rainfall years when grain yield prospects are low or when livestock prices are higher relative to grain prices.

Fulfilling year-round requirement of food, fodder, fuel: The IFS co-generates food (cereals, millets, pulses, oilseed, vegetable, fruit, milk and meat), fodder (green fodder, straw and leaf fodder from tree) and fuel (fuel wood and biogas), increasing the self-sufficiency for basic requirements of farmers and improving nutritional and livelihood security. The integration of *Ziziphus mauritiana*, *P. cineraria* and livestock with arable crops (pearl millet, mung bean, moth bean, sesame) in the IFS meets the requirements of food, fodder and fuel wood in the region. An eight year study by ICAR-CAZRI demonstrated that *ber* + cowpea system provided food (cowpea grain: 386 kg ha^{-1} yr^{-1}), fruit (3076 kg ha^{-1} yr^{-1}), fuel wood (1353 kg ha^{-1} yr^{-1}) and fodder (to sustain 700-1000 animal days ha^{-1} yr^{-1}) to sustain a modest family (Bhati *et al*., 2008).

Higher productivity and profitability: With decreasing production resources and increasing demand for agricultural products, a system is needed that increases the production per unit of land area per day. Results of several studies in hot arid regions demonstrated that IFS significantly increased land productivity compared to sole production systems (SPS) (Harsh and Tewari, 2007; Bhati *et al*., 2008; CAZRI, 2014; Patidar and Mathur, 2017; Verma *et al.,* 2017; Rathore *et al.,* 2018, 2019).

Agroforestry based IFS systems, involving co-cultivation of trees with arable crops, also improved land productivity. *P. cineraria, Hardwickia binata, A. senegal, Z. mauritiana* and *Tecomella undulata* are suitable tree species for this system. Long-term study in the region showed that integrated production of arable crops with *P. cineraria* provided good yield of arable crops along with an additional yield of dry leaves and twigs (0.65 to 1.05 t ha^{-1}) and fuel wood (1.8-2.6 t ha^{-1}) from *P. cineraria* trees. Seed yields of pearl millet, mung bean and clusterbean were higher in association with *P. cineraria* than in sole arable cropping (CAZRI, 2014). Kaushik and Kumar (2003) reported higher fodder yield in *P. cineraria*-based production system (*P. cineraria* in association with pearl millet - *Brassica tournefortii*) than sole cropping in arid regions of Haryana. There, yield of barley improved (16.8-86.0%) in association with *P. cineraria* and *T. undulata* (Kumar *et al*., 1998). The higher land productivity of *ber*-based cropping system compared to that of sole *ber* or sole crop/grass and 5-20% higher yields of intercrops in association with *ber* than sole cropping have been reported in several studies in the arid region (Gupta *et al.,* 2000; Saroj *et al.,* 2003; Singh *et al.,* 2003; Bhandari *et al.,* 2014). Co-cultivation of arable crops with *ber* enhanced fruit yield of *ber* by 7 and 52% compared to sole *ber* production at Bikaner, Rajasthan (Arya *et al.,* 2011) and Dantiwada, Gujarat (Patel *et al.,* 2003), respectively.

A study at ICAR-CAZRI demonstrated that IFS onaseven ha land provided 2.06 t food grain, 3.12 t fruit, 8.25 t milk, 0.34 t meat, 0.37 t clusterbean seed, 0.51 t grass seed, and 10.9 t fuel wood as compared to 2.06 t food grain, 0.80 t clusterbean seed, and 18.86 t of fodder by sole production (SPS). The IFS, thus, had 2.9-times higher food production than SPS (Tanwar *et al.,* 2018b).

IFS provides not only higher land productivity, but also multiple food products (millets, pulses, milk, meat and fruits) as compared to any SP system. Furthermore, the production of food and total economic products are less variable in IFS than in SCP (Fig. 2), thus enhancing resilience in arid regions.

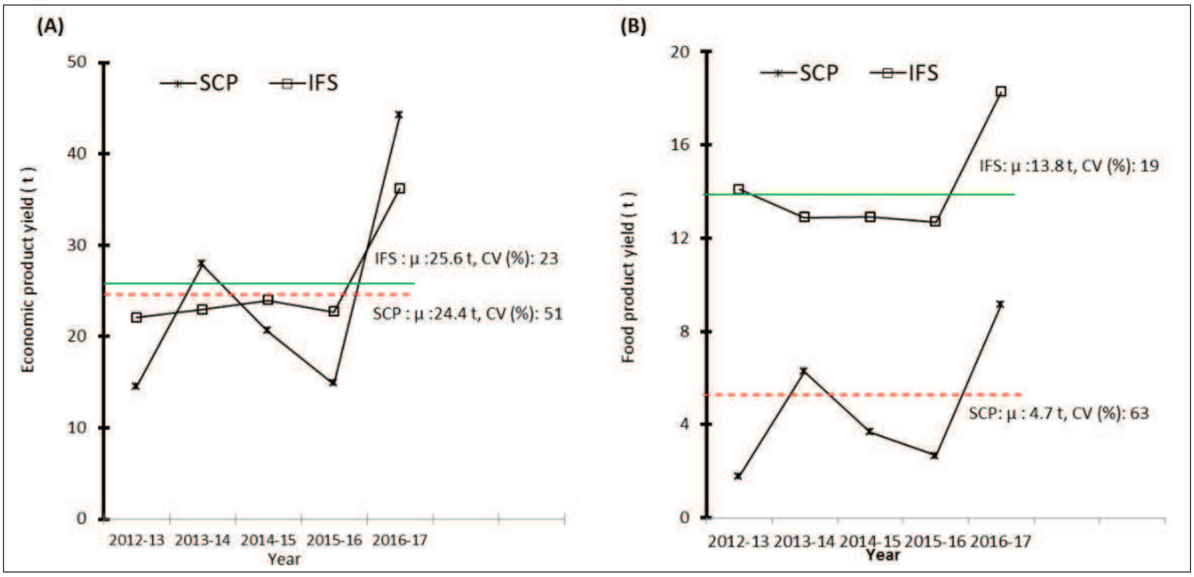

Figure 2. *Yield of (A) economic products and (B) food products in SCP and IFS at Jodhpur.*

IFS also provides an opportunity to enhance profitability relative to SCP through higher productivity and lower production costs as the by-products of one enterprise can be used as input for other enterprise, thus reducing the need for external inputs. Several studies indicate that IFS enhances profitability over sole production systems in hot arid and semi-arid regions (Table 1).

Results of a long-term study by ICAR-CAZRI indicated that IFS gave 23-506% higher net return than SCP, and the return was less variable (CV=28% for IFS and 93% for SCP). Averaged across the years, the IFS fetched 251% higher net return than SCP (Fig. 3). Furthermore, the difference in pattern of flow of income between SCP and IFS is worth mentioning. The income from SCP is season-specific (after harvest of crops) while in IFS it is throughout the year by the sale of a variety of farm produce (milk, egg, mushroom, vegetables, fruits and food grains) (Behera and Mahapatra, 1999; Maheswarappa *et al.,* 2001; Kumar *et al.,* 2013).

Table 1. *Relative profitability of IFS over SPS in hot arid and semi-arid regions of NW India*

Location	**Production system**	**Increase (%) due to IFS over SPS**	**Reference**
Jodhpur, Rajasthan	Sole crop: Pearl millet IFS: Pearl millet + *A. senegal* (140 plants ha^{-1})	 61	Harsh and Tewari (2007)
Jodhpur	Sole tree (ST): sole *H. binnata* Sole grass (SG) : *C. ciliaris* IFS: *H. binnata* + *C. Ciliaris*	 25% over ST 65% over SG	Harsh and Tewari (2007)
Jodhpur	Sole crop : Arable crops IFS : Arable crops + tree + fruit crop (*ber*)+ grass + 7 ACU (4 cows, 8 bucks and 4 rams)	 193	Tanwar *et al*., (2016)
Jodhpur	Sole crop : Mung bean : Clusterbean IFS: Mung bean + *ber* : Clusterbean + *ber*	 432 162	Meghwal and Henry (2009)
Bawal, Haryana	Sole crop: Clusterbean (C) - barley (B) IFS : *P. cineraria* + Guava + C-B *P. cineraria* + *Aonla* + C-B	 381 327	Kaushik *et al*. (2017)
Hisar, Haryana	Sole : Cropping alone IFS1: Cropping + crossbreed cattle IFS2: Cropping + buffalo	 346 35	 Singh *et al*., 1993

Adapted from Rathore *et al*. (2019)

Ensuring year-round gainful employment: SCP, being a season bound enterprise, has season and time specific labour requirement, with a peak during planting and harvesting of crops, and in the rest of the season there is inadequate employment opportunity. IFS could utilize labour more efficiently at farm and/or regional scale and provide an opportunity to enhance employment generation. A 5-year study by ICAR-CAZRI showed that IFS had 1.8 to 2.0 times more employment generation than SCP (823 to 918 man-days yr^{-1} in IFS, compared to 425 to 448 man-days yr^{-1} in SCP) (Fig. 4).

Gill *et al.* (2009) reported that integration of dairy with cropping generated 138 additional man-days compared to SCP in irrigated hot arid region of Punjab. A study at Coimbatore, South India indicated that integration of fish and goat with arable cropping generated additional 207 man-days yr^{-1} compared to sole cropping (Jayanthi *et al.,* 2001). In addition, the IFS ensures that women get higher opportunities to engage in farming activities, particularly in poultry, milch cattle and/or sheep/goat rearing, vegetable production, etc. (Sharmin *et al.,* 2012), and increases their access and control over the farm resources and income (Setboosarng, 2002).

Components of IFS: The selection of suitable components for integration is essential for harnessing the full benefits of IFS. The edapho-climatic conditions and complementarities between components along with availability of infrastructure (irrigation, electricity, markets, storage and transportation), socio-economic conditions, technology, and family requirement of various agricultural products are major determinants for selection of suitable components of site-specific IFS. Results of a study on *ber*-based integrated production system at ICAR-CAZRI demonstrated that amongst the arable crops, mung bean gave better yields in good rainfall years, clusterbean gave better yields in drought years, and cowpea showed yield stability in most of the years (Bhati *et al.,* 2008). Thus, cowpea and clusterbean are better than mung bean for imparting stability in land productivity and profitability

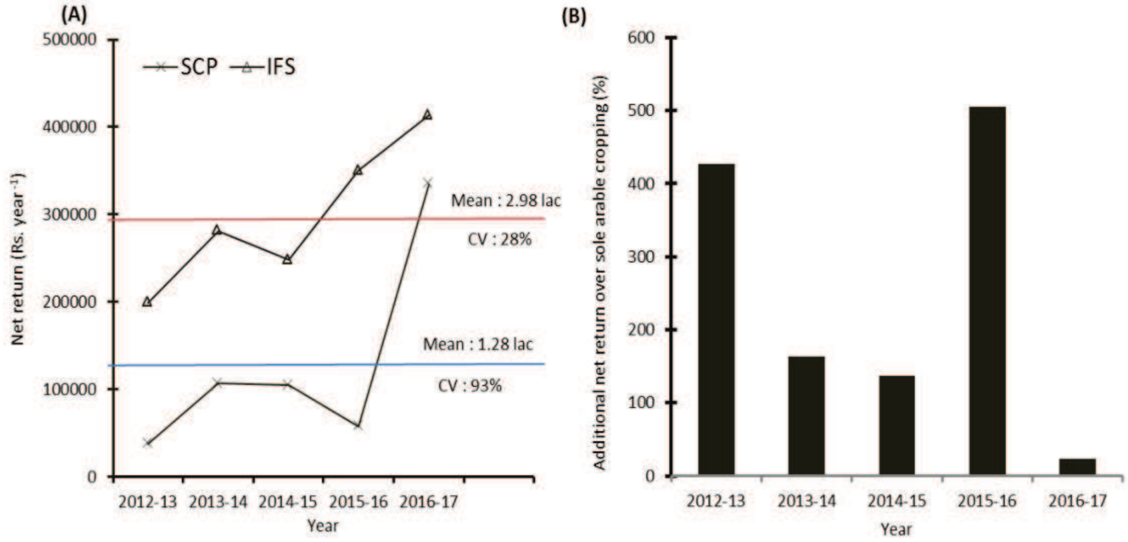

Figure 3. *(A) Comparative net return of sole crop production (SCP) system and IFS and (B) additional net return of IFS over SCP on a 7 ha land area in NW hot arid region.*

Figure 4. *Employment generated by SCP and IFS on a 7 ha holding in Jodhpur.*

Kumar *et al.* (1998) demonstrated better yield enhancement of barley in association with *P. cineraria* (86%) than with *T. undulata* (48.8%) and *A. indica* (16.8%). Evaluation of economic performance of IFS involving crops (cowpea, clusterbean and moth bean) and fruit crops (*aonla*, *ber* and pomegranate) in arid region of Gujarat revealed that clusterbean performed better than other crops in orchards: *ber* + clusterbean had highest profitability (benefit to cost ratio, BCR: 1.83) followed by *ber* + moth bean (BCR: 1.65) (Dayal *et al.,* 2015). Comparative analysis of productivity of three IF systems (crops + *P. cineraria*; crops + *Z. mauritiana* and crops + *H. binnata*) with sole pearl millet at Jodhpur indicated that IFS had 41-237% higher equivalent yield than SCP and *Z. mauritiana* based IFS had highest (237% greater) equivalent yields followed by *P. cineraria* (67% higher) and *H. binnata* (41% higher) based systems (Tanwar *et al.,* 2018a).

The above results clearly indicate that enhancing diversification is essential to impart resilience to farming and to cater to diverse needs of farming communities and ensuring higher land productivity, profitability and gainful employment round the year. Multiple arable crops, agroforestry, agri-horticulture, and horti/silvi-pasture systems provide options for diversifying the agricultural production systems. Within crop production, pearl millet, pulses, oilseeds and clusterbean should be included in approximately 40, 30, 10 and 20% area.

IFS options in NW hot arid region of India: Various landuse-based IFSs have been developed for NW hot arid region. The silvi-pasture system (i.e., co-cultivation of grasses, legumes with trees/shrubs) optimizes land productivity, conserving plants, soil and nutrients to produce forage, fuel wood, timber, etc. on sustainable basis. The areas receiving <200 mm annual rainfall, or degraded lands are suitable for silvi-pasture. *P. cineraria, A. tortilis, A. lebbeck, A. senegal, A. indica, H. binata, Z. rotundifolia, Z. nummularia* are suitable tree/shrub species, and *L. sindicus, C. ciliaris, C. setigerus, Panicum antidotale* and *Dicanthium annulatum* are suitable grass species for silvi-pasture system. Shankar (1980) reported that compared to natural grazing land, the silvi-pasture system enhanced forage/grazing availability and forage quality for a longer period of time and yielded 7-times more forage. Strip-planting in 1:2 ratio of *Z. nummularia* and *C. ciliaris* enhanced the productivity and return from mixed flock of sheep and goats over sole pasture (Bhat, 1997). Silvi-pasture of *Z. rotundifolia* and *C. ciliiris* could sustain 554 Tharparkar cattle days ha^{-1} with 60% pasture utilization (Pratap Narain and Bhati, 2004).

Horti-pasture system (i.e. growing of fruit crops and grasses) is a potential integrated production system for providing higher income from fruit trees and meeting demand of fodder. The *Z. mauritiana* based horti-pasture is suitable for class IV and V types of lands in hot arid regions. Horti-pastoral studies on sandy rangelands of Rajasthan revealed that *Z. mauritiana* + *C. ciliaris* system produced 1.2 t ha^{-1} forage and did not affect fruit yield of *ber* (Sharma and Diwakar, 1989). Long-term study on Samadari (Rajasthan) sandy rangeland showed that plantation of *Z. rotundifolia* and *Z. nummularia* @ 280, 140 and 170 plants ha^{-1} with C. *ciliaris* produced 624 to 824 kg ha^{-1} forage yield, and upto 280 plants ha^{-1} can be safely planted (Sharma and Vashishta, 1985).

Horticulture-based production system is ideal for economic returns, generating employment, and improving livelihood and nutritional security of people in hot arid regions (Chundawat, 1993; Pareek, 1999). Several drought-hardy fruit crops like *Capparis decidua*, *Salvadora oleoides*, *Cordia dichotoma*, *Cordia gharaf* and *Z. mauritiana* are suitable for the areas receiving <300 mm rainfall, and besides providing fruits these plants produce moisture laden nutritious leaves for livestock. Several other fruits such as *Emblica officinalis*, *Punica granatum*, *Aegle marmelos*, *Phoenix dactylifera*, and *Tamarindus indica* can be grown successfully in rainfall zone of 350-500 mm or where irrigation facilities are available (Pareek and Awasthi, 2008). In arid region, agri-horti system involving *Z. mauritiana* + mung bean/clusterbean has been found environmentally sound and economically viable even during drought years. Gupta *et al.* (2000) reported that *Z. maruitiana* @ 400 plants ha^{-1} in association with mung bean performed well with seasonal rainfall of 210 mm and increased net profit by Rs. 288.6 ha^{-1}, implying that agri-horti system minimizes risk in arid regions.

Saroj *et al.* (2003) demonstrated that clusterbean-Indian mustard and *Aloe* are suitable under-storey components in *ber*-based production system. The co-cultivation of *ber* with legume crops is reported to increase fruit yield of *ber* (Singh, 1997) and grain yield of legume crops (Singh *et al.,* 2003). Agri-horti system comprising *Ziziphus* + legume crops provides fruit, grain, fodder, fuel wood and round the year employment. Results of study conducted at Pali (Rajasthan) by ICAR-CAZRI showed that integration of arable crops (clusterbean, horse gram, mung bean and henna) with pomegranate improved the profitability over sole pomegranate (Lal, 2005). Pomegranate has also been found compatible with pearl millet, mung bean, *isabgol*, sorghum and cumin in Jalore district of Rajasthan (Gupta, 2000).

In the NW hot arid region, the arable crops remain on the land only for 70 to 100 days (during the rainy season of July to September). Agroforestry is therefore an efficient system of land and water utilization and sustained biomass production that can provide economic and social security in the event of crop failure in drought years. The integration of woody perennials has two important roles, provision of material output (fodder, fuel wood, fruit, timber etc.) and 'services' (nutrient cycling, soil amelioration, micro-climate modification, shelter). Besides imparting stability in land productivity during aberrant rainfall conditions, higher economic returns (Malhotra, 1984; Shankarnarayan *et al.,* 1987), soil amelioration (Man and Dauley, 1981; Muthana *et al.,* 1985) and micro-climate moderation (Ramakrishna *et al*., 1985) are some of the important benefits of agroforestry in Indian arid zones. Harsh (1995) indicated suitable tree and shrub species for different rainfall areas in NW hot arid zone and its adjoining regions (Table 2).

The benefits of tree integration largely depend upon efficient and judicious management of soil and water resources. Therefore, selection of suitable tree species, an appropriate combination of tree and crop, optimum densities and suitable management practices like pruning, lopping, thinning and root clipping are important aspects to enhance productivity of an agroforestry system. A long-term study at Jodhpur to evaluate crop productivity and define optimum tree density with advancing age of *P. cineraria* in an agroforestry system demonstrated that yield of annual crops was the highest at the densities of 278 trees ha^{-1} (4m × 9m) at 6- and 7-year age, 208 trees ha^{-1} (8m × 6m) at 10-year and <208 trees ha^{-1} at 11-year age of *P. cineraria* and amongst the crops, legume performed better than pearl millet (Singh *et al.,* 2007). About 200 plants ha^{-1} was optimum density of *ber* for agri-horticultural system at Jodhpur (Bhati *et al.,* 2008) and cowpea and clusterbean were better crops. At the age of five years, 417 stems ha^{-1} (4m x 6m) was optimum density of *T. undulata* in agroforestry system for total production (Singh *et al.,* 2005). Both higher and lower stem densities adversely affected crop production.

Canopy management of woody perennials is essential to harness the benefits of agroforestry systems. Harsh (1995) reported that in an agri-silvi system comprising of *Holoptelea integrifolia* (12-year old plantation) and arid legumes (clusterbean and mung bean), lopping of trees improved yields of the crops by 50-150% (Fig. 5). Singh and Rathod (2012) advocated use of silvicultural practices like trenching around tree trunk to reduce overlapping of roots of trees and crop for *C. mopane* based integrated production system.

Table 2. *Tree/shrub species for different rainfall regions*

Rainfall (mm)	Species
50-250	*Ziziphus nummularia, Acacia tortilis, A. senegal, Prosopis cineraria, Calligonum polygonoides, Tecomella undulata*
250-400	*P. cineraria, Hardwickia binata, Colophospermum mopane, Dichrostachys nutans, Ailanthus excelsa, Acacia catacheu, Grewia tenax, Acacia nilotica, Ziziphus mauritiana*
400-600	*Albizia amara, A. lebbeck, Cassia siamea, Emblica officinalis, Hardwickia binata, Ailanthusexcelsa, Moringa oleifera*

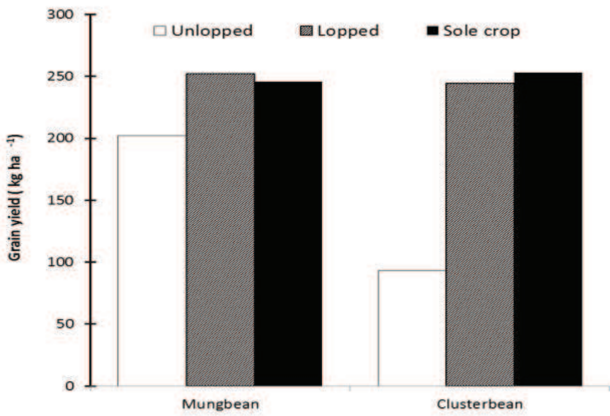

Figure 5. *Yield of legume crops under different canopy management practices in Holoptelea integrifolia based agroforestry systems in Indian hot arid region*

The integration of perennial grass with arable crops is also a suitable option to impart stability to crop production along with vegetative filter strip for arresting soil erosion. Strip cropping of grasses (*C. ciliaris, C. setigerus*) and *kharif* legumes (moth bean, clusterbean, mung bean) in 1:2 ratio with a strip width of 5 -10 m is found suitable for rainfed areas of NW hot arid region.

Inter- or mixed-cropping is an important strategy to minimize the risk in crop production in arid regions. Pearl millet + mung bean + moth bean + clusterbean + sesame is the most common crop mixture of western Rajasthan. The intercropping is shown to increase yield, profit and resource use efficiency compared to sole crops in arid regions. Pearl millet + legume is the most suitable intercropping for rainfed hot arid region. An additional yield of 265, 291, and 268 kg ha_{-1} of moth bean, mung bean and clusterbean, respectively, was recorded without any significant reduction in pearl millet yield in paired row planting of legume crop in interspaces of pearl millet in hot arid region (Joshi, 1999). Intercropping of grasses (*C. ciliaris* and *L. sindicus*) with grain legumes (moth bean, clusterbean, mung bean) recorded 20-30% higher yield of grasses compared to sole - grass. Sorghum + mung bean (2:1 ratio) is suitable intercropping system at Pali, Rajasthan. The available evidence suggests that to obtain maximum benefit of resource utilization and yield, suitable mixed/intercropping system should be adopted as per the local agro-climatic and socio-economic conditions. The component crops and their cultivars must be selected in accordance with rainfall pattern (amount, frequency, and intensity), rate of evapotranspiration, soil type etc.

A diversified IFS with 5-7 ha farm size has been developed for 300-400 mm rainfall zone of NW hot arid region based on a long-term experimentation since 2001 at ICAR-CAZRI, Jodhpur (Table 3). The model includes arable cropping (20%), agroforestry (30%), agri-horticulture (20%), silvi-pasture (10%) horti-pasture (10%) and boundary plantation (10%). In the livestock component, 'Tharparkar' cattle (0.75 ACU ha^{-1}) and 'Marwari' sheep and goat (3 animals ha^{-1}) were found rational to fully utilize family labour and available fodder (Tanwar *et al.,* 2018b). This system generates 130 man-days ha^{-1} and is capable of fully utilizing family labour and available fodder. The net returns estimated are Rs. 70,000 with a payback period of 5 years at an IRR of 35%.

Table 3. *A rainfed IFS model synthesized for an area of 5-7 ha for 300-400 mm rainfall area of NW arid zone (Adapted from Tanwar et al., 2018b)*

System	Component	% area
Arable cropping	Diversified cropping [pearl millet, mung bean, clusterbean in 4:1:1 ratio; replace 30% pearl millet with moth bean under delayed onset of monsoon (30th July onwards)]	20
Agroforestry	*Prosopis cineraria* (10 m X 15 m) + crops	30
Agri-horticulture	*ber* (Cv. Seb, Gola ; 5 m X 10 m) + crops	20
Silvi-pasture	*Hardwickia binata*/ *Ailanthus excelsa* + grass (*C. ciliaris*)	10
Horti-pasture	*Z. rotundifolia* / *Z. mauritiana* + grass (*C. ciliaris*)	10
Boundary plantation	*Acacia senegal, Hardwickia binata, Dalbergia sissoo* + trenching after 3 years of plantation	10
Cattle	Tharparkar breed (0.75 ACU ha^{-1})	
Goat and sheep	Marwari breed (3 animals ha^{-1})	

IFS for planet - carbon sequestration: The enhanced biodiversity within IFS, via integration of different plant and animal components in production system, performs an array of ecological services, including carbon sequestration, nutrient cycling, micro-climate regulation, soil microbial processes, and local hydrological processes, which lead to more sustainable agriculture with more reliance upon inputs generated within the system. The agroforestry system (AFS) provides a unique opportunity to combine the twin objectives of climate change adaptation and mitigation. Dhyani *et al.* (2016) studied the carbon sequestration potential (CSP) of AFS in India, and demonstrated that CSP of trees in AFS varied from 0.25 to 19.14 and of crops from 0.01 to 0.60 t C ha^{-1} yr^{-1}; and the contribution of AFS in soil carbon sequestration varied between 0.003 to 3.98 t C ha^{-1} yr^{-1}. A CAZRI study in arid regions of Gujarat demonstrated that the silvi-pastoral systems (trees: *A. tortilis*, *Azadirachta indica;* grasses: *C. ciliaris*, *C. setigerus*) sequestered 36.3 to 60.0% more total soil organic carbon (SOC) stock compared to sole tree and 27.1 to 70.8% more SOC stock than sole pasture systems (Mangalassery *et al.*, 2014). Study at Jodhpur demonstrated that agri-silviculture systems, i.e. *E. officinalis*, *H. binata* and *C. mopane* with *Vigna radiata,* sequestered 12.7-13.0, 8.6-8.8, 4.7-5.3 Mg C ha^{-1} (Singh, 2005). These results suggest that integration of trees in agricultural land is an important strategy to sequester carbon not only in the form of biomass but also in soil and may therefore maintain soil productivity. Besides climate change mitigation via C sequestration, the AFS also helps in adapting agriculture to climate change via moderating climate extremes, particularly high temperatures, as well as, intra-annual climatic fluctuations (Mbow *et al.,* 2014).

Efficient utilization of water: per drop more crop: The water scarcity is the major constraint for crop production in Indian hot arid regions and the efficient utilization of water is key for imparting resilience in agricultural production systems.

Water harvesting and supplemental irrigation: Rainwater being the major source of water for agriculture in NW hot arid regions of India, water harvesting (WH) and recycling for supplemental irrigation are important for enhancing agricultural productivity and resilience. Many variants of WH systems have been developed and standardized in accordance to bio-physical (rainfall, soil, topography, runoff and crop) and socio-economic characteristics of the region. The inter-plot WH (IPWH) with a ratio of 2/3 cropped area to 1/3 catchment area with 5% slope gave higher soil moisture content and yields of rainfed crops in the hot arid regions of India. The inter-row WH (IRWH) system consisting of ridge-furrow configuration (30-40 cm wide and 15 cm deep furrows with 60-90 cm wide ridge, constructed across slope) improved yields of rainfed crops. The IRWH system is suitable for moderately deep soils of medium to heavy texture. Singh and Singh (1997) reported that pearl millet yields with IPWH were 2425 and 1240 kg ha_{-1} as compared to 2320 and 400 kg ha_{-1} in flat sowing in good and low rainfall years, respectively. During low rainfall years the IPWH, thus, improved water productivity of pearl millet (WP) by 2-times.

In Western Rajasthan, various runoff farming systems have been traditionally developed and used for growing crops (Kolarkar *et al.,* 1983; Kolarkar and Singh, 1990) including already described *khadin* cultivation system followed in 100-200 mm rainfall zone in Jaisalmer district of western Rajasthan (Parsad *et al.,* 2004).

Supplemental irrigation (SI), especially during critical crop growth stages, provides many benefits that include higher and more stable crop yields, improved water productivity (WP), and reduced crop failure risks due to moisture deficit, thus enhancing resilience of farming in arid regions. Singh (1995) reported that when seasonal rainfall was 16.3 cm, a SI of 11.1 and 21.2 cm in pearl millet at reproductive stage gave 162 and 227% higher yields and 56 and 58% higher WP compared to rainfed crop without SI in arid region of Rajasthan. For harnessing full potential of SI, it should be combined with other improved management practices, including use of sprinkler and drip irrigation system.

Studies in NW Rajasthan showed that sprinkler and drip irrigation gave 12 to 86% greater WP than surface irrigation (Fig. 6). Suitable irrigation schedules for different crops, based on phenological stages or climatological approaches, have been developed to improve WP and saving water. Studies in canal irrigated areas of NW Rajasthan demonstrated that irrigations at the critical stages of growth of chickpea (at vegetative and 50% flowering stages), wheat (crown-root initiation, earing and milk stages), and cotton (50 DAS, square formation, flowering, boll formation, and boll development) gave high WP (Yadav and Chauhan, 2013).

Deficit irrigation (DI), application of irrigation water below the full crop ET or water requirement, is another way to increase WP in arid and semi-arid regions. Study by ICAR-

CAZRI at Pali, Rajasthan showed that compared to full irrigation, DI had 8 -20% greater WP in cotton (Singh *et al*., 2010), and 11-17% in wheat (Rao *et al*., 2013). Rathore *et al.* (2017) demonstrated that for wheat in hot arid region of India, moderate deficit irrigation (ETc 0.8) had highest WP, resulting in 17% saving of irrigation water with only 5% reduction in yield, as compared to full irrigation (ETc 1.0). It has been demonstrated that yields and WP could increase even more if DI is used in combination with suitable soil management practices such as FYM application, tillage (Rao *et al.,* 2013), N application (Rathore *et al.,* 2017) and application of growth regulators (Wakchaure *et al.,* 2016 a, b). A study at Pali, Rajasthan demonstrated that deep tillage with DI of 46, 62, 75, and 88% of full irrigation had, respectively, 3, 17, 19 and 20% greater WP of wheat compared to yield with conventional tillage (Rao *et al*., 2013).

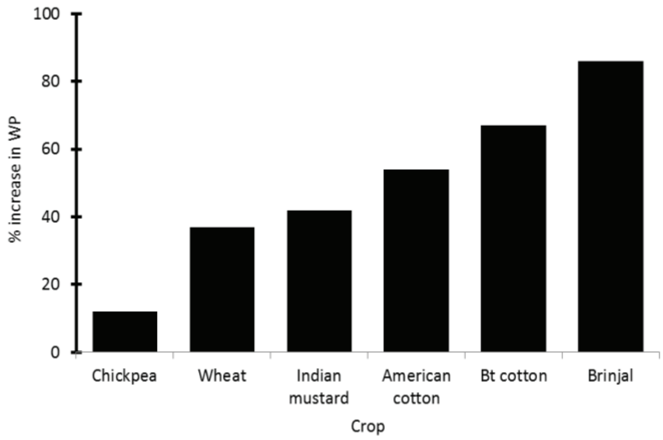

Figure 6. *Increase in WP due to pressurized irrigation methods (sprinkler and drip) relative to surface irrigation (Modified from Rao et al., 2016; Yadav and Chauhan, 2013).*

Even though, there are many options for enhancing WP, the one most appropriate will be site specific and depend on social and economic conditions of the farmers. Combining biological water saving measures with engineering solutions, agronomic measures and manipulation of soil environment in an integrated manner is the best strategy for improving WP. The adoption of these techniques is, however, slow due to many reasons. Improving WP requires enabling policies and institutional environment that align the incentives of producers, resource managers and society, and provide a mechanism for dealing with trade-offs between WP and yield.

Technological interventions to lessen the challenge

Intense and strategic research conducted in arid and drier semi-arid regions has led to identification of several technologies that can enhance the resilience of arid farming.

Right choice of crops and cultivars: The crop-growing period (CGP) in NW hot arid region in Rajasthan is short, varying from <6 to 12 weeks depending on rainfall. Short duration legumes are suitable for 250-300 mm yr^{-1} rainfall region with 8-10 weeks of CGP; whereas, pearl millet and medium duration legumes are suitable for 300-400 mm yr^{-1} rainfall region with 10-12 weeks of CGP (Rao *et al*., 1994). Long-term studies have indicated that 45, 23 and 32% area should be allocated to millets (pearl millet, sorghum), pulses and grasses, respectively, for achieving stable crop production in hot arid region (Faroda *et al*., 2007). Selection of suitable cultivar is crucial for success. Pearl millet cultivars HHB-67 Improved, CZP 9802, GHB-538, GHB-719, GHB-757, RHB-154, RHB-177, HHB-226, MPMH 17 and MPMH-21 ; moth bean RMO-40, RMO-225, RMO-435, RMO-423, RMO-257, RMB-2251, CAZRI Moth-2 ; clusterbean RGC-936, RGC 1003, RGC-1055, RGC-1066, RGC-1038, HG-365, HG-563; sesame RT-13, RT-46, RT-351; and mung bean K-851, IPM 2-3, IPM 205-7 are suitable for cultivation in NW hot arid region. Substitution of traditional cultivars by improved cultivars increased yields by 15-50%.

Enhancing fodder supply: Livestock are integral component of agrarian economy of the hot arid region (Rathore *et al.,* 2009, 2010). Their average productivity is low, primarily due to shortage of good quality fodder and other critical nutrients. Therefore, enhancing fodder supply is imperative to increase resilience of the farming in this region.

Community grazing lands are the primary source of fodder here, but most are degraded and production is hardly 300-400 kg ha^{-1}. There is a need to improve the common grazing resources in participatory mode by integrating soil and moisture conservation techniques, reseeding of palatable forage species, nutrient management, and protective site-specific grazing. Live fencing on the field boundary with woody perennials having forage value is an attractive option to augment fodder supply as it can provide 6-13.5 t ha^{-1} dry matter. Studies by ICAR-CAZRI demonstrated that reseeding with *C. ciliaris* enhanced fodder yield by 55% in the second year. An active participation of all the stakeholders is however essential for sustainable development of common grazing lands.

Furthermore, newly introduced fodder crops like fodder beet, spine-less cactus (*Opuntia ficus-indica*) and Hybrid Napier provide new avenues for enhancing fodder availability in the region. ICAR-CAZRI studies revealed that beet root can give 245 t ha^{-1} fresh fodder yield in four months and Hybrid Napier up to 400 t ha^{-1} when planted in crop geometry of 75cm × 60cm. Several high fodder yielding cropping sequences for irrigated areas have also been identified for the region. 'Cowpea-oat- pearl millet' and 'pearl millet+cowpea-oat-sorghum', with irrigation scheduled at 50 mm CPE, produced up to 87 t ha^{-1} of green fodder per annum in the studies at CAZRI. Promotion of dual purpose crops such as pearl millet, with cultivars having good grain and straw yields, is another important avenue for enhancing fodder availability in the region.

Complete Feed Blocks (CFB), Multi Nutrient Blocks (MNB), Multi Nutrient Mixtures (MNM) and urea-treated crop straw can play an important role in ensuring nutritional security of livestock (Patidar *et al.,* 2014).

Harnessing the natural strength: The utilization of the solar energy, abundant in the region, via solar photo-voltaic (PV) and solar thermal devices, provides immense opportunity to meet the energy needs for domestic and agricultural uses. Use of solar devices for pumping irrigation water, pesticide application, cleaning and drying of agricultural products, cooking animal feed, etc. enhances productivity and profitability of farming in the hot arid region. As mentioned before, agri-voltaic system provides opportunity for co-generation of electricity with crop production along with harvesting of rain water (Santra *et al*., 2018). Hence, itis an exciting technology for sustainable development of farming in the NW hot arid region.

Combating desertification

Desertification is a perennial challenge in the NW hot arid region of India. Wind and water erosion, water logging, salinity/alkalinity and vegetation degradation are the major factors, but lately industrial effluents and mining are also becoming important. About 76% area of western Rajasthan is affected by wind erosion, 2% by water erosion, 2% by salinization, 3% by vegetation degradation and 0.1% by mining activities. Overall, 5, 16, 41 and 30% area of western Rajasthan is very severely, severely, moderately and slightly affected by desertification, respectively (Kar *et al.,* 2007).

Wind erosion of sand is the one of the most important factors of desertification in NW Rajasthan. Inherent high soil erodibility, high wind speed, low rainfall, expansion of cultivation on less suitable marginal sandy lands including high slopes of sand dunes, land levelling in dune covered irrigated areas, degradation of vegetation covers, deep ploughing of the sandy tract and disappearance of practices like land fallowing and rotational grazing are major causes of sand destabilization, accelerating the wind erosion in NW Rajasthan. Water erosion through fluvial processes affects sizable area in Saurashtra & Kachchh uplands and the eastern margin of the Thar Desert having annual rainfall >350 to 500 mm. Water erosion in Gujarat is mainly related to accelerated runoff on moderately deep and fine textured soils on sloping terrain especially on ploughed lands without any soil and water conservation measures. In eastern margin of the Thar Desert, denudation of vegetation cover on slopes of hills is major factor responsible for accelerating water erosion.

Excessive irrigation coupled with inadequate drainage has caused water logging and soil salinization in canal command areas of Hanumangarh, Sri Gangangar and Bikaner districts. The occurrence of clay and gypsum beds at shallow depth in canal command areas restricts deep drainage and promotes water logging. Increase in soil salinity/alkalinity due to irrigation with brackish groundwater is a major form of degradation in medium to heavy textured soils of alluvial plains.

The unrestricted grazing, increased exploitation of vegetation (particularly for fuel-wood and other needs) coupled with encroaching of grazing lands has led to extensive degradation of natural vegetation in the NW hot arid region. The common grazing lands (*Oran, Gochar and Aagor*) are severely degraded. The degradation of vegetation leads to replacement of useful species by aggressive alien colonizers having less feed and fodder values, for example the replacement of nutritive grass species by *P. juliflora* in Banni Grasslands of Gujarat (Manjunath *et al.,* 2019).

Many technologies such as sand dune stabilization, shelterbelt plantation, water harvesting and conservation, watershed development, management for croplands/rangelands, rehabilitation of saline/water logged/mining damaged soils have been developed for combating desertification.

Sand dune stabilization: About 58% area of arid Rajasthan is under sand dunes. ICAR-CAZRI has developed vegetative methods for sand dune stabilization which include: (a) protection of dune from biotic interference (human and livestock encroachment); (b) creation of micro wind breaks on dune by using locally available dried brushes like twigs of *Z. nummularia*, *Calotropis procera*, *Crotolaria burhia*, *Aerva tomentosa* and *Leptadenia pyrotechnica,* either in checker-board pattern or in parallel strips across the direction of wind; (c) direct seeding or transplanting of suitable woody species viz. *Calligonum polygonoides, Colophospermum mopane, A. tortilis, A. nubica*, and in between the tree species root slips of grasses viz., *L. sindicus*, *P. turgidum, C. biflorus, C. setigerus* and creeper *Citrullus colosynthis* are planted. The technology has been widely adopted and about 400,000 ha area of sand dunes has been stabilized (Moharana *et al*., 2018). Over-emphasis was placed in the past on exotic tree species, which had less economic value (only fuel wood) with poor adoption by the farmers. ICAR-CAZRI has now suggested their replacement by locally adapted species with better economic returns. Creating awareness among the people pertaining to tangible and intangible gains of dune stabilization and ensuring their participation in the stabilization programme are crucial for success.

Shelterbelt plantation: Erection of shelterbelt (strips of multiple rows of trees and shrubs across the prevailing winds) helps to reduce wind speed and minimize the harmful effects on soils and crops. Shelterbelts have been successfully raised on a large scale along roads, railway tracks, open canals, around orchards and field boundaries in the NW hot arid region. It has been demonstrated that shelterbelts reduce the wind velocity by 20-46% on their leeward side at 2H to 10H distance and reduce soil loss by 66% compared to areas without shelterbelt. Furthermore, the shelterbelt helps to conserve soil moisture, improve micro-climate, enhance crop yields and provide economic products (fodder and fuel wood). A three row windbreak comprising of *A. tortilis, Cassia siamea* and *P. juliflora* as the side rows and *Albizzia lebbek* as the central row is suitable shelterbelt for NW hot arid region. Planting a 13 m wide tree belt across the wind, interspersed with 60 m wide grass belt, is also a promising option.

Other technologies: To tackle the problem of water erosion, many soil and water conservation practices like contour bunding, bench terracing, contour sowing, check dams, etc. have been developed. For amelioration of soil degraded by high RSC water, ICAR-CAZRI has standardized gypsum application technology [gypsum application @50% gypsum requirement and extra amount of gypsum to neutralize the excess RSC in irrigation water (i.e. for RSC in excess of 5 meq L^{-1}, 0.30 t ha^{-1} gypsum is required to neutralize 1 meq L^{-1} RSC)], which is followed by use of zinc sulphate @ 25 kg ha^{-1} in the second year. The irrigation led water logging and associated soil salinization problems can be countered by implementing vertical and horizontal and subsurface drainage. In areas where undulated land topography does not permit gravity surface drains, and where groundwater is saline, water table control can be obtained by bio-drainage to some extent. The potential of certain tree species to draw more water than the agricultural crops because of their deeper root system, higher transpiration rates throughout the year and the ability to minimize recharge from rain by intercepting it on their foliage, provides a way for keeping water table under control. *Eucalyptus camaldulensis, E. tereticornis, Atriplex lentiformis, Acacia nilotica,* and *Acacia ampliceps* are some of the species that offer a great potential to work as bio-pumps.

Enhancing adaptive capacity

Studies have identified economic development, education, technology, knowledge, infrastructure, institutions, equity and social capital as generic determinants of adaptive capacity (Adger *et al*., 2007). The adaptive capacity of a farming household depends on human, physical and financial resources, information and skill, awareness and training, technological capacities, social capital, institutional support, infrastructure facilities, etc. (Defiesta and Rapera, 2014; Abdul-Razak and Kruse, 2017).

The capacity to respond to changes in environmental conditions exists within communities to different degrees but not always all responses are sustainable (Altieri *et al.,* 2015). It is therefore, essential to identify the knowledge and practices that have helped desert dwellers survive under arid zone conditions, and to refine and upscale these so that vulnerability to climatic events can be reduced. Dissemination of proven technologies that have been found to enhance resilience to various stresses is essential to enhance adaptive capacity of farmers. FAO (2011) advocated promotion, dissemination and adoption of climate smart agricultural practices which increase adaptive capacity and resilience of farm production in the face of climate shocks and can also mitigate emission of greenhouse gases. As mentioned earlier, crop diversification rather than monocultures, agroforestry systems, crop-livestock mixed systems, proper residue and nutrient management, water harvesting and conservation, adoption of varieties recommended for the region, etc. can enhance the adaptive capacity of dryland farms of arid region.

Technologies are disseminated via demonstrations at farmers' fields, field days at various research institutions and progressive farmers' fields, and through short training programmes for farmers. ITC is also used to enhance access of farmers to various improved technologies and climate and weather information. Farmer producer organizations, farmer cooperatives, contract farming, etc. are being promoted to enhance social capital.

Most of the farmers of arid zone have poor financial resources. Cooperative banks, regional rural banks and nationalized banks give them loans at low interest rates but their penetration in rural areas and access to farmers still need to be enhanced to reduce farmer dependence on money lenders. Dryland agriculture in arid zones is inherently very risky. Insurance is available for major crops grown in NW hot arid zone, but its adoption is relatively low. The issues related to timely settlement of claims need to be resolved for wider insurance coverage as insurance cover alleviates the fear of total or major losses in case of severe weather aberrations and encourages farmers to adopt improved production technologies (Panda *et al*., 2013). Procurement of farm produce at assured minimum support price (MSP) is also a major booster to adaptive capacity and it needs to be extended also to those commodities produced in arid zone that are not presently covered under the MSP.

Timely availability of quality agri-inputs, like seeds and planting material, plant protection chemicals and fertilizers, have to be ensured so that knowledge and information can be translated into action. State and Central governments provide various incentives and subsidies to economically weaker farmers. There is need to create greater awareness among such groups to promote the use of such schemes.

Adoption of improved farming technologies

As already mentioned, a stream of technologies for sustainable utilization of natural resources and crop production has been generated for the NW hot arid region (Yadav, 2018). Adoption of suitable crops and cultivars for different production environments, tillage practices, rain water management (water harvesting, mulching, sub surface barriers for minimizing deep percolation of water), seed rate, planting time, integrated plant nutrient management, optimum planting density and pattern, weed management, insect-pest and disease management, crop production under abiotic stresses (suitable cultivars, planting methods, exogenous application of bio-regulators, seed priming, mid-season corrective measures), contingent crop planning, conjunctive and efficient use of irrigation in accordance with site-specific bio-physical and socio-economic conditions is essential for augmenting productivity and profitability of farming, which ultimately leads to enhancing resilience of arid lands.

Conclusion

For ages, the inhabitants of hot arid regions have been practicing subsistence farming, maintaining delicate balance between their needs and fragile natural resources. Land use pattern and farming experienced huge changes during recent decades due to increase in population, expansion of irrigation and increased use of mechanization and agri-inputs (improved seed, fertilizer, plant protection chemicals). Agriculture made an impressive progress in terms of increase in productivity and production of most of the field crops, fruits, vegetables, etc. owing to increase in cropping intensity, irrigation facilities in some areas and availability of better inputs like seed, fertilizer, pesticides, farm machinery and tools, etc. Although, the agricultural productivity is still low in NW hot arid region, the compound annual growth rate (CAGR) of food grain productivity during the period 1999-2000 to 2010-2011 was higher (3.2% in Rajasthan, 4.9% in Gujarat) than national average of 1.6%. Enhanced agricultural productivity coupled with infrastructural developments led to better livelihood security and overall development in the arid regions.

Despite the enormous progress made in the past, there are many daunting challenges which are threatening sustainable farming in the arid regions. The inherent climatic conditions of hot arid regions pose major constraint for farming which is likely to be worsened by the anticipated climate change, more specifically with rising temperatures and aberrant rainfall. Increasing human and livestock population strains the natural resources. The problems of water scarcity and natural resource degradation are increasing. Furthermore, the average productivity and profitability of majority of crops in the region is far below the experimental or potential yield in both rainfed and irrigated production systems. However, the hot arid region is endowed with rich biodiversity and its scientific conservation and utilization can help to meet diverse needs of inhabitants under anticipated climatic and biotic stresses. The cultivated and neglected and underutilized species (NUS) of plants and livestock have enormous variability, specifically adapted to thermal and water stresses, which make them potential resources in drier and warmer climate of future. Furthermore, the rich traditional wisdom of making livelihood under adverse climatic conditions and managing natural resources is of immense significance to enhance the resilience of farming. There is need to preserve and fine-tune these indigenous techniques. Arid regions are well-endowed with solar and wind energy, and there is vast scope for their systematic harnessing for domestic, agricultural and industrial uses.

Many technologies like sand dune stabilization, shelterbelt plantation, erosion control, soil management practices, crop management, pest and disease management, rehabilitation of wastelands, grassland improvement, watershed development, water management, arid land farming, arid horticulture, alternate land use systems, solar devices, and suitable integrated farming system models have been developed and demonstrated for achieving sustainably higher and economically viable land, water and animal productivity along with conservation of natural resources. Genetic improvement of plants for improving adaptation and tolerance to abiotic stresses, augmenting fodder availability, harnessing the potential of neglected and under-utilized plant species, value-addition to agri-products, and efficient utilization of scarce irrigation water and abundant solar energy require specific attention for enhancing productivity, profitability and resilience of the farming in coming years. Enhancing the component diversity (crop, cultivar, tree, grass, livestock) at farm level, in accordance with the site-specific bio-physical and socio-economic conditions, is prime-requisite to enhance resilience of farming and ensuring sustainable livelihood in the arid region.

For promoting implementation of various recommended technologies to a desired extent, there is need of creating adequate infrastructural facilities (storage, transportation, and marketing), strengthening extension activities, promotion of co-ordination among different stakeholders, and ensuring enabling policy framework and institutional support for implementation of policies.

References

Abdul-Razak, M. and S. Kruse. 2017. The adaptive capacity of smallholder farmers to climate change in the northern region of Ghana, *Climate Risk Management* 17:104-122.

Adger, W.N., S. Agrawala, M.M.Q. Mirza, C. Conde, K. O'Brien, J. Pulhin, R. Pulwarty, B. Smit and K. Takahashi. 2007. Assessment of adaptation practices, options, constraints and capacity. Pages 717-743 *in* Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (Eds. M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson). Cambridge University Press, Cambridge, UK.

Altieri, M.A., C.I. Nicholls, A. Henao and M.A. Lana. 2015. Agroecology and the design of climate change-resilient farming systems. *Agronomy for Sustainable Development* 35: 869-890.

Arya, R., O.P. Awasthi, J. Singh, I.S. Singh and J.R. Manmohan. 2011. Performance of component crops in tree- fruit crops under hot arid ecology. *Indian Journal of Horticulture* 68: 6-11.

Behera, U.K. and I.C. Mahapatra. 1999. Income and employment generation of small and marginal farmers through integrated farming systems. *Indian Journal of Agronomy,* 44: 431-439.

Bhandari, D.C., P.R. Meghwal and S. Lodha. 2014. Horticulture based production systems in Indian arid region. Pages 19-50 *in* Sustainable Horticultural Systems: Issues, Technology and Innovation (Ed. D. Nandwani). Cham: Springer India.

Bhati T.K., J.C. Tewari and S.S. Rathore. 2008. Productivity dynamics of integrated farming systems in western Rajasthan. Pages 23-30 *in* Diversification of Arid Farming Systems (Eds. Pratap Narain, M.P. Singh, A. Kar, S. Kathju, Praveen-Kumar), Arid Zone Research Association of India and Scientific Publishers (India), Jodhpur, India.

Bhati, T.K. 1997. Integrated farming system for sustainable agriculture in drylands. Pages 102-105 *in* Sustainable Dryland Agriculture*,* CAZRI, Jodhpur.

CAZRI, 2007. CAZRI Perspective Plan Vision-2025. Central Arid Zone Research Institute, Jodhpur, P. 94.

CAZRI, 2014. Annual Progress Report. CAZRI, Jodhpur, India. pp. 53-54.

CAZRI, 2015. CAZRI Vision -2050, Central Arid Zone Research Institute, Jodhpur. P. 24

Chundawat, B.S. 1993. Intercropping in orchards. *Advances in Horticulture* 2:763-767.

Dayal, D., S. Mangalassery, S.L. Meena and B. Ram. 2015. Productivity and profitability of legumes as influenced by integrated nutrient management with fruit crops under hot arid ecology. *Indian Journal of Agronomy* 60: 297-300.

Defiesta, G. and C.L. Rapera. 2014. Measuring adaptive capacity of farmers to climate change and variability: application of a composite index to an agricultural community in the Philippines. *Journal of Environmental Science and Management* 17: 48-62.

Dhyani S.K., A. Ram and I. Dev. 2016. Potential of agroforestry systems in carbon sequestration in India. *Indian Journal of Agricultural Sciences* 86: 1103-1112.

Dupraz, C., H. Marrou, G. Talbot, L. Dufour, A. Nogier and Y. Ferard. 2010. Combining solar photovoltaic panels and food crops for optimising land use: towards new agrivoltaic schemes. *Renewable Energy* 36: 2725-2732.

Faroda, A.S. 1998. Arid zone research - An overview. *In* Fifty Years of Arid Zone Research in India (Eds. A.S. Faroda and M. Singh), pp. 1-16. CAZRI, Jodhpur.

Faroda, A.S., D.C. Joshi and B. Ram. 1999. Agro-ecological zones of north-western hot arid region of India. *Annals of Arid Zone* 38: 1-8.

Faroda, A.S., N.L. Joshi, R. Singh and A. Saxena. 2007. Resource management for sustainable crop production in arid zone - A review. *Indian Journal of Agronomy* 52: 181-193.

Food and Agricultural Organization (FAO) 2011. Save and Grow: A Policymaker's Guide to the Sustainable Intensification of Smallholder Crop Production. Food and Agriculture Organization of the United Nations, Rome.

Gill, M.S., J.P. Singh and K.S. Gangwar. 2009. Integrated farming system and agriculture sustainability. *Indian Journal of Agronomy* 54: 128-139.

Goyal, R.K. 2004. Sensitivity of evapotranspiration to global warming: a case study of arid zone of Rajasthan (India). *Agricultural Water Management* 69: 1-11.

Goyal, R.K., J.P. Singh and M.K. Gaur. 2018. Khadin system of runoff farming for crop production. *Indian Farming* 68 (9): 26 -28.

Gupta, J.P. 2000. Agroforestry for sustained production. Technology Approach for Greening Arid Lands, CAZRI, Jodhpur.

Gupta, J.P., D.C. Joshi and G.B. Singh 2000. Management of arid ecosystem. Pages 551-668 *in* Natural Resource Management for Agriculture Production in India (Eds. J.S.P. Yadava and G.B. Singh), Indian Society of Soil Science, New Delhi.

Harsh, L.N. 1995. Alternate land use system for sustainable development: Silviculture. Pages 187-196 *in* Land Resources and Their Management for Sustainability in Arid Region (Eds. A.S. Kolarkar, D.C. Joshi and A. Kar), Scientific Publisher, Jodhpur.

Harsh, L.N. and J.C. Tewari. 2007. Agroforestry system in arid region (Rajasthan) of India. Pages 175-190 *in* Agroforestry Systems and Practices (Eds. S. Puri and P. Panwar). New India Publishing Agency, New Delhi.

Hoddinott, J. 2014. Looking at development through a resilience lens. Pages 19-26 *in* Resilience for Food and Nutrition Security (Eds. S. Fan, R. Pandya-Lorch and S. Yosef). International Food Policy Research Institute, Washington DC, USA.

IGNB, 2002. History of Indira Gandhi Nahar: A Venture to Turn Thar Desert into Granary, Indira Gandhi Nahar Board, Bikaner.

Jayanthi, C., A. Rangasamy, S. Mythili, M. Balusamy, C. Chinnusamy and N. Sankaran 2001. Sustainable productivity and profitability of integrated farming systems in low land farms. Pages 79-81 *in* Extended Summaries of National Symposium on Farming System Research on New Millennium, PDCSR, Modipuram.

Joshi, D.C. 2012. Land use planning for sustainable agriculture in arid agro-ecosystem: Issues and strategies. *Agropedology* 24: 262-282.

Joshi, D.C., N. Singh, B.K. Sharma and P. Raina. 1998. Soils: distribution, characteristics and nutrient dynamics. Pages 55-79 *in* Fifty Years of Arid Zone Research in India (Eds. A.S. Faroda and M. Singh). CAZRI, Jodhpur.

Joshi, N.L. 1999. Effect of component densities on the performances of pearl millet - mung bean intercropping systems under different rainfall situations in arid environment. *Annals of Arid Zone* 38(1): 15 - 25.

Kar, A. 2014. Agricultural land use in arid Western Rajasthan: Resource exploitation and emerging issues. *Agropedology* 24: 179-196.

Kar, A., P.C. Moharana and S.K. Singh. 2007. Desertification in arid western India: Current scenario. Pages 1-22 *in* Dryland Ecosystem: Indian Perspective (Eds. K.P.R. Vittal, R.L. Srivastava, N.L. Joshi, V.P. Tewari and S. Kathju). Central Arid Zone Research Institute, Jodhpur, and Arid Forest Research Institute, Jodhpur.

Kathju, S., N.L. Joshi, A.V. Rao and Praveen Kumar. 1998. Arable crop production. Pages 253-272 *in* Fifty Years of Arid Zone Research in India (Eds. A.S. Faroda and M. Singh). CAZRI, Jodhpur.

Kaushik, N. and V. Kumar 2003. Khejari (*Prosopis cineraria*)-based agroforestry system for arid Haryana. *Journal of Arid Environments* 55: 433-440.

Kaushik, N., A. Tikkoo, P.K. Yadav, R.P.S. Deswal and S. Singh. 2017. Agri-silvi-horti systems for semiarid regions of North-west India. *Agricultural Research* 62: 150-158.

Kavadia, P.S. and R. Hooja. 1994. Indira Gandhi Nahar Project: components, impacts and planning issues. *In* Planning for Sustainability in Agriculture Command Area Development and Indira Gandhi Nahar Project (Eds. Kavadia, P.S. and R. Hooja), Rawat Publications, Jaipur.

Kolarkar, A.S. and N. Singh 1990. Runoff farming in arid tract of India-a review. *Indian Journal of Soil Conservation* 18(3): 31-41.

Kolarkar, A.S., K.N.K. Murthy and N. Singh. 1983. Khadin-a method of harvesting water for agriculture in the Thar Desert. *Journal of Arid Environment* 6: 56-66.

Kumar, A., M.S. Hooda and R. Bahadur 1998. Impact of multipurpose trees on productivity of barley in arid ecosystem. *Annals of Arid Zone* 37: 153-157.

Kumar, S. 1998. Vegetation resources in the Indian Arid zone. Pages 89-119 *in Fifty Years of Arid Zone Research in India* (Eds. A.S. Faroda and M. Singh). CAZRI, Jodhpur.

Kumar, S. 2016. Biodiversity and its conservation in climate change scenario. Pages 107-122 *in* Climate Change and Agriculture: Adaptation and Management (Eds. R.K. Bhatt, U. Burman, D.K. Painuli, D.V. Singh, Ramavtar Sharma and S.P.S. Tanwar). Satish Serial Publishing House, Delhi.

Kumar, S., Shivani and S.S. Singh. 2013. Sustainable food and nutritional security through IFS. *Indian Farming* 63: 30-36.

Lal, G. 2005. Pomegranate based cropping system for sustainable production in arid ecosystem. Pages 55-60 *in* Diversification of Arid Farming System (Eds. Pratap Narain, M.P. Singh, A. Kar, S. Kathju and Praveen-Kumar). Arid Zone Research Association of India and Scientific Publisher (India) Jodhpur, India.

Maheswarappa, H.P., M.R. Hegde, R. Dhanapal, C.V. Sairam and T.V. Singh. 2001. Impact of integrated mixed farming systems in coconut (*Cocos nucifera*) on coconut yield and economic analysis. *Indian Journal of Agronomy* 46: 56-63.

Maleksaedi, H. and E. Karami 2013. Social-ecological resilience and sustainable agriculture under water scarcity. *Agro ecology and Sustainable Food Systems* 37(3): 262-290.

Malhotra, S.P. 1984. Traditional agroforestry practices in arid zone of Rajasthan. Pages 263-266 *in* Agroforestry in Arid and Semi-arid Regions (Ed. K.A. Shankarnarayan), pp. 263-266. CAZRI, Jodhpur, India.

Man, H.S. and H.S. Daulay. 1981. A review of forage forestry: Agroforestry research in India with special reference to arid and semi-arid regions. *Indian Journal of Range Management* 2: 87-93.

Mangalassery, S., D. Dayal, S.L. Meena and B. Ram. 2014. Carbon sequestration in agroforestry and pasture systems in arid north-western India. *Current Science* 107: 1290-1293.

Manjunatha, B.L., M. Sureshkumar, P. Tewari, D. Dayal and O.P. Yadav. 2019. Livestock population dynamics in *Banni* grasslands of Gujarat. *Indian Journal of Animal Sciences* 89: 319-323.

Mbow, C., M. Van-Noordwijk, E. Luedeling, H. Neufeldt, P.A. Minang and G. Kowero. 2014. Agroforestry solutions to address food security and climate challenges in Africa. *Current Opinion in Environmental Sustainability* 6: 61-67.

McNeely, J.A. 2003. Biodiversity in arid regions: values and perceptions. *Journal of Arid Environments* 54: 61-70.

Meghwal, P.R. and A. Henry. 2009. Economic evaluation of different agri-horticulture systems under rainfed condition of arid zone. Pages 299- 303 *in* Legumes in Dry Areas (Eds. D. Kumar, A. Henry and K.P.R. Vittal). Indian Arid Legume Society and Scientific Publishers, Jodhpur.

Millennium Ecosystem Assessment. 2005. Ecosystems and Human Well-being: Synthesis. Island Press, Washington, D.C., USA.

Moharana P.C., P. Kumar, D.V. Singh and O.P. Yadav. 2018. Sand dune stabilization in the Indian Thar desert: Impact and ecosystem services. Pages 87-97 *in* Agriculture and Ecosystem Services (Pal, S., Ed.). National Institute of Agricultural Economics and Policy Research, New Delhi.

Moharana, P.C., P. Santra, D.V. Singh, S. Kumar, R.K. Goyal, D. Machiwal and O.P. Yadav. 2016. ICAR-Central Arid Zone Research Institute, Jodhpur: Erosion Processes and Desertification in the Thar Desert of India. *Proceedings of Indian National Science Academy* 82: 1117-1140.

Muthana, K.D., S.K. Sharma and L.N. Harsh. 1985. Study of silvi-pastoral system in arid zone. *My Forest* 21: 233-238.

Panda, A., U. Sharma, K.N. Ninan and A. Patt. 2013. Adaptive capacity contributing to improved agricultural productivity at the household level: empirical findings highlighting the importance of crop insurance. *Global Environmental Change* 23: 782-790.

Pareek, O.P. 1999. Dryland Horticulture. Pages 475-484 *in* Fifty Years of Agricultural Research in India. CRIDA, Hyderabad.

Pareek, O.P. and O.P. Awasthi. 2008. Horticulture-based farming systems for arid region. Pages12-22 *in* Diversification of Arid farming System (Eds. Pratap Narain, M.P. Singh, Amal Kar, S. Kathju and Praveen-Kumar). Arid Zone Research Association of India and Scientific Publisher (India) Jodhpur, India.

Patel, B.M., S. Patel, S.K. Patel, and S.B. Patel. 2003. Intercropping studies in ber (*Zizyphus mauritiana* LAMK.). *Agricultural Science Digest* 23: 113 - 115.

Patel, J.M., S.N. Jaimini and S.B. Patel. 2008. Evaluation of neem and ardu based agri-silvi systems. Pages 114-118 *in* Diversification of Arid Farming Systems (Eds. Pratap Narain, M.P. Singh, A. Kar, S. Kathju and Praveen-Kumar). Arid Zone Research Association of India and Scientific Publishers (India), Jodhpur, India.

Patidar, M., A.K. Patel, A.K. Misra, A.S. Sirohi, R.N. Kumawat, P.R. Meghwal and M.M. Roy. 2014. Improving Livelihood of farmers through Livestock Interventions in Nagaur District of Rajasthan. Central Arid Zone Research Institute, Jodhpur, p. 56.

Patidar, M. and B.K. Mathur. 2017. Enhancing forage production through a silvi-pastoral system in an arid environment. *Agroforestry Systems* 194: 713-727.

Patil, N.V., B.K. Mathur, M.A. Khan, H.C. Bohra, A.K. Patel, M. Patidar, P.P. Rohilla, D.K. Saha, Khem Chand, A.C. Mathur, S. Kachhawaha, S.K. Kaushish, S.A. Karim, A.K. Shinde, K.M.L. Pathak and Champak Lal. 2009. Improvement of livestock productivity in arid region. Pages 180-209 *in* Trends in Arid Zone Research in India (Eds. Amal Kar, B.K. Garg, M.P. Singh and S. Kathju). CAZRI, Jodhpur.

Peterson, C.A., V.T. Eviner and C.M. Gaudin Amélie. 2018. Ways forward for resilience research in agro ecosystems. *Agricultural Systems* 162: 19-27.

Prasad, R., R.S. Mertia and Pratap Narain. 2004. Khadin cultivation: a traditional runoff farming system in Indian Desert needs sustainable management. *Journal of Arid Environments* 58: 87-96.

Pratap Narain and A. Kar. 2005. Drought in Western Rajasthan- Impact, Coping Mechanism and Management Strategies. CAZRI, Jodhpur, P. 45.

Pratap Narain and T.K. Bhati. 2004. Alternative Farming System: Issues and opportunities in arid ecosystem. Pages 57-64 *in* Alternative Farming Systems (Eds. A.K. Singh, B. Gangwar and S.K. Sharma). Farming System Research and Development Association, Modipuram.

Ramakrishan, Y.S., A.S.R.A.S. Sastri and K.D. Muthana. 1985. A note on the importance of radiant energy penetration in silvopastoral system. *My Forest* 17: 1-3.

Rao, A.S. 2009. Climatic variability and crop production in arid western Rajasthan. Pages 48-61 *in* Trends in Arid Zone Research in India (Eds. A. Kar, B.K. Garg, M.P. Singh and S. Kathju). Central Arid Zone Research Institute, Jodhpur.

Rao, A.S. and R.S. Singh. 1998. Climatic features and crop production. Pages 17-38 in *Fifty Years of Arid Zone Research in India* (Eds. A.S. Faroda and M. Singh). Central Arid Zone Research Institute, Jodhpur.

Rao, A.S., Y.S. Ramakrishna and J. Venkatswarlu. 1994. Determination of crop growing period in arid and semi-arid region of Rajasthan. *Annals of Arid Zone* 35: 229-231.

Rao, S.S., P.L. Regar and S.P.S. Tanwar. 2016. Effect of deficit irrigation, phosphorous inoculation and cycocel spray on root growth, seed cotton yield and water productivity of drip irrigated cotton in arid environment. *Agricultural Water Management* 169: 14-25.

Rao, S.S., P.L. Regar, S.P.S. Tanwar and Y.V. Singh. 2013. Wheat yield response to line source sprinkler irrigation and soil management practices on medium-textured shallow soils of arid environment. *Irrigation Science* 31: 1185-1197.

Rathore, M.S. 2004. State Level Analysis of Drought Policies and Impacts in Rajasthan, India. Working Paper-93, Drought Series Paper No. 6, International Water Management Institute, Colombo.

Rathore, V.S., J.P. Singh and R.K. Beniwal. 2009. Rainfed farming systems of hyper arid north-western Rajasthan - An analysis. *Annals of Arid Zone* 48: 125-131.

Rathore, V.S., J.P. Singh, M.L. Soni, N.D. Yadava and R.K. Beniwal. 2010. Evaluation of irrigated farming systems of hot arid region of north-western Rajasthan. *Annals of Arid Zone* 49: 23-29.

Rathore, V.S., N.S. Nathawat, S. Bhardwaj, P.S. Renjith, B.M. Yadav, M. Kumar, P. Santra, N.D. Yadava and O.P. Yadav. 2017. Yield, water and nitrogen use efficiencies of sprinkler irrigated wheat grown under different irrigation and nitrogen levels in an arid region. *Agricultural Water Management* 187: 232-245.

Rathore, V.S., Praveen Kumar and O.P. Yadav. 2018. Integrated farming system in arid and semi-arid regions: Need and significance. *Indian Journal of Arid Horticulture* 13: 1-10.

Rathore, V.S., S.P.S. Tanwar, Praveen Kumar and O.P. Yadav. 2019. Integrated farming system: Key to sustainability in arid and semi-arid regions. *Indian Journal of Agricultural Sciences* 89: 181-192.

Reynolds, J.F., D.M. Stafford Smith, E.F. Lambin, B.L. Turner, M. Mortimore, S.P.J. Batterbury, T.E. Downing, H. Dowlatabadi, R.J. Fernandez, J.E. Herrick, E. Huber-Sannwald, H. Jiang, R. Leemans, T. Lynam, F.T. Maestre, M. Ayarza and B. Walker. 2007. Global desertification: Building a science for dryland development. *Science* 316: 847-851.

Safriel, U. and Z. Adeel. 2005. Dryland systems. Pages 623-662 *in* Ecosystems and Human Well-being, Current State and Trends, Millennium Ecosystem Assessment (Eds. R. Hassan, R. Scholes and N. Ash), Vol. 1. Island Press, Washington.

Santra, P., R.K. Singh, D. Jain and O.P. Yadav. 2018. Agri-voltaic system to enhance land productivity and income. *Indian Farming* 68: 108-111.

Saroj, P.L., G. Dhandhar, B.D. Sharma, R. Bhargava and C.K. Purohit. 2003. Ber (*Ziziphus mauritiana* L.) based agri-horti system: a sustainable land use system for arid ecosystem. *Indian Journal of Agroforestry* 5: 30-35.

Setboosarng, S. 2002. Gender division of labour in integrated agriculture/ aquaculture of Northeast Thailand. Pages 253-274 *in* Rural Aquaculture (Eds. P. Edwards, D.C. Little and H. Demaine). CABI, U.K.

Shankar, V. 1980. Silvipasture research: a review. *Forage Research* 6: 107-122.

Shankarnarayan, K.A., L.N. Harsh and S. Kathju. 1987. Agroforestry in arid zones of India. *Agroforestry Systems* 5: 69-88.

Sharma, S.K. and B.B. Vashishta. 1995. Evaluation of jujube-buffel grass horti-pastoral system under arid environment. *Annals of Arid Zone* 24: 203-209.

Sharma, S.K. and G.D. Diwakar. 1989. Economic evaluation of horti-pastoral system on arid region of western Rajasthan. *Indian Journal of Range Management* 10: 119-122.

Sharmin, S., M.S. Islam and M.K. Hasan. 2012. Socioeconomic analysis of alternative farming systems in improving livelihood security of small farmers in selected areas of Bangladesh. *Agriculturists* 10: 51-63.

Singh, C.B., J.A. Renkema, J.P. Dhaka, K.P. Singh and J.B. Schiere. 1993. Income and employment on small farmers. Pages 67-76 *in* Proceedings of International Workshop on Feeding of Ruminants on Fibrous Crop residues: Aspects of Treatment, Feeding, Nutrient evaluation, Research and Extension. Karnal, Haryana, 4-8 February, 1991.

Singh, G. 2005. Carbon sequestration under an agri-silvi-cultural system in the arid region. *Indian Forester* 131: 543-552.

Singh, G. and T.R. Rathod. 2012. Resource use and crop productivity in a *Colophospermum mopane* tree based agro-ecosystem in Indian desert. *Applied Ecology and Environmental Research* 10: 503 -519.

Singh, G., S. Mutha and N. Bala. 2007. Effect of tree density on productivity of a *Prosopis cineraria* agroforestry system in North Western India. *Journal of Arid Environments* 70: 152-163.

Singh, G., S. Mutha, N. Bala, T.R. Rathod, N.K. Bohra and G.R. Kuchhawaha. 2005. Growth and productivity of *Tecommela undulata* based agroforestry system in the Indian Desert. *Forests, Trees and Livelihoods* 15: 89-102.

Singh, R.S. 1997. Note on effect of intercropping on growth and yield of ber (*Ziziphus maurtiana* Lamk) in semi-arid region. *Current Agriculture* 21: 117-118.

Singh, R.S., J.P. Gupta, A.S. Rao and A.K. Sharma. 2003. Micro-climatic quantification and drought impacts on productivity of green gram under different cropping systems of arid zone. Pages 74-80 *in* Human Impact on Desert Environment (Eds. P. Naraian, S. Kathju, A. Kar, M.P. Singh and Praveen Kumar). Scientific Publishers, Jodhpur.

Singh, S.D. and Y.V. Singh. 1997. Runoff efficiencies of four catchments sealing materials and water nitrogen interaction. Pages 92-108 *in* Water Harvesting in Desert (Ed. Singh S.D). Manak Publisher, New Delhi.

Singh, Y.V. 1999. Maximizing water-use efficiency for sustainable crop production in arid ecosystem. Pages 427-434 *in* Management of Arid Ecosystem (Eds. A.S. Faroda, N.L. Joshi, S. Kathju and A. Kar). Arid Zone Research Association of India and Scientific Publishers, Jodhpur.

Singh, Y.V., S.S. Rao and P.L. Regar. 2010. Deficit irrigation and nitrogen effects on seed cotton yield, water productivity and yield response factor in shallow soils of semi-arid environment. *Agricultural Water Management* 97: 965-970.

Tanwar, S.P.S., Akath Singh, M. Patidar, B.K. Mathur and K. Lal. 2016. Integrated farming system with alternate land uses for achieving economic resilience in arid zone farming. Pages 246-247 *in* Extended Summaries Vol. I, 4th International Agronomy Congress held at New Delhi November 22-26, 2016.

Tanwar, S. P S., Akath Singh, M. Patidar, A.S. Sirohi and M.M. Roy. 2014. Performance of integrated farming system in arid region diversified with perennials under delayed monsoon situations. Pages 564-565 *in*Extended Summaries of Volunteer Paper of National Symposium of Agricultural Diversification for Sustainable Livelihood and Environmental Security held at PAU, Ludhiana November 18-20, 2014.

Tanwar, S.P.S., Akath Singh, P. Kumar, B.K. Mathur and M. Patidar. 2018a. Rainfed integrated farming systems for arid zone: diversification for resilience. *Indian Farming* 68: 29-32.

Tanwar, S.P.S., T.K. Bhati, Akath Singh, M. Patidar, B.K. Mathur, Praveen Kumar and O.P. Yadav. 2018b. Rainfed integrated farming systems in arid zone of India: Resilience unmatched. *Indian Journal of Agronomy* 63: 403-414.

Verma, A., K. Shiran, J.C. Tewari, R.K. Kalia, N.V. Saresh, M. Gaur and S. Kumar. 2017. Agroforestry: A sustianble, multifunctional and diversified production system for hot arid zone of India. Pages 251-272 *in* Climate Change and Agroforestry (Eds. C.B. Pandey, Mahesh Kumar Gaur and R.K. Goyal). New India Publishing Agency, New Delhi, India.

Wakchaure, G.C., P.S. Minhas, P. Ratnakumar and R.L. Choudhary. 2016a. Effect of plant bioregulators on growth, yield and water production functions of sorghum [*Sorghum bicolor* (L.) Moench]. *Agricultural Water Management* 177: 138-145.

Wakchaure, G.C., P.S. Minhas, P. Ratnakumar and R.L. Choudhary. 2016b. Optimising supplemental irrigation for wheat (*Triticum aestivum* L.) and the impact of plant bio-regulators in a semi-arid region of Deccan Plateau in India. *Agricultural Water Management* 172: 9-17.

Walker, B.H., J.M. Anderies, A.P. Kinzig and P. Ryan. 2006. Exploring resilience in social-ecological systems through comparative studies and theory development: introduction to the special issue. *Ecology and Society* 11: 1.

Yadav, B.S. and R.P.S. Chauhan. 2013. Three Decades of Research on Water Management in Canal Command of North Western Rajasthan (1980-2012), Agricultural Research Station, SK Rajasthan Agricultural University, Sriganganagar. P. 96.

Yadav, O.P. 2018. Six-decades journey of CAZRI - Addressing arid zone production system in inclusive way. *Indian Farming* 68: 6-15.

Research, technology and policy implementation synergy for resilient dryland production systems in India

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Abstract

Dryland agriculture in India is mainly rainfed and is crucial for national crop and livestock production. It provides economic goods in terms of food, feed, fuel, forestry products and various ecosystem and regulatory services. Dryland agriculture ecosystems are complex, diverse, fragile, risky and often underinvested. The water scarcity problem in such areas and marginal potential of the system necessitate technological interventions, management, investment priorities and policy interventions. This paper throws light on technologies developed for sustainability of dryland ecosystems, viz. selection of crops, cropping systems, intercrops, rainwater conservation, efficient water utilization for higher productivity, Conservation Agriculture, crop residue management, cover crops, agroforestry, integrated farming systems, energy-efficient systems, adaptations to climate change, contingency-planning, etc. It also focuses on various schemes and policies developed in the country keeping in consideration the enhancement of resource potential in drylands. Strong synergy is essential between research/technology developments with policy/policy-implementation in dryland regions for sustainability of rainfed-dryland ecosystems.

Introduction

Almost 40% of global terrestrial area is constituted by arid and semi-arid regions and is inhabited by around 2 billion people and 50% of world's livestock. The area accounts for 35% of total terrestrial carbon fixation (ICRISAT, 2010). Nearly 60% of the drylands are in developing countries where grain yields average around half of those in irrigated regions. Of the total land area (329 m ha) in India, only 143 m ha is arable, and rainfed agriculture systems account for 57% of net sown area, contributing about 44% to the total food grains production in the country and feeding about 40% of country's population.

Arid and semi-arid regions experience grave water scarcity in the events of severe drought, adversely impacting crop yields and the livelihood of farmers. Water scarcity intensified by climate change might cost some regions upto 6% of their GDP, accelerate migration and trigger conflicts. India ranks 103 among 119 countries in 2018 Global Hunger Index. In comparison to irrigated regions, drylands register higher hunger index, which can be attributed to low agricultural productivity. Other key constraints associated with dryland ecosystems are fragile soils, fragmented land holdings, poor socio-economic condition, limited access to markets and lack of infrastructure which all contribute to uncertain livelihood. Emphasis has therefore got to be laid on technological interventions, management, investment and policy interventions.

Technology needs for sustainable rainfed dry land systems and potential of different technologies for enhanced productivity in India are depicted in Fig. 1 and Table 1, respectively. In order to attain sustainability of rainfed dryland regions strong synergy has to be developed between research/ technology development with policy/policy- implementation.

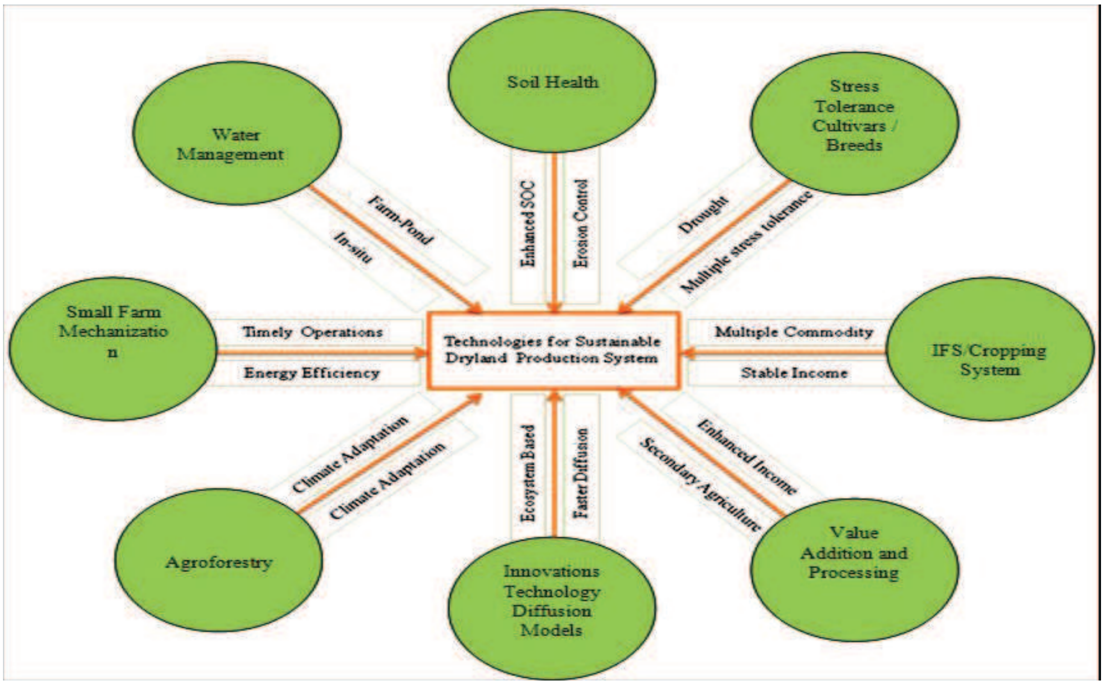

Figure 1. *Technology needs for sustainable rainfed dryland system.*

Table 1. *Potential of different technologies (%) for enhanced productivity of dryland systems*

Technology	Potential of technology (%)
Water based	20-30
Soil health improvement	15-20
Tolerant cultivars	15-20
Crops and cropping systems	15-25
Farm mechanization	23-33
Integrated Farming System	54-142
Agroforestry	10-35
Synergy technology package	150-250

Source: Srinivasarao *et al*. (2014; 2015)

Research, technology and policy synergy

Crop planning, cropping systems, intercrops, improved cultivars, seed systems

Suitable production technology has to be developed to protect these fragile systems as they assume prominence in sustaining growing population. Appropriate crop planning, selection of drought tolerant crops and varieties, and adoption of suitable cropping systems can help minimise the production losses because of drought in the arid and semi-arid regions. In the Indo-Gangetic Plains, diversification of 'rice-wheat' rotation with 'rice-chickpea', 'rice-lentil', 'rice-grasspea' would help in achieving higher net profits and benefit-cost ratio (BCR). Also, practicing intercropping can augment total yield per unit input, insulate farmers against complete crop failure and adverse market fluctuations, protect and enhance soil quality, and contribute to higher net profits and climate resilient livelihoods.

Continued reduction in agriculture workforce, associated with migration from rural to urban areas, necessitates rapid appropriate mechanization of farm operations. Development of high yielding and drought tolerant varieties is essential to augment yield in drylands, but timely production and distribution of high quality seeds is also of paramount significance. Hence, strengthening of seed systems is an important component towards improving productivity and higher returns to dryland farmers. Crop diversification and crop planning policies need to be promoted in diverse agro-ecosystems to ensure stability and sustainability of dryland farming. National Rainfed Area Authority (NRAA) and National Mission for Sustainable Agriculture (NMSA) dealing with rainfed farming need to emphasize the crop efficient zones in India (Srinivasarao *et al.,* 2016).

Water conservation and its efficient utilization

a) Rainwater conservation:

In drought prone areas, rainwater conservation is an important means to enhance agricultural productivity and meeting the needs of domestic water supply. *In-situ* and *ex-situ* rainwater harvesting are both essential for harnessing full potential. *In-situ* water conservation can be accomplished by such soil surface manipulations as contour bunding, contour cultivation, tied ridges, blind furrows, broadbed and furrow, trenching, creation of micro catchments, stubble mulches, etc. Apart from aiding in groundwater recharge and sustaining crops, these conservation measures also significantly contribute to reduction in runoff and soil loss (Srinivasarao *et al.,* 2015). Location specific *in-situ* moisture conservation practices in India are presented in Table 2.

***Table 2**. Location-specific in-situ moisture conservation practices in India*

Region	***In-situ* moisture conservations practices**
Arid (rainfall <500mm)	Conservation furrows, contour farming/ cultivation, deep ploughing, mulching and inter- row water conservation systems
Semi-arid (rainfall 500-1000 mm)	Runoff strips, tied ridges, graded ridging, mulching, live hedges, conservation furrows, contour farming, ridge and furrow system, off-season tillage on conserved soil moisture, graded border strips, compartmental bunding, broad beds and furrows.
Sub humid (rainfall >1000 mm)	Vegetative bunds, level/graded terraces, contour trenches, field bunds, graded bunds, raised bed and sunken forrow system, inter-plot water harvesting,

Source: NRAA (2009)

Farm-pond technology is an important *ex-situ* water conservation technique in rainfed drylands to overcome water shortage. It aids in enhancing the water availability for supplemental irrigation, and contributes to increse in cropped area and production, resulting in increased net benefits from crops. Under climate change scenario, farm pond offers a panacea to overcome the threat of increased frequency of drought, particularly mid-season and terminal droughts (Srinivasarao *et al.,* 2014). Owing to small land-holdings, farmers in arid region are hesitant to divert part of their cultivable land for making farm pond. High initial investment, lack of awareness among farmers, seepage and evaporation losses from pond and moderate benefits during the normal years are a few limitations that impede large scale adoption of farm ponds in the region (Srinivasarao *et al.,* 2017). National programmes like *Pradhan Mantri Krishi Sinchai Yojana* (PMKSY) and several state missions, like dryland missions of Maharashtra and Karnataka and state level programmes like Kakateeya

Mission in Telangana and Chettu Neeru in Andhra Pradesh, are contributing towards rainwater harvesting and efficient utilization. However, constant technical support at the ground level is essential to implement these programmes efficiently.

b) Enhancing water use efficiency

Micro irrigation: Micro-irrigation systems (drip, sprinkler) can help cater irrigation water needs of larger areas with limited water resource. Fertigation, using these systems, can enhance both water and fertilizer use efficiency. Cash crops and vegetables, having potential to generate high profit, are preferred candidates for pressurized irrigation. The dearth of knowledge in handling and maintenance of the system, however, restricts its large scale adoption (Srinivasarao *et al.,* 2014).

Mulch-cum-manuring: The foliage of such trees as *Peltophorum ferrugenum, Pongamia glabra, Delonix regia,* etc., grown widely in various parts of the country, can be utilized as a mulching material in semi-arid and arid regions. After decomposition, the mulch helps meet the nutrient needs of the growing crops (Srinivasarao *et al.,* 2017a). *Gliricidia sepium,* through its loppings, can provide material for green manuring and mulching, besides stabilizing bunds for conserving moisture and reducing soil erosion losses. *Gliricidia* green manuring has improved yields of finger millet on red soils in Karnataka, groundnut on red soils in Andhra Pradesh, pearl millet on light-textured soils in Gujarat and sorghum on medium to deep black soils in Maharashtra. *Gliricidia* green-leaf manuring (equivalent to 20 kg N ha_{-1}) augmented yield of maize from 1.7 to 2.1 t ha_{-1} on acid red and lateritic soils of Bhubaneswar, Odisha (Srinivasarao *et al.,* 2011).

Hydrogels: They are cross-linked polymers possessing hydrophilic property enabling them to absorb large quantities of water without getting dissolved (Schacht, 2004). As they are effective even at high temperatures (40-50ºC), they can perform well in arid and semi-arid regions, and increase water use efficiency. Row application of PAM polymer in rainfed maize at 25 kg ha_{-1} delayed the wilting of maize plants by 5-6 days during initial dry spell at early growth stage and gave 16% higher yield than control (CRIDA, 2013-14).

Minimizing evaporation from farm ponds: Storing farm-pond water for life-saving irrigation in *rabi* crops is a major challenge because of high evaporation losses of stored water. Covering pond-water surface with a thin film of oil, asbestos floats, shade netsor solar panels can minimize losses (Srinivasarao *et al.*, 2017a; Srinivasarao and Gopinath, 2016).

Policy initiatives: Several policy initiatives and programmes, listed below, that can enhance efficient utilization of harvested water, need to be implemented in synergy with technological developments for efficient outputs at farm level:

- A dedicated micro-irrigation fund created with NABARD has been approved with an initial corpus of Rs. 5000 crore (Rs. 2000 crore for 2018-19 & Rs. 3000 crore for 2019-20) for encouraging public and private investments in micro irrigation.
- *Pradhan Mantri Krishi Sinchai Yojna* (PMKSY), has been launched with the objective of extending coverage of irrigation '*Har Khet ko Pani*" (irrigation to every field) and enhancing water use efficiency ('more crop per drop') in a dedicated

manner, with end to end solution on source creation, distribution, management, field application and extension activities (Drought Management Plan, 2017).

- National Mission for Sustainable Agriculture (NMSA) has been formed for improving agricultural productivity in dryland areas, particularly emphasizing on soil health management, integrated farming, water use efficiency and synergizing resource conservation. NMSA would help in attaining key dimensions of 'Nutrient management', 'Water use efficiency' and 'Livelihood diversification' through implementation of sustainable development pathway by gradually shifting to eco-friendly technologies, conservation of natural resources, adoption of energy-efficient equipment, integrated farming, etc.
- Water Mission: The National Water Mission' is one of the 8 missions in the National Action Plan on Climate Change initiated by the Prime Minister to confront the negative impacts of global warming. Conservation of water, curtailing wastage and ensuring its rightful distribution both within and across States, through integrated water resources development and management, is the prime objective of this Mission.

Soil health

Dryland soils are highly prone to erosion and health deterioration. Strategies to enhance soil health include the following:

Crop residue management: The effective management of roots, stubbles and other crop residues and weed biomass has useful impact on soil fertility by adding organic matter, plant nutrients and creating better physical condition. Nearly 500 million tons/year of agricultural biomass is estimated to be available (2010-2011), part of which needs to be returned back to the soil after meeting fodder needs. Non-availability of proper chopping and soil incorporation equipment and high cost of labour and transport contribute to colossal wastage of this biomass. Hence, emphasis has to be laid on adopting such technologies as briquetting, anaerobic digestion, vermicomposting, making biochar, etc. (Srinivasarao *et al.,* 2013).

Conservation Agriculture: In conservation agriculture (CA) systems, a permanent residue or vegetative cover on the soil surface minimizes erosion, improves soil aggregation, increases water infiltration, reduces soil compaction, moderates soil temperature, suppresses weeds and increases microbial activity. CA also improves soil carbon sequestration by maximizing C inputs and lessening outputs (Srinivasarao *et al.,* 2013a).

Cover crops: The leguminous cover crops, viz. cowpea, sunhemp and groundnut, augment soil health by addition of organic carbon through their biomass and improving N status through symbiotic N fixation. They aid in protecting the soil from surface runoff and also increase soil C sequestration. The improved soil chemical and physical properties (i.e., soil macro and micronutrients and soil aggregate stability) improve soil fertility.

Mulching: It minimizes soil deterioration by reducing runoff and soil erosion, controls weeds and reduces evaporation losses. Thus, it promotes soil moisture retention and reduces soil temperature fluctuations, and improves chemical, physical and biological properties of soil.

*Policy initiatives***:** The Government of India initiated, in year 2014-15, the 'Soil Health Card'scheme under which cards are issued to all farmers in the country, containg information on their soil nutrient status along with recommendation on fertilizer nutrients to be applied. Regular assessment of soil status will be done in the scheme, every three years, to help identifying nutrient deficiencies and provide updated crop-specific recommendations for nutrient application. For improving nutrient use efficiency and reducing input cost, the use of neem-coated urea is being promoted as the release of the nitrogen in the soil from such urea is slow and over an extended peroiod, enhanceing N uptake. Since 2015, 100% of the indigenous urea production is neem coated.

Agroforestry

In the regions experiencing recurring drought, agroforestry provides an effective resilience to the production system. Trees provide a range of products (fodder, fruits, fuel wood, pulpwood, etc.) and environmental services (carbon sequestration, conserving soil and water etc.). Introduction of high value intercrops, organic production practices, canopy management, high density planting of fruit trees can increase profits from agroforestry. These practices can be integrated in the developmental programmes aimed at preventing land degradation and enhancing employment generation (Prasad *et al.,* 2014). Promising multipurpose trees, fruit crops and grasses for various agroforestry systems in dryland areas of arid and semi-arid regions in India are summarized in Table 3.

High emphasis on agroforestry for efficient nutrient cycling, enhancing the vegetation cover and adding organic matter for sustainable agriculture has been placed by policy initiatives of the government like the 'Green India Mission 2010', 'National Policy on Farmers 2007','National Bamboo Mission 2002', 'Planning Commission Task Force on Greening India 2001','National Agriculture Policy 2000,' and 'National Forest Policy 1988'. In spite of various policy initiatives, agroforestry did not receive the desired acceptance in the past. To tackle issues of tree insurance, quality planting material and restrictions on transit and harvesting, agroforestry-produce marketing, research and extension, the National Agroforestry Policy was formulated in 2014, but the success has been limited and it needs to be further reviewed to improve acceptance.

Integrated farming systems (IFS)

In arid and semi-arid regions sole practice of arable farming would narrow down the profits because of the frequent climatic aberrations; this situation therefore calls for adoption and development of integrated farming systems. The subject has been well discussed by Yadav *et al.* (2019) in a companion chapter in this volume. Minimizing the competition and maximizing the complementarity between the enterprises must be the principle on which the selection of enterprises in IFS must be done (Mynawathi and Jayanthi, 2015). Effective integration of livestock into agricultural system permits harnessing of complementarity of different components, and improves livelihoods and resilience of dryland farmers in the face of climatic abberations. Properly designed biogas energy solutions (Shalander Kumar *et al.,* 2015) can reduce the carbon footprint of the livestock component of the IFS. Many components of IFS are implemented in different national and state programmes and more coordination is essential among these programmes for better implementation at the ground level.

Energy-efficient systems

Use of firewood, agricultural waste and cow-dung cakes for cooking in rural India is causing damage to the fragile ecosystem of arid and semi-arid zone, besides causing health hazard. This calls for the utilization of energy-efficient systems, viz. solar energy and biogas. Intensive research and development activities have been, therefore, undertaken in the country in this regard by different institutions, as has been reported by Yadav *et al.* (2019) in this volume.

Table 3. *Promising crops, grasses, multipurpose tres for various agroforestry systems in dryland areas of arid and semi-arid regions in India (Srinivasarao et al., 2017b)*

		Promising species		
Zone	**System**	**Crops/grasses/shrubs**	**Forestry plants**	**Fruit plants**
Arid	Agri-siliviculture	Crops: Moth bean (*Vigna aconitifolia* Jacq Marechal), Mung bean (*Vigna radiata*), Cowpea (*Vigna unguiculata* L. Walp), Clusterbean (*Cyamopsis tetragonoloba* L. Taub), Sesame and Pearl millet	Khejri (*Prosopis cineraria* L. Druce.), Desert Teak, Anjan (*Hardiwickia binata* Roxb.) and Wild Jujube	Date Palm (*Phoenix dactylifers* L.) and Indian Plum *Ber* (*Ziziphus mauritiana* Lamk.)
	Silvi-pasture	Grasses: Buffel grass, irdwood grass (*Cenchrus setigerus* Vahl.) Sewan grass and Marvel grass (*Dicanthium annulatum*) Forsk. Stapf.)	Jujube, Mopane and Anjan	Khejri, Indian Plum and Caper (*Capparis decidua* Forssk. Edgew)
	Shelterbelts	-	Umbrella thorn, Kassod tree (*Cassia siamea* Lamarck Irwin et Barneby), Mesquite, Siris and Neem (*Azadirachta indica* A. Juss.)	-
Semiarid	Agri-silviculture	Crops: Sorghum, Pearl millet, Clusterbean, Cow pea, Pigeon pea, Mung bean, Sesame and Groundnut	Cottonwood (*Populus deltoides* Bartr.), Babul, Tree of Heaven (*Ailanthusexcelsa* Roxb.), Sissoo, Khejri, and Anjan	Guava, Citrus, Amla and Bael (*Aegle marmelos* L. Correa), Indian plum, Mango (*Mangifera indica* L.),
	Silvi-pasture	Seasonal grasses: Rat's tail grass (*Sehima nervosum* Rottl. Stapf.), Blue Panic grass (*Panicum antidotale* Retz.) and Buffel grass	Khejri, Babul, Sissoo and Acacia	-
	Farm boundary	-	Babul, *Eucalyptus* spp. Cottonwood, Butter tree (*Madhuca latifolia* Roxb.) and Sissoo	-

Several novel solar devices and systems viz. solar drier, non-tracking solar cooker, animal feed solar cooker, three in one solar device, solar PV pumping system, solar PV duster, PV winnower cum drier, solar PV sprayer, solar distillation unitare available (Srinivasarao *et al.,* 2017c). Utilization of biogas as energy source would aid in curtailing the expenditure on electricity, but biogas installations are costly and their success rate has been low for individual farmers. The reduction in cost and increased adoption could be attained by encouraging customized solutions comprising community biogas plants.

The missions pertaining to enhanced energy efficiency are:

- 'National Mission for Enhanced Energy Efficiency' (NMEEE), implemented since 2011, is one of the 8 national missions under the 'National Action Plan on Climate Change' (NAPCC). NMEEE targets to build up the market for energy efficiency by generating favourable regulatory and policy regime.
- The 'National Solar Mission', part of NAPCC, was launched in 2010 for creating the suitable policy conditions for diffusion of solar energy across the country.

Adaptation to climate change

Climate change and climate variability are emerging as major concerns encountered by Indian agriculture. Temperature rise can elevate crop respiration rates, reduce crop duration, alter photosynthesis, impact the distribution and survival of pests, accelerate mineralization of nutrients in soils, lower fertilizer use efficiencies and enhance evapotranspiration and soil carbon loss, and adversely affect livestock production and health. Adaptation to extreme events and climate variability can decrease vulnerability to long-term climate change.

Strategies developed to manage year to year climatic aberrations will have long term impact in developing resilience and overcoming the perils of climate change (Srinivasarao *et al.,* 2016). Prospective adaptation strategies are developing cultivars resistant to drought and flood and tolerant to heat and salinity stress, altering crop management practices, improving water management, implementing crop diversification and resource-conserving technologies, improving pest management, improving weather forecasting, crop insurance and harnessing farmers' traditional knowledge (Singh *et al.*, 2019). *Pradhan Mantri Fasal Beema Yojana* (Prime Minister's Crop Insurance Scheme) is an actuarial/bidded premium based scheme under which farmer has to pay a maximum premium of only 2% for *kharif*, 1.5% for *rabi* food and oilseed crops and 5% for annual commercial/horticultural crops and remaining part of the actuarial/bidded premium is shared equally by the Centre and State Government. One of the objectives of the scheme is to facilitate prompt claims settlement, within two months of harvest, subject to timely provision of both yield data and share of premium subsidy by the State Government.

Though individual components of various technologies are available for climate adaptation (Fig. 2), there is a strong need in technology synergy to bring the stability of food systems at the farm level. Climate adaptive technologies are promoted by several ministries like Ministry of Agriculture & Farmers Welfare, Environment, Forestry and Climate Change, Science & Technology, Water Resources, Renewable Energy, Rural Development, etc.

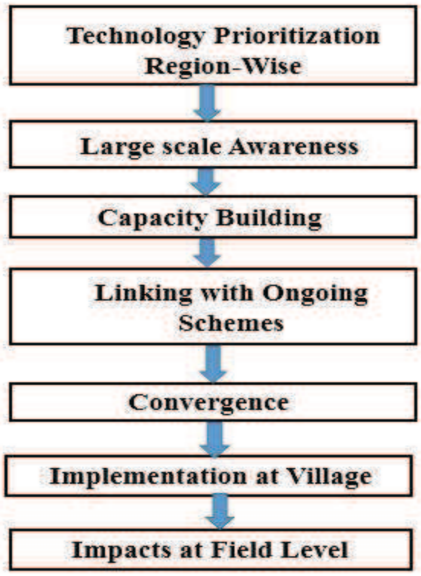

Figure 2. *Steps for effective implementation technology with policy synergy at village level.*

Components for establishing climate adaptive villages in water stressed ecosystems is presented in (Fig. 3). A strong synergy is needed among climate adaptive plans and implementation among ministries for improved ground level impacts.

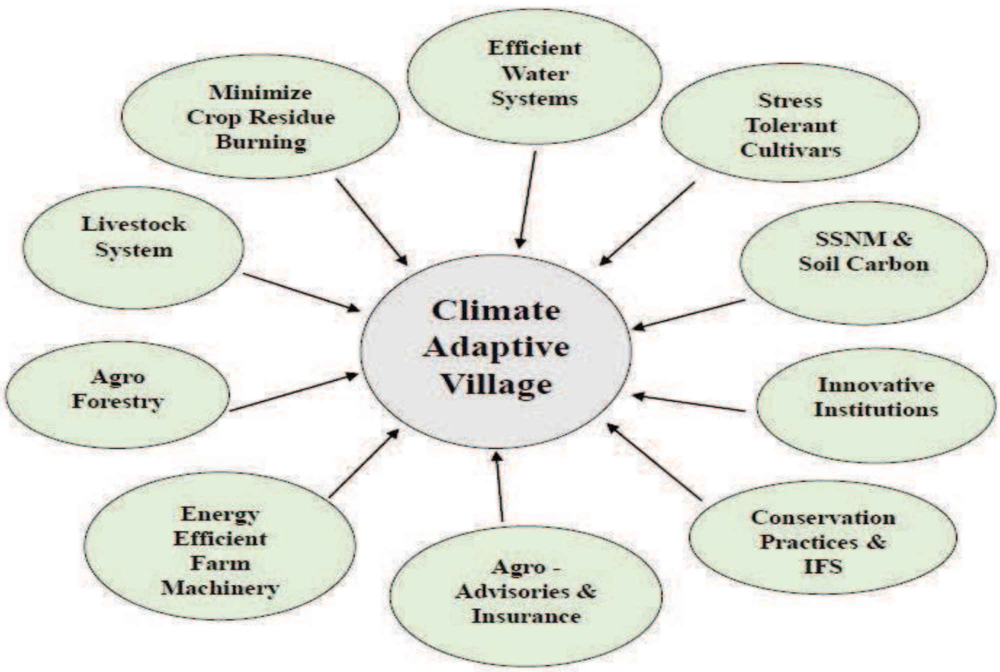

Figure 3. *Components for establishing climate adaptive villages in water stressed ecosystem.*

The National Action Plan on Climate Change (NAPCC) was initiated by Government of India on the advice of Prime Minister's Council on Climate Change to overcome adversities of climate change in the country. As indicated before, NAPCC has a total of eight national missions: ‘Water’, ‘Sustainable Agriculture’, ‘Enhanced Energy Efficiency’, ‘Solar Energy’, ‘Sustaining the Himalayan Ecosystem’, ‘Sustainable Habitats’, ‘Green India’, and ‘Strategic Knowledge for Climate Change’. The National Adaptation Fund for Climate Change was initiated in August 2015 to cater to the cost of adaptation to climate change for the vulnerable State and Union Territories of India. The Fund, governed by the Ministry of Environment, Forestry and Climate Change, is expected to promote adaptation of various systems in the country including agriculture sector.

Contingency plan implementation

Technical documents, envisioned to be ready reckoner for line departments and farming community, on prevalent farming systems and technological interventions for various weather aberrations (drought, heat and cold waves, cyclones, hailstorms, etc.) - addressing diverse sectors of agriculture including horticulture, livestock, poultry, fisheries, can be used to sustain the production systems and are referred to as ‘Contingency Plans’. The plans comprise information on alternate crop varieties/crops to be selected in events of delayed onset of monsoon or early season drought and also on agronomic measures for terminal and mid-season drought (Srinivasarao *et al.,* 2013c; 2016a; Srinivasarao, 2018). Figure 4 presents the representation of implementation of District Contingency Plans. There is scope to further downsizing the plan to the sub-district level for effective field level impacts. Infact, several ministries and departments can come together and look for effective implementation of these plans. The plans are developed with research and technological outputs of NICRA (National Initiative on Climate Resilient Agriculture), CRIDA (ICAR- Central Research Institute for Dryland Agriculture), AICRPDA (ICAR All India Coordinated Research Project on Dryland Agriculture) and the SAU (State Agricultural Universities) with their respective KVKs (*Krishi Vigyan Kendras,* the Agricutural Science Centers). The implementation at district level is done with State Government authorities, while at the *Taluq*, *Mandal* and village level it is done by the above indicated research institutions and their networks.

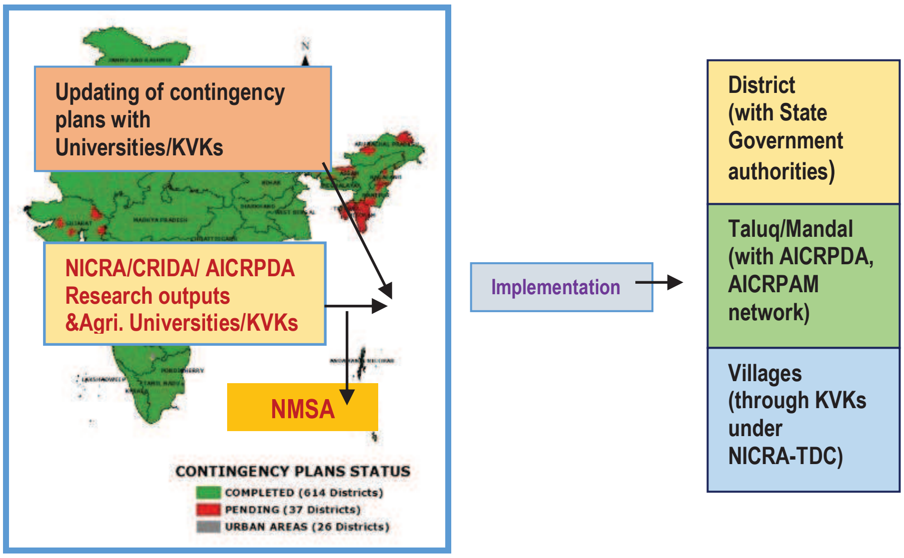

Figure 4. *Implementation of District Contingency Plan in India.*

Synergy between research-technology and policy implementation

For effective field implementation of any technology a strong synergy is essential between research/technology and policy implementation process (Fig. 5). Although a technology might be successful at research station, KVK and farm level, several implementation issues arise when it is upscaled. For example, the agroforestry technology is implemented in several agro ecosystems but the pricing element is missing in agroforestry policy causing distress to implementing farmers. The technical constraints identified during implementation should be communicated to technology developers to address them for better implementation.

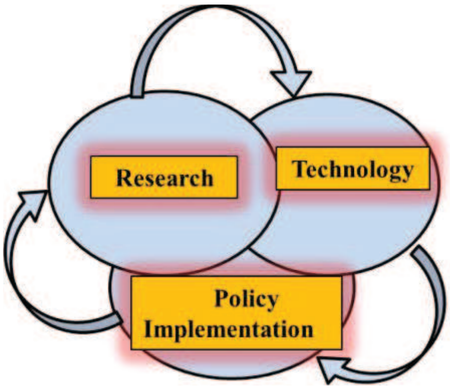

Figure 5. *Synergy between research-technology and policy implementation essential for effective technology transfer.*

Conclusions and way forward

Rainfed drylands are important ecosystems in overall food security and sustainability of agriculture, livestock towards meeting sustainable development goals (SDGs) such as zero hunger, nutrition security and climate action. Ecosystems of rainfed drylands are fragile and climate change impacts on them have become more serious. To meet these multiple challenges of this ecosystem, technology packaging is essential instead of promoting single technology. For example, rainwater conservation, soil health, tolerant varieties or cultivars along with institutions are critical for overcoming above challenges.

Similarly, several programmes and policies have been developed at national and state level. Their periodic monitoring is needed to strengthen implementation. Several ministries are implementing various programmes for achieving sustainability of rainfed dryland systems. A coherent action plan and implementation will yield better results.

References

CRIDA. 2013-14. Annual Report. Central Research Institute for Dryland Agriculture. Hyderabad, India. P. 197.

Government of India. 2017. Drought Management Plan, November. 2017. Government of India, Ministry of Agriculture and Farmers Welfare, Department of Agriculture, Cooperation and Farmers Welfare.

ICRISAT. 2010. ICRISAT Annual Report, International Crop Research Institute for the Semi-Arid Tropics, Patancheru, India.

Mynavathi, V.S. and C. Jayanthi. 2015. Dryland integrated farming system - A review. *Agricultural Review* 36: 67-72.

NRAA. 2009. Drought Management Strategies - 2009, National Rainfed Area Authority, Ministry of Agriculture, Government of India, New Delhi.

Prasad, J.V.N.S., Ch. Srinivasarao, B. Venkateswarlu, and V.P. Singh. 2014. Livelihood diversification through agroforestry in semi-arid regions of India. World Congress on Agroforestry.

Schacht, E.H. 2004. Polymer chemistry and hydrogel systems. *Journal of Physics*. *Conference Series* 3: 22-28.

Shalander Kumar, B.M.K. Raju, C.A. Ramarao and Thiagarajah Ramilan. 2015. Sensitivity of livestock production to climatic variability under Indian drylands and future perspective. *Current Agriculture Research Journal* 3(2): 142-149.

Singh, N.R., S.K. Bhal, S. Malleswari, Ranjit Kumar and Ch. Srinivasarao. 2019. Challenges and opportunities in weather based crop insurance in India: *In*: Challenges and Emerging Opportunities in Indian Agriculture. P. 289.

Srinivasarao, Ch. 2018. Climate change and extreme climatic events: Impacts and adaptation strategies for agriculture. *The Andhra Agricultural Journal* 65(2): 253-259.

Srinivasarao, Ch. and K.A. Gopinath. 2016. Resilient rainfed technologies for drought mitigation and sustainable food security. *Mausam* 67(1): 169-182.

Srinivasarao, Ch., A.K. Indoria and K.L. Sharma. 2017a. Effective management practices for improving soil organic matter for increasing crop productivity in rainfed agro ecology of India. *Current Science* 112 (7): 1497-1504.

Srinivasarao, Ch., B. Venkateswarlu, M. Dinesh Babu, S.P. Wani, S. Dixit, K.L. Sahrawat and S. Kundu. 2011. Soil Health Improvement with *Gliricidia* Green Leaf Manuring in Rainfed Agriculture, On Farm Experiences. Central Research Institute for Dryland Agriculture, Santoshnagar, P.O. Saidabad, Hyderabad 500 059, Andhra Pradesh.

Srinivasarao, Ch., B. Venkateswarlu, R. Veeraiah, S. Rammohan, V.S. Jakkula, Sreenath Dixit, B. Shivarudrappa and R.V. Rammohan. 2013. Vermicomposting for Efficient Crop Residue Recycling, Soil Health improvement and Imparting Climate Resilience- Experiences from Rainfed Tribal Regions. Central Research Institute for Dryland Agriculture, Hyderabad, Andhra Pradesh. 40 p.

Srinivasarao, Ch., B. Venkateswarlu, Rattan Lal, A.K. Singh and S. Kundu. 2013a. Sustainable management of soils of dryland ecosystems of India for enhancing agronomic productivity and sequestering carbon. *Advances in Agronomy* 121: 253-329.

Srinivasarao, Ch., C.G. Ravindra, P.K. Mishra, S.G. Reddy, G.R.M. Sankar, B. Venkateswarlu and A.K. Sikka. 2014. Rainfed Farming-A Compendium of Doable Technologies. All India Coordinated Project for Dryland Agriculture, Indian Council of Agricultural Research, Hyderabad.

Srinivasarao, Ch., G. Ravindra Chary, P.K. Mishra, R. Nagarjuna Kumar, G.R. MaruthiSankar, B. Venkateswarlu and A.K. Sikka. 2013b. Real Time Contingency Planning: Initial Experiences from AICRPDA. All India Coordinated Research Project for Dryland Agriculture (AICRPDA), Central Research Institute for Dryland Agriculture (CRIDA), ICAR, Hyderabad- 500 059, India.

Srinivasarao, Ch., I. Srinivas, R.V. Adake, P. Santra, B. Sanjeeva Reddy, Manoranjan Kumar, K.V. Rao, K. Sammi Reddy, O.P. Yadav and Mohan C. Saxena. 2017c. Utilization of renewable energy sources in dryland systems. Pages 537-552 i*n Proceedings of 12thInternational Conference on Dryland Development, International Dryland Development Commission*.

Srinivasarao, Ch., K.A. Gopinath, C.A. Ramarao, B.M.K. Raju, R. Rejani, G. Venkateswarlu and V. VishaKumari. 2017b. Dryland agriculture in south Asia - Experience challenges and opportunities. *Innovation in Dryland Agriculture* 345-392.

Srinivasarao, Ch., K.A. Gopinath, J.V.N.S. Prasanna Kumar and A.K. Singh. 2016. Climate resilient villages for sustainable food security in tropical India: Concept, process, technologies, institutions, and impacts. *Advances in Agronomy* 140: 104-201.

Srinivasarao, Ch., K.V. Rao, S. Desai, A.V.M. Subba Rao, Md. Osman, I. Srinivas, and S.S. Balloli. 2016a. Preparedness for Agriculture Contingencies - *Kharif*, 2016. Summary of Interface Meetings and Way Forward. Technical Bulletin 2/2016. Central Research Institute for Dryland Agriculture, Indian Council of Agricultural Research, Hyderabad. P. 29.

Srinivasarao, Ch., R. Lal, J.V.N.S. Prasad, K.A. Gopinath, R. Singh, V.S. Jakkula, K.L. Sahrawat, B. Venkateswarlu, A.K. Sikka and S.M. Virmani. 2015. Potential and challenges of rainfed farming in India. *Advances in Agronomy* 133: 113-118.

Srinivasarao, Ch., R. Rejani, C.A. Rama Rao, K.V. Rao, M. Osman, K. Srinivasa Reddy, Manoranjan Kumar and Prasanna Kumar. 2017. Farm ponds for climatic resilient rainfedagriculture. *Current Science* 112(3): 471-477.

Evening Lectures

Climate change as a trigger to poverty and outmigration in the dry areas

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Extended Summary

Climate Change is here. Not only are we witnessing many more extreme weather events all around the world, but also witnessing distressing signs of drier, hotter climates in the arid and semi-arid regions. Desertification is expanding, and at the borders of the deserts, the already limited rainfall will become more sporadic, alternating periods of flood and drought. Several billion poor people are affected by that change, and these populations are likely to grow rapidly.

Many of the countries concerned are very poor and depend on small-holder agriculture. Thus measures of adaptation to this likely future are an absolute necessity. Climate change will not only make their already precarious lives even more perilous, but it also will force many of them to seek new homes. They will become environmental refugees at a time when populist politics in the north and in other neighboring countries that could potentially be recipients of such migrants, are become stridently inimical to immigration.

Population growth

Most of the dry areas are in Africa and West Asia, and population forecasts are very problematic, especially for Africa and Asia, where the UN Consensus forecasts of 2015 see more than a billion persons being added to each of these two continents by 2050. Africa is seen as having continuing growth reaching a population of 4.4. billion by 2100, starting from a base of 1.1 billion in 2015. Even if these forecasts of a quadrupling of African population by 2100 are high, as IIASA estimates, the African population is still expected to triple by the end of the century.

Just to feed the populations concerned with less fertile soils and less reliable water supplies will require a dramatic transformation of agriculture and agricultural practices. Only a scientific based system of agricultural management that can be applied at the small-holder level will help combat further impoverishment and avoid massive people movements due to cycles of droughts and floods and inadequate infrastructure, with concomitant forced migration.

Furthermore, to cope with the expected population bulge it will not be enough to ensure that macro-economic conditions are sound. We must quickly focus on removing rigidities and obstacles to the functioning of the labor market, enhance education and health, make special efforts to empower women, and to do all that on an accelerated schedule to avoid (or minimize) the problems of youth unemployment in both the rural and urban areas.

Transforming agriculture

To achieve the requisite agricultural and rural transformation, these countries have to increase rural productivity by reducing trade barriers, investing in rural infrastructure and securing

land rights and above all in directing scientific research and new technologies to solving the problems of the poorest farmers. And they have to address mitigating and adapting to climate change and increasing the resilience of the threatened communities. Technological innovations, including bio-technology and GMOs, are necessary for both increasing productivity and adapting to climate change.

For this rural transformation to happen, African agriculture needs to grow much faster. Given the predominance of rain-fed agriculture, adapting to the expected impacts of climate change poses significant challenges that must also be addressed as part of the transformation.

Whether in Asia or in Africa, but especially in Africa, agriculture, agro-industry, and agro-services can be competitive and create jobs. Farmers can be entrepreneurs. Given knowledge, access to markets, and secure land title, they can create many high-productivity jobs. Links through agricultural production chains offer a particular opportunity for small farmers.

Urbanization

Urbanization is a dominant feature of our existence today, where already more than half the global population is classified as urban. The UN estimates that about 2.5 billion people will be added to urban populations by 2050, with close to 90% of the increase concentrated in Asia and Africa. Industrialization, including the development of modern food processing capabilities will be part of both creating jobs and raising overall income levels.

The rapid urbanization that these countries are witnessing will require the production of crops that are storable and more transportable, and to minimize post-harvest losses as the food processing industries begin to play their full role. Additional intensive urban agriculture can also play a role. All this will require a transformation of the traditional agriculture that exists in many parts of Asia and Africa today.

Climate change and agriculture

Despite the rapid urbanization, the rapid growth in the working-age population will mean that for a generation or so most of the new jobs will still be in traditional activities, including agriculture. It is therefore essential to also increase the productivity of traditional agriculture and also climate change will have its biggest impact on agriculture - so adaptive investment and technical innovations are needed. Almost all climate models show rising temperatures, increasingly variable rainfall and more severe weather events. The resulting challenges for maintaining and increasing crop yields will be especially big in Africa where little farmland is irrigated.

Adapting to this change requires investment in climate-resilient agricultural infrastructure but even more to raise the productivity of agriculture. Genome research to create heat- and water-tolerant crops that have a shorter growing season, and even to develop nitrogen fixing capabilities in many new crops are all part of the promises of scientific research in these early decades of the 21st century, whether it is in ICT, robotics or genetics. Precision farming would be the result of being able to deploy the technologies that come from these scientific discoveries in ways that benefit the poor in the dryland areas.

Such a science-based transformation would also offer opportunities for new jobs but require the corresponding scientific manpower. Given that women manage many farms and rural household enterprises, a concerted effort to improve resiliency will also improve their wellbeing and contributions to the economy.

Building capacity for science, technology and innovation

Science-based agriculture must help these weak countries cope with the growing challenges and the development of a new agriculture for new smart cities must also be accelerated. We need an intensive expansion of science and technology, with a special focus on the needs of the drylands, accompanied by special efforts to build up local capacity in Science, Technology and Innovation (STI) in the poorest arid and semi-arid countries. That is how we can help to meet these challenges where climate change is a trigger for both increased poverty and outmigration.

Re-carbonizing soils of global drylands

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Abstract

World's drylands represent 41.3% (60.9 million km^2) of Earth's land area, and comprise of desert (6.6%), semi-desert (10.6%), grassland (15.2%), and rangeland (8.7%). Drylands are home to about 2.7 billion people representing 35.5% of the world's population in 2018. Being vulnerable to desertification, drylands have already expanded by 4-8% over the 20th century and may continue to expand by an additional ~10% compared with the baseline of 1961-1990, and probably cover ~50% of the Earth's land area by 2100. Drylands contain 46% of the terrestrial carbon stocks compromising of 53% of global soil C stock (1-m depth) and 14% of global biotic carbon stock. The soil C stock in drylands has two distinct but related components: soil organic C (SOC) and soil inorganic C (SIC). The SOC stock is more in soils of the humid and sub humid regions and the SIC is more in those of the semiarid and arid regions. The SIC stock comprises of the carbonates and bicarbonates, and also bicarbonates in the ground water. Combined with bicarbonates, the SIC stock to 1-m depth may be as much as 2344 Pg C. The SOC stock, more reactive and dynamic than the SIC, is prone to depletion caused by climate change, land use and land use change, and soil degradation. The projected climate change would lead to increasingly drier deep soil layers during the growing season, exacerbate the problem of soil degradation, adversely impact the SOC stock, and weaken the provisioning of critical ecosystem services (e.g., water, biodiversity, food, feed). The reduction in soil moisture storage would aggravate warming, increase evapotranspiration, aggravate depletion of soil water reserves, and severely reduce the agronomic productivity and use efficiency of inputs. On the contrary, restoration of degraded/desertified drylands and ecosystems and adoption of saline agriculture can sequester C in biomass and soil, contribute to mitigating anthropogenic climate change, enhance socio-ecological resilience and improve the environment.

Introduction

Total carbon (C) stock in world soils to 1-m depth estimated at 2200 Pg (Pg = peta gram = 10^{15}g = 1 billion metric ton = 1 Gt), comprises of 2/3 as soil organic carbon (SOC) and 1/3 as soil inorganic carbon (SIC) (Banwart *et al.,* 2015; Plaza *et al.*, 2018). In contrast, C stock in global drylands to 1-m depth comprises of 1048 Pg, of which 470 Pg is SOC (Table 1) and 578±8 Pg is SIC (Table 2). To 2-m depth, total C stock in drylands is 1883 Pg, of which 646±9 Pg is SOC and 1237±15 Pg is SIC. The ratio of SOC:Total soil C stock is 0.63 in 0-0.3 m depth, 0.45 in 0-1 m depth, and 0.34 to 0-2 m depth (Tables 1 and 2, Plaza *et al.,* 2018). Expectedly, the total SOC stock increases with increase in mean annual rainfall. In comparison with the total SOC stock in 0-2 m depth in the hyper arid ecoregions, the SOC stock is 4.1 times in the arid, 8.4 times in semiarid and 7.4 times in the dry sub humid biomes. Similarly, the SIC stock in 0-2 m depth is 3.8, 3.6 and 1.3 times in the arid, semiarid and sub humid biome compared with that in the hyper-arid region (Tables 1 and 2).

Table 1. *Estimates of the soil organic carbon (SOC) stocks in global drylands (recalculated from Plaza et al., 2018)*

Depth (m)	SOC Stock (Pg C)									
	Hyperarid		Arid		Semi-arid		Dry Sub-humid		Total	
	Stock	Ratio	Stock	Ratio	Stock	Ratio	Stock	Ratio	Stock	Ratio
0-0.3	11±1	1.0	45±3	1.0	100±2	1.0	91±3	1.0	248±6	1.0
0-1	22±1	2.0	91±3	2.0	190±3	1.9	167±4	1.8	470±7	1.9
0-2	31±1	2.8	127±3	2.8	259±3	2.6	228±6	2.5	646±9	2.6
Ratio among biomes	1.0		4.1		8.4		7.4		20.8	

Table 2. *Estimates of soil inorganic carbon (SIC) stocks in global drylands (recalculated from Plaza et al., 2018)*

Depth (m)	SIC Stock (Pg C)									
	Hyperarid		Arid		Semi-arid		Dry Sub-humid		Total	
	Stock	Ratio	Stock	Ratio	Stock	Ratio	Stock	Ratio	Stock	Ratio
0-0.3	20±2	1.0	63±2	1.0	48±2	1.0	15±1	1.0	145±4	1.0
0-1	65±3	3.3	241±5	3.8	204±4	4.3	66±2	4.4	578±8	4.0
0-2	127±5	6.4	487±9	7.7	456±7	9.5	168±4	11.2	1237±15	8.5
Ratio among biomes	1.0		3.8		3.6		1.3		9.7	

The SOC, comprised of the remains of plants and animals at various stages of decomposition, is highly reactive and a strong determinant of soil health and of numerous ecosystem services of value to human wellbeing and nature conservancy (Lal, 2004). The SIC stock is less reactive and comprises of three components: 1) primary or lithogenic carbonates derived from the weathering of parent materials, 2) secondary or pedogenic carbonates (caliche or concrete) derived from pedologic processes, and 3) bicarbonates contained in the ground water (Monger *et al.,* 2015). Formation of secondary carbonates is related to the microbial decomposition of soil organic matter (SOM) leading to enrichment of the concentration of CO_2 in soil air, its dissolution in soil water to form weak carbonic acid, and precipitation as carbonates through reaction with Ca^{+2} and Mg^{+2} brought in from outside the system (i.e., aeolian and alluvial deposition, application of compost/manure and other amendments including mulch, use of inorganic fertilizers).

Thus, transfer of atmospheric CO_2 into soil through biotic and abiotic processes into SOC and SIC compounds with a long mean residence time (MRT) has strong impacts on the global C cycle (GCC). Three principal processes of transfer of atmospheric CO_2 into soil as SOC and SIC, or carbon sequestration comprise of the following: 1) photosynthesis and input of biomass-C into soil as roots and shoots to form humus and any pyrogenic compounds (i.e., soot, charcoal or biochar) through in-field or *in-situ* burning, 2) pedogenesis and formation of secondary carbonates or caliche, and 3) translocation of bicarbonates into the ground water.

A rapid increase in atmospheric concentration of CO_2, especially so since the on-set of Industrial Revolution, from 280 ppm in 1750 to 410 ppm in 2017 (WMO, 2018), has created a strong interest in the sequestration of SOC and SIC in soil to off-set anthropogenic emissions for adaptation and mitigation of climate change. Estimated to 2-m depth, total soil C stock (SOC and SIC) in global drylands (Tables 1 and 2) represents ~46% of the Earth's terrestrial C stocks (Safriel *et al.,* 2005). The land-based or terrestrial C sinks are estimated to have absorbed 32.5% of the anthropogenic emissions between 1750 and 2017, 29.6% for the decade of 2008-2017, and 33.6% for the year 2017 (Table 3, Global Carbon Budget, 2018). Therefore, prudent management of drylands is considered an important tool/strategy to sequester atmospheric CO_2 while also enhancing Sustainable Development Goals (SDGs) of the U.N. or the Agenda 2030 (Lal *et al.,* 2018). Thus, the objective of this paper is to deliberate the potential and challenges of global drylands to sequester atmospheric CO_2 as SOC and SIC for adaptation and mitigation (ADAM) of anthropogenic climate change (ACC) in conjunction with advancing SDGs.

Table 3. *Magnitude of land-based C sinks (Pg C) (Global C Budget, 2018)*

Parameter	1750-2017	2008-2017	2017
Total Emissions	660	10.8	11.3
Sinks:			
Atmosphere	275	4.7	4.6
Ocean	165	2.4	2.5
Terrestrial	215	3.2	3.8
Terrestrial (% of Emission)	32.5	29.6	33.6

Global drylands

Drylands, the Earth's largest ecoregion, cover 41.3% of Earth's land area and are home to 2.7 billion people. A large proportion of world's 2.5 billion poor people live in dryland biomes (Prăvălie *et al.,* 2016). On the basis of the aridity index (AI = precipitation: potential evapotranspiration), drylands are regions with AI of < 0.65 mm mm^{-1} (Middleton and Thomas, 1997; UNEP, 1992).). Thus, water deficit (scarcity or drought) is the most important determinant of the net primary productivity (NPP). However, climate change has a strong impact on the global extent of drylands, which are steadily increasing in area.

The revised estimates of land area under dryland regions are as follows: i) hyper-arid with AI of < 0.05 at 5.86%, ii) arid with AI of 0.05-0.2 at 14.16%, iii) semiarid with AI of 0.2-0.5 at 16.38%, and iv) dry sub humid with AI of 0.5-0.65 at 8.36%; with a total land area of 45.36% (Table 4). Global drylands may expand by an additional 10% compared with that in 1961-1990 by about 5.8 x 10^6 km^2 till 2100 (Schlaepfer *et al.,* 2017). Furthermore, deep soil layers may become increasingly dry during the growing season, leading to a major shift in vegetation, and decline in provisioning of ecosystem services such as agronomic yield of food staple cereals (Lobell and Gourdji, 2012; Ray *et al*., 2002; Feng and Fu, 2013).

Most of the expansion of drylands is and will occur in the tropical regions, but temperate drylands may contract by a third and convert to sub-tropical drylands. By 2100, the global extent of drylands may cover > 50% of the planet's area (Schlaepfer *et al.,* 2017). Expansion of drylands, and increase in frequency and intensity of drought, can deplete the SOC stocks. During the decadal drought between 1998 and 2008 in central Asia, the temperate drylands lost ~0.46 Pg C from 1979 to 2011 (Li *et al*., 2015). The magnitude of loss was severe in Kazakhstan where the rate of decline in annual rainfall was 90 mm/decade (Li *et al.,* 2015).

Table 4. *Change in global drylands between 2005 and 2016*

Region	Area (10^6 km^2)		% of the World Total Land	
	Safriel *et al.* (2005)	Prăvălie (2016)	Safriel *et al.* (2005)	Prăvălie (2016)
Hyper-arid	9.8	8.6	6.6	5.86
Arid	15.1	20.8	10.6	14.16
Semi-arid	22.6	24.0	15.2	16.38
Dry sub-humid	12.8	13.2	8.7	8.97
Total	60.3	66.7	41.0	45.36

Terrestrial area of dryland = 66.7 x 10^6 km^2

Total land area of Earth = 147 x 10^6 km^2

With such a large land area, global drylands will have increasingly stronger impact on the GCC and thus on the feedback to the climate change. The feedback may be positive (increasing the radiative forcing) through acceleration of the gaseous emission or negative (reducing the radiative forcing through C sequestration in global drylands). The positive feedback to climate change is exacerbated by degradation and desertification of drylands. The problem of desertification and scarcity of essential resources (i.e., water) may be further aggravated by rapid increase of urbanization in drylands.

The data in Table 5 indicate increase in population of some cities over the 80-year period (1950 to 2030) by a factor ranging from 16 to 175. Such a drastic increase in urban population in dry and fragile environment necessitates careful planning and reuse/recycling of resources to enhance use efficiency and sustain productivity (Lal and Stewart, 2017). Furthermore, water erosion and chaotic urbanization can deplete the SOC stock. Darwish and Fadel (2017) reported irreversible loss of 25 and 54 Pg of SOC by erosion and urbanization, respectively, in Arab countries.

Table 5. *Increase in population of some cities in drylands*

City	Population (10^6)				
	1950	2000	2016	2030	Factor
Dubai	0.02	0.9	2.5	3.5	175.0
Jaipur	0.3	2.3	3.5	4.9	16.3
Jodhpur	~0.1	0.8	1.3	1.8	18.0
Khartoum	0.2	3.5	5.3	8.2	40.0
Kuwait	0.15	1.3	2.9	3.9	26.0
Las Vegas	0.025	1.3	2.3	2.9	116.0
Lima	1.1	7.3	10.1	12.2	11.1
Mecca	0.15	1.2	1.8	2.1	14.0
Phoenix	0.11	2.9	4.1	4.8	43.6
Riyadh	0.08	3.6	6.5	7.9	98.8

Positive feedback through degradation and desertification of drylands

Desertification, decline in quality and functionality of drylands (UNCCD, 1994; MEA, 2005), is a serious problem in these fragile ecoregions. However, the causes and determinants of desertification are poorly understood (Hutchinson, 1996). Yet, six widely recognized dimensions of desertification include: water erosion, wind erosion, vegetation loss/degradation, salinization, soil compaction and soil fertility decline (Dregne, 2002). However, there is an important seventh dimension of desertification and that is the depletion of the terrestrial C stock through loss of SOC, biomass-C and of SIC. This article is specifically focused on reversing the trends in loss of the soil C stock through sequestration of atmospheric CO_2 along with the attendant increase in soil health and functionality and advancement of the SDGs.

The accelerating ACC, along with the land misuse and soil mismanagement, has exacerbated the risks of desertification of these fragile ecosystems. Over and above the ecohydrological interactions across multiple space and time scales (Turnbull *et al*., 2008), there is also an increasing dominance of abiotic mechanisms of desertification in drylands because of increase in aridity and frequency of droughts (Ravi *et al.,* 2010). Interaction between the ACC (aridification) and land use-land use change (LULUC) are among the major drivers of the transition between stable state and eventually leading to a desertified state (D'Odorico *et al.,* 2013). The complex conundrum of aridification and desertification encompasses mutually-reinforcing and highly interactive processes (Fig. 1).

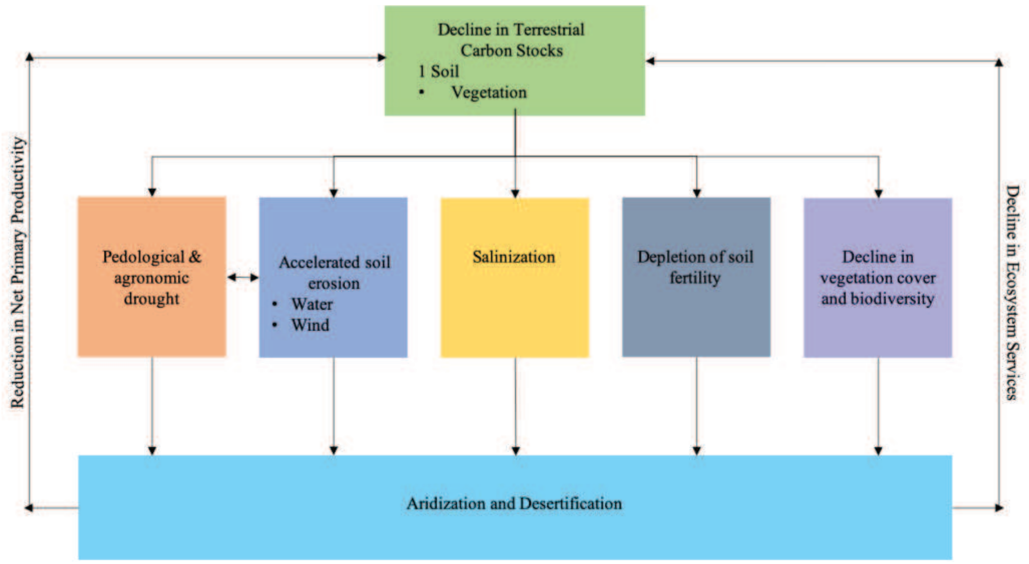

Figure 1. *Drivers of aridization and desertification with mutually-reinforcing feedbacks*

Rapid and severe depletion of SOC stock in conjunction with increase in frequency and intensity of pedologic/agronomic droughts (reduction in plant-available water capacity at the critical stages of crop/vegetation growth) sets-in-motion the downward spiral that leads to a drastic reduction in NPP, weakening of ecosystem services and creation of several disservices (Fig. 1). Notable among disservices are aggravation of food and nutritional insecurity, water scarcity, loss in biodiversity, and risks of soil degradation.

The use of GIS and remote sensing techniques can detect soil degradation by erosion, salinization and other degradation processes (Adamu *et al*., 2014). Decline in SOC stock is exacerbated both by accelerated erosion through aeolian and hydrologic processes (Chappell *et al*., 2019; Ravi *et al.,* 2010), salinization (Setia *et al*., 2013; FAO, 2005; Rengasamy, 2008) and combination of both (DeLong *et al.,* 2015). In this regard, preventive measures to minimize risks of soil degradation are better than corrective actions because once the process of aridification is set-in-motion it keeps expanding the areal extent of drylands (Prăvălie, 2016).

In addition to decline in the plant-available water capacity, severe reduction in SOC and the terrestrial C stocks also deplete soil fertility and create elemental imbalance. Indeed, the severe problem of soil degradation in Sub-Saharan Africa (SSA) is closely associated with poor soil fertility (Zingore *et al.,* 2015) and the negative nutrient budget on a continental scale (Smaling *et al.,* 1999). The process is exacerbated by the use of extractive farming practices over a long time period. Furthermore, indiscriminate intensification of agriculture to feed the growing population of SSA is also among primary causes of the current and the projected rate of aridification and desertification (Tully *et al.,* 2015).

Some indicators of decline in soil fertility include pH, cation exchange capacity, and SOC concentration, which have direct impact on soil health and functionality (Tully *et al.,* 2015). Soil degradation and desertification, strongly interacting with climate change, have severe adverse impacts on food security and provisioning of other critical ecosystem services. Identification and adoption of climate-resilient agricultural practices, which also reverse the desertification trends, must be considered in planning of any restorative measures and their adoption (Webb *et al.,* 2017).

Creating a positive soil and terrestrial carbon budget in agro-ecosystems

Depletion of the soil and terrestrial C stocks being among the primary and critical determinants of aridification and desertification, restoring C stocks is essential and a priority condition to reversing the desertification trends and strengthening the provisioning of essential ecosystem services. Sequestration of atmospheric CO_2 is also pertinent to advancing several SDGs including #2 (zero hunger), #6 (clean water), #13 (climate action), and #15 (life on land) (Lal *et al.,* 2018). The strategy of SOC sequestration is to create landscapes in drylands that enhance biodiversity and also improve human wellbeing (Kremen and Merenlender, 2018).

A positive trend in soil C stock and its impact on the GCC can be created through restoration of drylands. Keller and Goldstein (1994; 1998) estimated the potential of C sequestration of 0.8 Pg/yr. Cultivation of halophytes (Douglas, 1993) is one of the options to create a positive soil/ecosystem C budget. Conversion of conventional tillage to no-till or conservation agriculture (CA) is another useful option (Plaza-Bonilla *et al*., 2015). Controlled or non grazing in drylands can also increase SOC storage over time. There are also abiotic processes of SIC sequestration including formation of secondary carbonates and translocation of bicarbonates (Serrano-Ortiz *et al.*, 2012). In addition to the surface layer, there is an additional SOC storage capacity in the sub-soil below 0.1 m depth (Hoyle *et al.,* 2014).

Soil organic carbon and sustainable land management

The magnitude and quality of SOC stock and the Land Degradation Neutrality (LDN) are strongly inter-connected (Cowie *et al.,* 2018). Therefore, restoring the SOC stock of degraded and depleted soils, which is often as low as 0.05% in croplands of South Asia and Sub-Saharan Africa along with those of the Caribbean and the Andean regions, advances the LDN and vice versa. In this context, implementing sustainable land management (SLM) options (Dumanski, 1997; Hurni, 2000) can enhance SOC, restore and sustain soil health, and achieve LDN (Table 6). Appropriate SLM must be validated and fine-tuned under site-specific conditions with due consideration to biophysical (i.e., soil, climate, terrain), socio-economic (land tenure, farm size, infrastructure, institutional support, access to market, gender issues) and cultural issues (faith, traditions, rituals). There is no such thing as "one size fits all" SLM option for 300,000 known soil series and multitude of site-specific factors.

Some examples of SLM include CA with residue retention as mulch and cover cropping, complex farming systems based on judicious integration of crops with trees and livestock, integrated nutrient management involving judicious combination of organic and inorganic sources of plant nutrients, and precision or soil specific agriculture. Choice of appropriate SLM would lead to a positive soil/ecosystem C budget such that input of biomass-C (i.e., residue retention, compost, biochar) exceeds the losses of SOC (by erosion, decomposition and leaching). Under dryland conditions, the rate of SOC sequestration may range from 0.1 to 0.25 Mg C ha_{-1} yr (Lal, 2002). However, adoption of SLM would also enhance sequestration of SIC as secondary carbonates or caliche, and through leaching of bicarbonates into the groundwater (Monger *et al.,* 2015). Dryland ecosystems have biotic and abiotic mechanisms of SIC sequestration, both of which can be enhanced and sustained through adoption of SLM.

Table 6. *Impacts of sustainable land management (SLM) on soil organic carbon sequestration, soil health restoration and land degradation neutrality*

SLM Technology	Potential Impacts Towards LDN
Conservation agriculture	Erosion control, water conservation, SOC sequestration, minimal soil disturbance
Agroforestry	Nutrient cycling, moderation of micro-climate, windbreak, biodiversity
Contour hedges	High biodiversity, integrated pest management, biomass as mulch, runoff management
Complex farming systems	Biological nitrogen fixation, high use efficiency, sustainable production, high biodiversity
Agro-pastoral systems	Nutrient cycling, sustainable production, resource efficiency

Establishing relationship between SLM and SOC for key benchmark locations

In addition to the choice of site-specific SLM, the rate of SOC sequestration also depends on soil, climate, vegetation and interaction among them as altered through anthropogenic interventions. Improvements in SOC through SLM have strong beneficial impacts on soil properties and processes (Table 7). Despite being an ecosystem property, the net rate of SOC sequestration for site-specific SLM must be determined by establishing long-term (5-10 year) experiments for key benchmark locations in drylands (Lal, 2019). These on-farm studies must be conducted with farmer participation from the planning through the monitoring stages. The community-based benchmark sites should be established for predominant soil orders within an eco-region (Dregne, 1976). Predominant soils within these ecoregions are Inceptisols, Arenosols, Psamments, Vertisols, and Alfisols (Table 8).

The rate of SOC sequestration must be correlated with soil properties (e.g., texture, plant available nutrient reserves, CEC, pH, EC, MBC), climate (temperature and moisture regime), input of biomass-C, and NPP or agronomic yield. Land resources can be saved for nature conservancy by restoring soil health through SOC sequestration (Lal, 2018). The benchmark sites can be established along a transect through the rainfall gradient representing different demographic characteristics (Lal, 2019). Results obtained can be extrapolated and scaled up on the basis of the specific soil order within the eco-region.

Table 7. *Beneficial impacts of soil organic carbon on soil health and functionality*

Constraint	Impact
Drought	Water conservation, soil temperature moderation, root system proliferation, improved green water supply
Soil fertility	Nutrient retention and availability; reduced losses by leaching, volatilization and erosion; high nutrient use efficiency
Soil health	Disease-suppressive soils, high soil biodiversity, improved plant growth and vigor, soil resilience
Soil tilth	Low risks of crusting and compaction, better soil aeration, favorable porosity and pore size distribution
Production	Sustainable agronomic production, assured minimum yield, better nutritional quality

Table 8. *Choice of benchmark sites for establishing relation between SLM and SOC through participation and community-based on-farm research*

Soil Order	Eco Region			
	Hyper-Arid	Arid	Semi-arid	Dry Sub-humid
Alfisols				
Arenosols				
Inceptisols	Identifying Transects Along AI and Soil Gradients			
Psamments				
Plinthic				
Vertisols				

Saline agriculture

With the world population of 7.8 billion in 2018 and projected to reach 11.2 billion by 2100 necessitate identification of innovative means to enhance global food production. There is also a strong need for adoption of the strategy of eco-intensification, producing more from less land area (Rudel *et al.,* 2009; Lal, 2018). With increase in land area under drylands and risks of secondary salinization, it is prudent to adopt saline agriculture and enhance food production through identification and use of salt-tolerant crops (Ladeiro, 2012; Epstein *et al.,* 1980; Galvani, 2007; Yamaguchi and Blumwald, 2005). Indeed, halophytes are an important resource for future innovations in agriculture (Khan and Duke, 2001) and for increasing the land resource base through bio-reclamation of salt-affected soils by growing halophytes (Shekhawat *et al*., 2006). Increase in biomass production through adapting halophytes on hitherto unproductive salt-affected soils can also increase terrestrial C sequestration (Glenn *et al*., 1992; Setia *et al*., 2011). Halophytes are useful to grow animal feed even by irrigation with seawater (Glenn *et al.,* 1995).

Conclusions

Drylands are among the largest and a significant biome for human wellbeing and nature conservation. Drylands impact and are impacted by the ACC, and have a large potential of sequestration of SOC and SIC. Processes, practices and factors affecting the rate and magnitude of sequestration of SOC are soil and site specific and vary among ecosystems of the drylands. However, the available soil moisture content in the root zone, the so-called "green water," is the most critical factor to restoring degraded drylands and strengthening ecosystem services, especially the NPP.

Dryland farming, based on CA and judicious management of rainwater in the root zone along with saline agriculture, is essential to improving and sustaining productivity. The plant available water capacity is affected by texture, SOC stock, soil structure and effective rooting depth. In addition to water, availability of plant nutrients (both macro and micro) is also essential to improving the above and below-ground biomass, enhancing SOC stock and increasing the rate of formation of secondary or pedogenic carbonates in soils of drylands. The carbon sequestration potential of soils of drylands is estimated at 0.7-1.3 Gt C yr^{-1}., equivalent to ~10% of the global fossil fuel emissions. There is also potential of leaching of bicarbonates into the ground water especially in soils irrigated with good quality water. In ground water, the SIC is sequestered as bicarbonates.

In addition to mitigating climate change by reducing the net anthropogenic emissions, sequestration of C in soil (SOC, SIC and bicarbonates) and biomass (above and below ground) would also advance the SDGs of the U.N. or the Agenda 2030. Specific SDGs impacted through re-carbonization of the terrestrial ecosystems in dryland would include #2 (end hunger), #6 (clean water), #13 (climate action), and of course #15 (life on land). Restoration of soil health through sequestration of C in the terrestrial ecosystems of the drylands would improve the wellbeing of 1-2 billion people already impacted by water scarcity. In this context, the importance of the concept of LDN adopted by the U.N. Convention to Combat Desertification (UNCCD) cannot be over-emphasized. Therefore, the criteria of soil and land degradation, as determined by the critical limits of key soil properties, must be carefully established and the extent and severity of land/soil degradation by different processes credibly established at local, regional, national and global scales.

The strategy of soil C sequestration has been adopted by the COP21 in Paris as the "4 per Thousand Program", and in COP22 in Marrakech in 2016 as the "Adapting African Agriculture" (AAA) program. The COP 23 in Bonn in 2017 also recognized the importance of sustainable management of world soils and of agro-ecosystems as solution to mitigating anthropogenic climate change and improving the environment. The French Government is promoting the concept of Planet A, and arguing that there is no Planet B. Thus, judicious management of the natural resources of Earth (soil, water, vegetation, climate and biodiversity) is essential to human wellbeing and nature conservancy.

References

Adamu, G.K., M.A. Yusuf and M. Ahmed. 2014. Soil degradation in drylands. *Academic Research International* 5(1): 78.

Banwart, S.A., H. Black, Z. Cai, P.T. Gicheru, H. Joosten, R.L. Victoria, E. Milne, E. Noellemeyer and U. Pasual. 2015. The global challenge for soil carbon. *Soil carbon: Science, Management and Policy for multiple benefits* pp.1-9.

Chappell, A., N.P. Webb, J.F. Leys, C.M. Waters, S. Orgill and M.J. Eyres. 2019. Minimising soil organic carbon erosion by wind is critical for land degradation neutrality. *Environmental Science & Policy* 93: 43-52.

Cowie, A.L., B.J. Orr, V.M.C. Sanchez, P. Chasek, N.D. Crossman, A. Erlewein, G. Louwagie, M. Maron, G.I. Metternicht, S. Minelli and A.E. Tengberg. 2018. Land in balance: The scientific conceptual framework for Land Degradation Neutrality. *Environmental Science & Policy* 79: 25-35.

D'Odorico, P., A. Bhattachar, K.F. Davis, S. Ravi and C.W. Runyan. 2013. Global desertification: drivers and feedbacks. *Advances in Water Resources* 51: 326-344.

Darwish, T. and A. Fadel. 2017. Mapping of soil organic carbon stock in the Arab countries to mitigate land degradation. *Arabian Journal of Geosciences* 10(21): 474.

DeLong, C., R. Cruse and J. Wiener. 2015. The soil degradation paradox: Compromising our resources when we need them the most. *Sustainability* 7(1): 866-879.

Douglas, J. 1993. A rich harvest from halophytes. *EPRI Journal* 18(7): 16-24.

Dregne, H. 1976. Soils of Arid Lands. Elsevier, Amsterdam. p. 237.

Dregne, H.E. 2002. Land degradation in the drylands. *Arid Land Research and Management* 16(2): 99-132.

Dumanski, J. 1997. Criteria and indicators for land quality and sustainable land management. *ITC journal* 3(4): 216-22.

Epstein, E., J.D. Norlyn and D.W. Rush. 1980. Saline culture of crops: a genetic approach. *Science* 210(4468): 399-404.

FAO. 2005. Global network on integrated soil management for sustainable use of salt affected soils. FAO Land and Plant Nutrition Management Service, Rome, Italy.

Feng, S. and Q. Fu. 2013. Expansion of global drylands under a warming climate. *Atmospheric Chemistry and Physics* 13 (10): 1-10.

Galvani, A. 2007. The challenge of the food sufficiency through salt tolerant crops. *Reviews in Environmental Science and Biotechnology* 6(1-3): 3-16.

Glenn, E.N. Hicks, J. Riley and S. Swingle. 1995. Seawater irrigation of halophytes for animal feed. *In* Halophytes and Biosaline Agriculture, Marcel Dekker, New York, NY, USA.

Glenn, E.P., L.F. Pitelka and M.W. Olsen. 1992. The use of halophytes to sequester carbon. *Water, Air, and Soil Pollution* 64(1-2): 251-263.

Hoyle, F.C., M. D'Antuono, T. Overheu and D.V. Murphy. 2014. Capacity for increasing soil organic carbon stocks in dryland agricultural systems. *Soil Research* 51(8): 657-667.

Hurni, H. 2000. Assessing sustainable land management (SLM). *Agriculture, Ecosystems & Environment* 81(2): 83-92.

Hutchinson, C.F. 1996. The Sahelian desertification debate: a view from the American south-west. *Journal of Arid Environments* 33(4): 519-24.

Keller, A.A. and R.A. Goldstein. 1994. The human effect on the global carbon cycle: Response functions to analyze management strategies. *World Resources Review* 6: 63-87.

Keller, A.A. and R.A. Goldstein. 1998. Impact of carbon storage through restoration of drylands on the global carbon cycle. *Environmental Management* 22(5): 757-766.

Khan, M.A. and N.C. Duke. 2001. Comparative physiology of salt and water stress. *Plant, Cell and Environment* 9(6): 455-456.

Kremen, C. and A.M. Merenlender. 2018. Landscapes that work for biodiversity and people. *Science* 362(6412): eaau6020.

Ladeiro, B. 2012. Saline agriculture in the 21st century: using salt contaminated resources to cop food requirements. *Journal of Botany* 2012. DOI:10.1155/2012/310705

Lal, R. 2002. Soil carbon dynamics in cropland and rangeland. *Environmental Pollution* 116(3): 353-362.

Lal, R. 2004. Soil carbon sequestration impacts on global climate change and food security. *Science* 304(5677): 1623-1627.

Lal, R. 2018. Digging deeper: A holistic perspective of factors affecting soil organic carbon sequestration in agroecosystems. *Global Change Biology* 24(8): 3285-3301.

Lal, R. 2019. Promoting "4 per thousand" and "adapting African agriculture" by south-south cooperation: conservation agriculture and sustainable intensification. *Soil and Tillage Research* 188: 27-34.

Lal, R. and B.A. Stewart (Eds.). 2017. Urban Soils. Taylor & Francis, Boca Raton, FL. p. 400.

Lal, R., R. Horn and T. Kosaki. (Eds.). 2018. Soil and Sustainable Development Goals. Catena-Schweizerbart, Stuttgart. 2018: p. 196.

Li, C., C. Zhang, G. Luo, X. Chen, B. Maisupova, A.A. Madaminov, Q. Han and B.M. Djenbaev. 2015. Carbon stock and its responses to climate change in Central Asia. *Global Change Biology* 21(5): 1951-1967.

Lobell, D.B. and S.M. Gourdji. 2012. The influence of climate change on global crop productivity. *Plant Physiology* 160(4): 1686-1697.

MEA. 2005. Millennium Ecosystem Assessment: Ecosystems and Human Well-Being: Desertification Synthesis. World Resource Institute, Washington, D.C.

Middleton, N. and D. Thomas. 1997. World Atlas of Desertification. London, UK.

Monger, H.C., R.A. Kraimer, S.E. Khresat, D.R. Cole, X. Wang and J. Wang. 2015. Sequestration of inorganic carbon in soil and groundwater. *Geology* 43(5): 375-378.

Plaza-Bonilla, D., J.L. Arrúe, C. Cantero-Martínez and R. Fanlo, A. Iglesias and J. Álvaro-Fuentes. 2015. Carbon management in dryland agricultural systems. A review. *Agronomy for Sustainable Development* 35(4): 1319-1334.

Plaza, C., C. Zaccone, K. Sawicka, A.M. Méndez, A. Tarquis, G. Gascó, G.B. Heuvelink, E.A. Schuur and F.T. Maestre. 2018. Soil resources and element stocks in drylands to face global issues. *Scientific Reports* 8: 13788. doi: 10.1038/s41598-018-32229-0

Prăvălie, R. 2016. Drylands extent and environmental issues. A global approach. *Earth-Science Reviews* 161: 259-278.

Rangasamy, P. 2008. Salinity in the landscape: a growing problem in Australia. *Geotimes* 53: 34-39.

Ravi, S., D.D. Breshears, T.E. Huxman and P. D'Odorico. 2010. Land degradation in drylands: Interactions among hydrologic-aeolian erosion and vegetation dynamics. *Geomorphology* 116(3-4): 236-245.

Ray, J.D., R.W. Gesch, T.R. Sinclair and A.L. Hartwell. 2002. The effect of vapor pressure deficit on maize transpiration response to a drying soil. *Plant Soil* 239: 113-121.

Rengasamy, P. 2008. Salinity in the landscape: A growing problem in Australia. *Geotimes* 53(3): 34.

Rudel, T.K., L. Schneider, M. Uriarte, B.L. Turner, R. DeFries, D. Lawrence, J. Geoghegan, S. Hecht, A. Ickowitz, E.F. Lambin and T. Birkenholtz. 2009. Agricultural intensification and changes in cultivated areas, 1970-2005. *Proceedings of the National Academy of Sciences* 106(49): 20675-20680.

Safriel, U., Z. Adeel, D. Niemeijer, J. Puigdefabregas, R. White, R. Lal, M. Winslow, J. Ziedler, *et al*. 2005. Chapter 22: Dryland systems. Pages 623-662 *in* Millennium Ecosystem Assessment- Ecosystems and Human Well-being. World Resoures Institute, Washington DC, USA.

Schlaepfer, D.R., J.B. Bradford, W.K. Lauenroth, S.M. Munson, B. Tietjen, S.A. Hall, S.D. Wilson, M.C. Duniway, G. Jia, D.A. Pyke, A. Lkhagva and K. Jamiyansharav. 2017. Climate change reduces extent of temperate drylands and intensifies drought in deep soils. *Nature Communications* 8(14196): 1-9.

Serrano-Ortiz, P., E.P. Sánchez-Cañete and C. Oyonarte. 2012. The carbon cycle in drylands. Pages 347-368 *in* Recarbonization of the Biosphere. Springer, Dordrecht.

Setia, R., P. Gottschalk, P. Smith, P. Marschner, J. Baldock, D. Setia and J. Smith. 2013. Soil salinity decreases global soil organic carbon stocks. *Science of The Total Environment* 465: 267-72.

Setia, R., P. Smith, P. Marschner, J. Baldock, D. Chittleborough and J. Smith. 2011. Introducing a decomposition rate modifier in the Rothamsted carbon model to predict soil organic carbon stocks in saline soils. *Environmental Science Technology* 45(15): 6396-6403.

Shekhawat, V.P.S., A. Kumar and H.H. Neumann. 2006. Bio-reclamation of secondary salinized soils using halophytes. pp. 147-154 *in* Biosaline Agriculture and Salinity Tolerance in Plants.

Smaling, E.M.A., O. Oenema and L.O. Fresco (Eds.). 1999. Nutrient Disequilibria in Agroecosystems: Concepts and Case Studies. CABI, Wallingford, UK. p. 322.

Tully, K., C. Sullivan, R. Weil and P. Sanchez. 2015. The state of soil degradation in Sub-Saharan Africa: Baselines, trajectories, and solutions. *Sustainability* 7(6): 6523-6552.

Turnbull, L., J. Wainwright and R.E. Brazier. 2008. A conceptual framework for understanding semi-arid land degradation: Ecohydrological interactions across multiple-space and time scales. *Ecohydrology: Ecosystems, Land and Water Process Interactions, Ecohydrogeomorphology* 1(1): 23-34.

UNCCD. 1994. Elaboration of an International Convention to Combat Desertification in countries experiencing serious drought and/or desertification, particularly in Africa. *AC* 241: 27.

UNEP. 1992. World Atlas of Desertification. London, UK.

Webb, N.P., N.A. Marshall, L.C. Stringer, M.S. Reed, A. Chappell and J.E. Herrick. 2017. Land degradation and climate change: building climate resilience in agriculture. *Frontiers in Ecology and the Environment* 15(8): 450-459.

Yamaguchi, T. and E. Blumwald. 2005. Developing salt-tolerant crop plants: challenges and opportunities. *Trends in Plant Science* 10(12): 615-620.

Zingore, S., J. Mutegi, B. Agesa, L. Tamene and J. Kihara. 2015. Soil degradation in sub-Saharan Africa and crop production options for soil rehabilitation. *Better Crops* 99(1): 24-26.

Concurrent Session Presentations

Theme 1:
Impact of Climate Change in Drylands

Lead Lectures

Managing increasing climatic risks in agriculture: Opprotunities and constraints

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Extended Summary

Climatic risks directly and indirectly affect agriculture and food security of all countries. Degradation of natural resources and climate change are likely to compound food security issues further. Numerous studies have shown that the productivity of crops, fish and livestock would decline further if corrective actions were not taken now to increase the adaptive capacity. Reducing such risks to food systems from climate change will be one of the major challenges of the 21st century. If the Sustainable Development Goal of ending poverty, achieving food security and promoting sustainable agriculture is to be realised, climate change adaptation and mitigation interventions need to be implemented in earnest. There is, therefore, an urgent need to identify cost-effective, inclusive (gender and marginalized farmers) and evidence-based integrated solutions to enhance adaptive capacity of most vulnerable farming communities.

Research has shown that there are several potential adaptation options available to mitigate moderate to severe climatic risks in agriculture. Changes in agronomic practices (e.g. altering inputs, timing and location of cropping activities), adoption of new technologies (e.g. improvement in input use efficiency, conservation of water and energy, and pest/disease/weed management) and the use of relevant information (e.g. climate-information based agro-advisories and weather-index based insurance) at the farm level can be key components in improving adaptability of agriculture to climate change. These options can significantly improve crop yields, increase input-use efficiencies and net farm incomes, and reduce greenhouse gas emissions. Several of these interventions have been successful in raising production, income and building resilience of farming communities in many locations. These interventions have, however, varying costs and economic impacts, and their implementation requires appropriate investment decisions in both on-farm capital and for wider agricultural outreach programs.

CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) is scaling out the Climate-Smart Villages (CSVs) model (https://ccafs.cgiar.org/climate-smart-villages) in South Asia to promote Climate-Smart Agriculture (CSA). CSVs are sites where a portfolio of the most appropriate technological and institutional interventions, determined by the local community, are implemented to increase food production, enhance adaptive capacity and wherever possible reduce emissions. Interventions are bespoke to each village but the concept lends itself to be applied in any region under the right circumstances. Initial results suggest a large potential to maximize synergies among different interventions.

In past two decades, many governments have taken several policy and institutional initiatives that directly or indirectly lead to greater adoption of CSA practices (FAO, 2018). While most of these interventions have indeed shown increased production, resilience and even mitigation at local scale, efforts are needed to increase their coverage. This requires improved understanding of the adaptation domains of CSA practices and technologies, their linkages with demand and supply of foodgrains, and appropriate 'business models' to scale them out. Complex problems of widespread poverty, poor governance, weak institutions and human capital need to be addressed simultaneously to realize the full potential of CSA practices, technologies, institutions and policies.

Reference

FAO. 2018. Climate-Smart Agriculture Case Studies 2018. Successful approaches for different regions. Food and Agriculture Organization of the United Nations, Rome. 33 pp.

Climate change and the strategy of decreasing its harmful influence on agriculture in Central Asia and South Caucasus countries

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Abstract

Central Asia and Caucasus region is a vast territory consisting of deserts, prairies, and mountains. For many years, the people living in this region have been fighting with difficult climatic conditions characterized by low, non-regular precipitation and abrupt temperature change. During Soviet period, monoculture was practiced on a large scale, which resulted in decreased soil fertility and build up of pests and diseases, and thus low yields. Priority has, therefore, to be given to devising land and water resource management practices that raise productivity and developing measures that will reduce the negative effect of climate change. Strategic plans addressing these problems have been worked out by government organizations of each country of the region. The main components of the strategy are: rational exploitation of water resources, improved soil and water management practices and crop species which are more resistant to high temperatures, pests and diseases, diversification of agriculture to make it more resilient to climate change, forecasting of climate change related events at the level of micro zones and working out measures for decreasing their adverse effect.

Introduction

Central Asia and Caucasus (CAC) region is a vast region, spread on almost 4.0 million km^2, having a population of 80.3 million people, with its territory consisting of deserts, prairies, and mountains. Approximately 70% of total area, about 416 million ha, is agricultural land but only 15% is managed. Wheat, cotton, fruit crops and animal production are the leading components of agriculture of the region. Agriculture is main economic activity providing employment to one-third of the local working population. The region has been exposed to difficult climatic conditions characterized by low, and highly irregular precipitation and large abrupt fluctuations in the temperatures.

During Soviet era, monoculture was the main agriculture production system, spread on a large areas. This resulted in decrease in soil fertility and increase in crop losses because of pests and diseases. The research community was also very isolated and had little opportunity for outside exposure. Since then, scientific studies carried out by the researchers of Central Asia and Caucasus region have emphasized that priority should be given to raising the productivity of agriculture, through appropriate land and water resource management, and developing measures, which will reduce the negative effect of climate change. Some of the main concerns were conservation of genetic resources, diversification of agricultural crops, raising the capability of young specialists, and strengthening international relations. Particular attention was paid to strengthening relations with international scientific organizations of

CGIAR, especially, ICARDA, CIMMYT, ICRISAT, CIP, IWMI, Bioversity International, and other institutions that play an important role in helping the CAC countries in planning and execution of research for solving the urgent agricultural problems in the region. Climate change and working out the measures for its reduction is one of the most acute problems that exist in agriculture of the region.

Climate change in CAC is primarily experienced through extreme climatic events, decreasing precipitations, increasing temperatures, land degradation, loss of biodiversity, increased occurrence of pests and disease and dwindling supply of irrigation water. These adverse conditions for crop and livestock production have serious consequences on food and nutritional security in the region. Strategic plans which address those problems have been worked out by government organizations of each country of the region, main direction of which are: rational use of water resources and use of crop species and their cultivars which are resistant to high temperature, more drought tolerant and have resistance to crop pests and diseases.

The researchers of the region have focused on some of the major problems faced by the agriculture sector in last years. These are presented below:

Wheat production

Wheat is the most important food crop in the CAC region accounting for 85% of all cereals consumed. The major climate-related constraints to wheat production in the region include diseases, pests, drought, heat, salinity, and cold (lethal low temperatures).

Yellow rust has been a continuous scourge to winter wheat production in the CAC region as reflected through 9 disease epidemics between 2001 and 2015. Favorable conditions for yellow rust epidemics include mild winter, wet and cool spring, virulent fungal strains and susceptible varieties. The CAC region has been spending millions of dollar on fungicide to control yellow rust. Yellow rust not only reduces grain yield by up to 60%, but also reduces the quality of grain and straw. To address the problem, national wheat research programs in the CAC region, in collaboration with International Winter Wheat Improvement Program (IWWIP) of ICARDA and CIMMYT, have released winter wheat varieties with high level of resistance to yellow rust. These include 'Gozgon', 'Buniyodkor', 'Shams', and 'Yaksart' in Uzbekistan; 'Norman', 'Alex' and 'Chumon' in Tajikistan; 'Askaran' in Azerbaijan, and 'Agruni-1' in Georgia. The cultivation of these varieties has already slowed down epidemics of yellow rust in the past three years. More resistant cultivars are being evaluated by State Variety Testing Commission in different countries.

Tan spot and root rot of wheat are emerging disease constraints to irrigated wheat and already serious for dryland wheat. The adoption of resource conservation practices in wheat, where residues are allowed to stay in the field, although important for soil and moisture conservation, may cause severe incidence of tan spot and root related diseases. Improved germplasm tolerant to tan spot and root rot, developed by the wheat researchers at ICARDA, CIMMYT and IWWIP, are being used by the researchers of CAC countries facing the problem of these diseases to develop disease resistant cultivars adapted to their wheat growing conditions.

Cropping system diversification for controlling abiotic stresses

Extreme events in climate are already showing their negative consequences on crop productivity. In past 10 years, four years (2008, 2011, 2014, 2018) faced extreme drought conditions in many parts of CAC region, resulting in lower than normal crop yields under irrigated conditions and crop failures under rainfed conditions for winter and spring cereals. Cultivation of drought resistant cool season legumes such as chickpea and lentil offers huge potential of increasing productivity of rainfed lands. Similarly, cultivation of drought tolerant varieties of winter cereals by replacing the current varieties developed for fully irrigated conditions could help reduce the extent of crop yield losses. The most dominant crop rotation in the CAC region is 'cotton-wheat', which demands high irrigation water and depletes soil health. Use of drought and heat tolerant leguminous crops such as mung bean, cowpea, and fodder legumes can help increase land and water productivity and improve soil health.

Heat during the advanced stages of winter crops is a major constraint causing severe reductions in grain yield in the CAC region. The problem of heat stress is expected to aggravate under the climate change scenarios. The current strategy to address the problem of heat stress includes early planting and early maturing winter crop varieties to avoid extreme heats during the grain development phase. The problem of heat stress is also being tackled through heat tolerant varieties of winter crops, and planting heat tolerant crop such as mung bean during summer months

Soil salinity is an important constraint to food production in the CAC region. The problem of salinity is expected to aggravate under climate change. The current practice of leaching salt from upper layers of soil is not a sustainable solution due to dwindling supply of water for agriculture. The strategy for increasing food production on saline soils includes planting of salt tolerant varieties of crops. Managing salt by using bed planting is an emerging technology in the CAC region.

Frost can damage winter crops in the CAC region prior to onset of winter, during winter, and during early spring season. The crop damage could be up to 100%. Early spring frost can also cause severe damage to fruit crops in flowering stage. Severe winter damage to wheat crop was experienced during 2012-2013 winter season and during spring of 2015. As such, there is no technology to guarantee complete protection from frost damage. However, there are some options to reduce damage. One such technology is planting wheat at 4 cm depth, which allows better root establishment and regrowth of the crop in the event of frost damage to emerging shoots. Another option is planting wheat varieties relatively tolerant to frost that allow regrowth after frost damage.

On-farm water management

The share of water for agriculture is going to decrease overtime, hence lesser water will be available for irrigation. This would require more judicious use of water to produce food crops. One recent development of on-farm water management allows substantial saving of irrigation water. Pilot work done on evapotranspiration-based (ET-based) irrigation scheduling in Khorezm and Fergana provinces of Uzbekistan showed saving of 45% water compared to the prevalent farmers' practice.

Conservation Agriculture

Conservation Agriculture (CA) is a widely adopted practice that saves resources such as water and fuel and improves soil health. This practice has been piloted both under irrigated and rainfed conditions in the CAC region. CA provides huge opportunities for sustainable crop production under climate change.

Impact of climate change

Eight countries of CAC Region (Kazakhstan, Uzbekistan, Kirgizstan, Tajikistan, Turkmenistan, Azerbaijan, Armenia, and Georgia) differ significantly in their climatic and soil conditions and thus have been differently impacted by the climate change.

To make comparison, we discuss two countries - Kirgizstan from Central Asia, and Georgia from Caucasus region. The territory of Kirgizstan according to natural and climatic conditions is divided into four zones: lowlands - lower than 1200 meters; upland and mountainous - up to 2200 m; highlands - from 2000 to 3500 m, and above 3500 m from sea level. The specialists have calculated economic losses in agriculture sector because of climate change in million dollars. The results are as follows: water resources - 718, agriculture - 70, energy resources - 200, healthcare - 110, forest and biodiversity 94.8. According to the data of specialists, the most negative effect on agricultural crops was because of draught and lack of water resources. Considering this fact, practically all the arable land of the republic falls under the desert or semi-desert zones and is likely to become more adversely affected by future climate change.

Interesting information has been generated by the healthcare specialists on the possible negative effect of climate change on people's health. It is anticipated that the number of the cases of cardio-vascular diseases may rise by 10.5%, and increase of intestinal diseases by 17-18%. The scientists also predict spread of malaria, particularly in the southern parts of the country, as well as spread of infectious diseases, such as encephalitis, caused by pests.

The territory of Georgia is comparative small, 69,700 km^2. The climatic conditions are extremely diverse, considering the nation's small size. There are two main climatic zones, roughly corresponding to the eastern and western parts of the country. The Greater Caucasus Mountain Range plays an important role in moderating Georgia's climate and protects the nation from the penetration of colder air masses from the north. The Lesser Caucasus Mountains partially protect the region from the influence of dry and hot air masses from the south. Grape-growing and winemaking industry of Georgia accounts for major economic returns to the country for thousands of years. More than 500 local varieties are cultivated, known for their winemaking quality.

We studied the influence of climate change on grape growing in East Georgia - Kakheti. Today, in this region there are more than half of the vineyards of the country. It is distinguished for the wines, which are produced in the unique micro zones of Rkatsiteli and Saperavi. On this small territory, the reason for production of such a diverse assortment of high-quality wines lies in the fact that there is a large variety of grapes, and it is endowed with special agro-climate, soil and technological particularities.

On the basis of the data of UNFCCC (2009), the average annual temperature in the winter and summer seasons in Georgia has increased by 0.2-0.6°C, the precipitation has increased by 6-13%; the precipitation has become more irregular, resulting in events of heavy rains and floods with significant economical losses. With the rise in the level of Black Sea, the storms have become more frequent; and wind speed has been increasing. In East Georgia the drought period has grown and the frequency of drought events has doubled. It is expected that the average annual air temperature in the period 2030-2040 in Georgia will increase by 1.4-2.1°C, and the amount of precipitation decrease by 3%. In 2010, in the Alazani basin, the inflows decreased for 26-35%. In the steppe (valley) ecosystem increasing degradation has taken place on the plains, the forests have moved upwards, the spread of invasive species has widened, and the frequency of extreme natural phenomena has increased. These factors have increased the environmental risks, which correspondingly will cause decrease in winemaking by 10-15%. This highlights the necessity of studying the impact of the agricultural climate conditions on vine and developing ways for adaptation.

The climate change influences the grape vines because climate and soil have impact on their phenology and grape harvest and quality. Increase of the temperature in a particular region might cause deterioration of the quality of some varieties and, incompliance with the appropriate wine region regulation - the borders of the growing regions might change as well as the wine style, assortment of the species, and the directions of vine-growing. This may also cause spread of the existing diseases as well as arrival of new ones. The negative impact of the extreme weather conditions will have to be considered. The effect of the raised levels of CO_2 is uncertain, but there is going to be increased need for the irrigation water. Impact of the climate changes might not be equal on all the varieties and the regions. But adaptation might soften the negative effects caused by such changes. Studies during the last few years have confirmed that the impact of the climate changes is the subject of wide concern in the framework of the world vine-growing and winemaking. Various models of climate change, and the response of vines to those changes, have been developed making it possible to model proposed scenarios of the changes and devise effective adaptation mechanisms.

Reference

UNFCCC. 2009. Report of the Conference of the Parties on its fifteenth session, held in Copenhagen from 7 to 19 December 2009. United Nations Framework Convention on Climate Change (UNFCCC), FCCC/CP/2009/11/Add.1.

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Climate resilient agriculture in rainfed areas: Adaptation strategies in Indian context

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Extended Summary

The Indian agriculture production system is challenged with the daunting task of feeding 17.5% of the global population with only 2.4% of land and 4% of water resources of the World at its disposal. The air temperature trend in India over the past 100 years has indicated an increase of 0.6°C, which is likely to impact many crops, and thus affect food and livelihood security. Since agriculture contributes currently ~15% of India's Gross Domestic Product (GDP), a negative impact on production implies cost of climate change to roughly range from 0.7 to 1.35% of GDP per year. All the CMIP5 models simulate stronger seasonal mean rainfall in the future compared to the historic period under the RCP8.5 scenarios. Instrumental records suggest a significant negative rainfall trend in the eastern parts of Madhya Pradesh, Chhattisgarh and parts of Bihar, Uttar Pradesh, parts of North-west and North-east India and also a small pocket in Tamil Nadu. Rainfall is likely to decline by 5 to 10% over southern parts of India whereas 10 to 20% increase is likely over other regions. The recent ensemble models project that the frequency of extreme precipitation days (>40 mm day^{-1}) are likely to increase.

Rainfed crops are likely to be worst hit by climate change because of the limited options for coping with variability of rainfall and temperature (Kumar, 2009). Enhancing agricultural productivity, therefore, is critical for ensuring food and nutritional security for all, particularly the resource poor small and marginal farmers who would be the most affected by climate change. In India, the estimated countrywide agricultural loss in 2030 will be over $7 billion that will severely affect the income of 10% of the population. However, this could be reduced by 80%, if cost-effective climate resilience measures are implemented (ECA, 2009). The total dependence on south-west monsoon, high proportion of population depending on agriculture and excessive pressure on natural resources make rainfed areas most vulnerable, thus impacting agricultural production and the economy in terms of agricultural output and farmers' income.

Climate resilient agriculture

Climate resilient agriculture (CRA) essentially involves judicious and improved management of natural resources (land, water, soil and genetic resources) through adoption of best bet practices (NAAS, 2013). Adaptation could be the immediate approach to bring resilience to the climate change/variability impacts in agriculture. Adaptation refers to adjustments in ecological, social or economic systems in response to actual or expected stimuli and their effects or impacts. This term refers to change in process, practices and structures to moderate potential damages or to benefit from opportunities associated with climate change (IPCC, 2001). Depending on its timing, goal and motive of its implementation, adaptation can either be reactive or anticipatory, private or public, planned or autonomous. Adaptation can also be short or long term and localized or widespread. The proactive adaptation measures include real-time contingency plan implementation, crop diversification etc., and reactive or *ex-poste* adaptations include agroforestry and multi-enterprise agriculture.

Adaptation strategies to climate resilient agriculture in rainfed areas

Real-Time Contingency Planning (RTCP): To address the frequent weather aberrations around the year and to improve the efficiency and profitability of the rainfed production systems RTCP was conceptualized in All India Coordinated Research Project for Dryland Agriculture (AICRPDA) and is considered as "any contingency measure, either technology related (land, soil, water, crop) or institutional and policy based, which is implemented based on real time weather pattern (including extreme events) in any crop growing season". Since 2011, under National Innovations in Climate Resilient Agriculture (NICRA), 23 AICRPDA centres have been implementing RTCP in 32 villages in 17 states through innovative village institutions like Village Climate Risk Management Committee, Farm Implements/Machinery Custom Hiring Centre etc. The impact study of RTCP measures indicated that introduction of short duration drought tolerant cultivars during delayed onset of monsoon gave about 15-35% higher yields compared to local/farmers' varieties; during early season drought, *in-situ* moisture conservation and mulching helped in adaptation of crops and realizing improved yields by 16-31% compared to no contingency measures; foliar sprays of thiourea and KNO_3 for mitigating midseason drought/dry spells gave 10-20% higher yield in different crops compared to no spray and the terminal drought was mitigated mostly by providing supplemental irrigation from harvested rainwater in ponds, and foliar sprays of nutrients wherein the supplemental irrigation improved yields by 25% in cotton, 40% in groundnut and 55% in soybean while foliar application of water soluble NPKS complex fertilizer (18:18:18:6) @ 0.5% + $ZnSO_4$ @ 0.5% increased maize grain yield (2961 kg ha^{-1}) by 36% compared to water spray (2192 kg ha^{-1}) (AICRPDA-NICRA Annual Reports. 2013-14 to 2017-18).

Crop diversification: Agroecology-specific crop diversification could be an adaptation strategy in rainfed areas. The cropping intensity could be increased considerably depending on the soil types and moisture availability period. However, the duration of the crop cultivars influenced the selection of a cropping system. Hence, in high rainfall (>1000 mm) regions of Orissa, Eastern Uttar Pradesh and Madhya Pradesh, a second crop could be grown in the residual moisture after a 90 days' duration variety of upland rice than 120 days' duration. Similarly, in the Vertisols of Malwa (Madhya Pradesh) and Vidarbha (Maharashtra), a change of 140 or 150 days' duration sorghum cultivars to about 90 or 100 days' duration cultivars provided an opportunity to grow chickpea or safflower in sequence. Double cropping was possible only in areas receiving more than 750 mm rainfall with a soil moisture storage capacity of more than 200 mm (Chary *et al.,* 2012). The assured supplemental irrigation from harvested rainwater enabled to increase cropping intensity and crop diversification, for example with 'soybean - sweetcorn/vegetables/chickpea' in semiarid Vertisols of Malwa zone of Madhya Pradesh.

Agroforestry systems: As a method of adapting agriculture to climate change, agroforestry systems have been shown to increase on-farm production resilience to climate variability by buffering crops from the effects of temperature and precipitation variation as well as strong winds associated with storms. *Amla* + finger millet in alfisols of southern Karnataka, tamarind + guinea grass in Vertisols of northern Karnataka, neem + *Acacia nilotica* + *Cenchrus ciliaris* + stylo in Vertisols of central Maharashtra, guava + blackgram in northern Saurashtra (Gujarat) are some of the proven dryland agri-horticulture systems for wider upscaling.

References

AICRPDA-NICRA. 2013-14 to 2017-18 Annual Reports. Managing Weather aberrations through Real-time contingency planning. AICRPDA, ICAR-CRIDA, Hyderabad, India.

Chary, G.R., B. Venkateswarlu, S.K. Sharma, J.S. Mishra, D.S. Rana, and Ganesh Kute. 2012. Agronomic research in dryland farming in India: An overview. *Indian Journal of Agronomy* 57 (3rd IAC special issue): 157-167.

Economics of Climate Adaptation (ECA). 2009. Shaping Climate-Resilient Development: A Framework for Decision-making. A Report of the Economics of Climate Adaptation Working Group. Climate Works Foundation, Global Environment Facility, European Commission, McKinsey & Company, The Rockefeller Foundation, Standard Chartered Bank and Swiss Re. 164 pp.

IPCC. 2001. Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, USA.

Kumar, K. 2009. Impact of climate change on India's monsoon climate and development of high resolution climate change scenarios for India (http:moef.nic.in).

NAAS. 2013. Climate Resilient Agriculture in India. Policy Paper No. 65, National Academy of Agricultural Sciences, New Delhi. 20 pp.

Resilience to changing climate in dryland agriculture: Experiences from India

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Extended Summary

Drylands are home to more than 38% of the world's population i.e. about 2.5 billion people (Mortimore, 2009; Huang *et al*., 2016), and 90% of these people live in developing countries (GLP, 2005; Armah *et al*., 2010). The global area of dryland is increasing rapidly. According to projections of 20 global climate models, global dryland area may increase by 11% and 23% by the end of the 21st century under a moderate and high-end scenario of climate change, RCP4.5 and RCP8.5 scenario, respectively, relative to the reference period of 1961-1990. As a result, drylands will cover the global land surface by 50-56% in 2100. Under the high-end scenario of climate change, 78% of dryland expansion may occur in developing countries. The increasing aridity, enhanced warming and rapidly growing human population will exacerbate the risk of land degradation and desertification in these countries in the near future (Huang *et al*., 2016).

Low fertility of dryland soils makes them extremely sensitive to degradation induced by climate warming and human activities (Maestre *et al*., 2013; Li *et al*., 2016; Zhou *et al*., 2016). Just as shifts in vegetation belts are expected in non-drylands, in the drylands of Asia a shift in dryland types is expected as a result of climate change. Because soil moisture is likely to decline in this region, the least-dry type land (dry sub-humid drylands) is expected to become semi-arid, and semi-arid land is expected to become arid. Therefore, semi-arid drylands, which are intermediate in aridity as compared to arid drylands and dry sub-humid ones, are most susceptible to becoming further desertified (Safriel, 1995). Because the semi-arid drylands are very common among Asian drylands, large areas will become not only dry but also desertified as a result of climate change.

While climate change impacts agriculture sector in general, dryland agriculture in India is likely to be more vulnerable in view of its high dependence on monsoon and the likelihood of increased extreme weather events due to aberrant behaviour of south-west (SW) monsoon. About 74% of annual rainfall occurs during SW monsoon (June-September). This rainfall exhibits high coefficient of variation, particularly in arid and dry semi-arid regions. Skewed distribution has now become more common with reduction in numbers of rainy days. Aberrations in SW monsoon, which include delay in onset, long dry spells and early withdrawal, all of which affect the crops, strongly influence the productivity levels. These aberrations are likely to further increase in future.

Strategies for climate resilient dryland agriculture

The Climate Resilient Agriculture (CRA), encompassing adaptation and mitigation strategies and the effective use of biodiversity at all levels - genes, species and ecosystems, is an essential pre-requisite for sustainable development in the face of changing climate. Improved water storage through *in-situ* moisture conservation and stored runoff are basic for bringing resilience to drought or moisture stress conditions often encountered by the dryland crops. Other strategies for bringing resilience are through soil management, resilient intercropping systems, drought tolerant short duration cultivars, use of suitable farm implements for small holdings, fodder systems, integrated farming systems etc.

Rainwater management: Rainwater management is central issue for bringing any kind of resilience in dryland farming (Table 1). Utilizing every drop of rainwater becomes crucial under overall efficient rainwater management. Storing rainwater in soil by various location specific water conservation measures is first priority and excess runoff collection in farm ponds and its recycling at critical crop stages is the second important strategy (Srinivasarao *et al*., 2016).

Table 1. Recommended soil and water conservation measures for various rainfall zones of India

Seasonal rainfall			
< 500 mm	500-700 mm	750-1000 mm	> 1000 mm
Contour cultivation with conservation furrows	Contour cultivation with conservation furrows	BBF (on Vertisols) conservation furrows	BBF (on Vertisols)
Ridging	Ridging	Sowing across slopes	Field bunds
Sowing across slopes	Sowing across slopes	Tillage	Vegetative bunds
Mulching	Scoops	Lock and spill drains	Graded bunds
Scoops	Tied ridges	Small basins	Level terrace
Tied ridges	Mulching	Field bunds	
Off-season tillage	Zing terrace	Vegetative bunds	
Inter-row water harvesting systems	Off-season tillage	Graded bunds	
Small basins	Broad-Bed-Furrow (BBF)	*Nadi*	
Contour bunds	Inter-row water harvesting system	Zing terrace	
Field bunds	Small basins		
Khadin	Modified contour bunds		
	Field bunds		

Building resilience with better soil management: Soils hold the key to productivity and resilience to climate vagaries including drought in dryland agriculture. Improved soil organic matter storage in soil profile retains more water and provides drought proofing in dryland agriculture during long gaps between two rains. Based on 16 long-term manurial experiments under rainfed conditions in All India Coordinated Research Project for Dryland Agriculture (AICRPDA) network, it was showed that each ton of soil organic carbon improved rainfed crops' productivity by upto 0.15 t ha^{-1} $year^{-1}$. Location specific integrated nutrient management (INM) practices were identified and are being promoted based on locally available organic resources. Balanced nutrition, particularly optimum potassium nutrition, also contributes to mitigation of water stress conditions as potassium controls water relations in plant growth. On-farm generation of organic matter with appropriate policy support needs to be promoted for maintaining soil health and crop productivity (Srinivasarao *et al*., 2014).

***Resilient crops and cropping systems*:** Crop-based approaches for drought mitigation include growing crops and varieties that suit the conditions of changed rainfall and seasons. In addition, adoption of intercropping systems, crop diversification, improved agronomic practices, and agroforestry systems helps to cope with any adverse event, and in particular rainfall variability and drought. With the available dryland technologies like rainwater management, choice of crops, short duration varieties, and other agronomic practices, a greater portion of rainfed areas can be put under intensive cropping systems including relay cropping and double cropping. Double cropping is also possible with rainwater harvested in farm ponds, which is used for establishing winter crop (Srinivasarao and Gopinath, 2016).

Contingency crop planning: Contingency crop planning is essentially aimed at stabilization of crop output in the situation of late onset of monsoon, and mid season and terminal droughts. The 23 centres of All India Coordinated Research Project for Dryland Agriculture (AICRPDA) under National Innovations in Climate Resilient Agriculture (NICRA) project adopted 34 villages in 15 states to demonstrate real-time contingency measures with two pronged approach i.e. drought preparedness and real-time implementation of land, water, crop, soil, nutrient and energy (farm implements) management practices to cope with weather aberrations. During 2011 to 2016, under the conditions of delayed onset of monsoon, varieties of major rainfed crops were assessed for their suitability and best performing ones were identified. On an average, these varieties gave about 15-35% higher yields compared to local/farmers' varieties. Early season drought conditions were addressed through *in situ* moisture conservation and mulching, which helped in adaptation of crops and realizing improved yields by 16-31% compared to no contingency measures. RTCP measures of foliar sprays of thiourea and KNO_3 in mitigating midseason drought/dry spells gave 10-20% higher yield in different crops compared to no spray. The effect of terminal drought on different crops was mitigated mostly by providing supplemental irrigation from harvested rainwater in ponds, and foliar sprays. Supplemental irrigation improved yields by 25% in cotton, 40% in groundnut and 55% in soybean at different locations. Similarly, foliar spray of 1% KCl in rice during dry spell at flowering-milking stage increased yield by 25% compared to no spray (Chary *et al*., 2017).

Weather based agro-advisories: Location-specific weather based agro meteorological advisory services (AAS) were found to help in cultivar selection based on seasonal rainfall forecast, choosing windows for sowing/harvesting operations, mitigation from adverse weather events, nutrient management, fertilizer application, and feed, health and shelter management for livestock (optimal temperature for dairy/hatchery). There is an increased role of weather based AAS in farming activities for access to real time weather information, timely agricultural operations, improved crop yields, reduced cost of cultivation, need-based changes in cropping patterns and finally improved livelihoods (Srinivasarao *et al*., 2016).

Institutional interventions: Institutional interventions, either by strengthening the existing ones or initiating new ones relating to seed bank, fodder bank, commodity groups, custom hiring centre, collective marketing, introduction of weather index based crop insurance and climate literacy through a village level weather station, ensure effective adoption of all other interventions and promote community ownership of the entire programme. Under National Innovations in Climate Resilient Agriculture (NICRA) project in India, in each of the 151 village clusters, a Village Climate Risk Management Committee (VCRMC) was formed to effectively co-ordinate with farmer groups on climate variability/ change related issues. A weather station and custom-hiring center were also established in each village to promote weather literacy and enable farmers in timely completion of farm operations during delayed onset of monsoon.

Conclusion

The increasing aridity, enhanced warming and rapidly growing human population will aggravate the risk of land degradation and desertification in the near future in the drylands of developing countries. There are a number of options in soil, water and nutrient management technologies that contribute to both adaptation and mitigation including *in situ* moisture conservation, rainwater harvesting and efficient utilization, integrated nutrient management modules, resilient crops and cropping systems. Further, ongoing studies under NICRA and other network projects in the country will provide insight into how climate change impacts dryland agriculture in the future, and ways and means to develop strategies for location-specific sustainable development of drylands in India.

References

Armah, F.A., G.T. Yengoh, S. Obiri, D.O. Yawson and E.K.A. Afrifa. 2010. Food security and climate change in drought-sensitive savanna zones of Ghana. *Mitigation and Adaptation Strategies for Global Change* 16(3): 291-306.

Chary, R.G., K.A. Gopinath, B. Narsimlu, D. Anantha Rao and A. Rasul. 2017. Real time contingency planning to cope with climate variability - Experiences from AICRPDA. Pages 15-16 *in* Abstracts, International Seminar on Global Climate Change: Implications for Agriculture and Water Sectors, 14-16 December, 2017, Aurangabad, Maharashtra.

GLP 2005. Global Land Project—Science Plan and Implementation Strategy, IGBP (International Geosphere Biosphere Program) Report no. 53/International human dimensions programme report no. 19, IGBP secretariat, Stockholm.

Huang, J., H. Yu, X. Guan, G. Wang and R. Guo. 2016. Accelerated dryland expansion under climate change. *Nature Climate Change* 6(2): 166-171.

Li, J., Z. Liu, C. He, W. Tu and Z. Sun. 2016. Are the drylands in northern China sustainable? A perspective from ecological footprint dynamics from 1990 to 2010. *Science of the Total Environment* 553: 223-231.

Maestre, F.T., C. Escolar, M. Ladrón de Guevara, J.L. Quero R. Lázaro, M. Delgado-Baquerizo, V. Ochoa, M. Berdugo, B. Gozalo and A. Gallardo. 2013. Changes in biocrust cover drive carbon cycle responses to climate change in drylands. *Global Change Biology* 19(12): 3835-3847.

Mortimore, M. 2009. Dryland opportunities, IUCN, Gland, Switzerland, HED, London, UK and UNDP, New York, USA.

Safriel, U. 1995. The evolution of Palearctic migration—the case for southern ancestry. *Israel Journal of Zoology* 41(3): 417-431.

Srinivasarao, Ch. and K.A. Gopinath. 2016. Resilient rainfed technologies for drought mitigation and sustainable food security. *Mausam* 67(1): 169-182.

Srinivasarao, Ch., K.A. Gopinath, Y.G. Prasad, A.K. Sikka, and R. Singh. 2016. Climate resilient rainfed agriculture - Status and strategies. *Indian Farming* 66(2): 2-6.

Srinivasarao, Ch., Rattan Lal, Sumanta Kundu, M.B.B. Prasad Babu, B. Venkateswarlu and A.K. Singh. 2014. Soil carbon sequestration in rainfed production systems in the semiarid tropics of India. *Science of the Total Environment* 487: 587-603.

Zhou, L., H. Chen, W. Hua, Y. Dai and N. Wei. 2016. Mechanisms for stronger warming over drier ecoregions observed since 1979. *Climate Dynamics* 47(9): 2955-2974.

Theme 2: Managing Land Degradation and Desertification

Lead Lectures and Rapid Presentations

A crop-livestock-bioenergy system for rural farmers in South Africa

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Abstract

The study aimed at introducing biogas technology as an alternative energy source to the rural farmers in the Maluti-a-Phofung Municipality, Free State, South Africa. To enhance adoption of the technology by the rural farming community, the first step was to undertake a situational analysis, followed by awareness and training, then installation of the biodigester units and lastly, monitoring of their functionality. The results showed that only five out of the twelve households kept their farm animals in kraals, making it difficult to collect fresh manure. Water availability was not a constraint on any of the farms. Ten out of the twelve households were found to be suitable for the study. Farmers were trained on biodigester principles, and feeding and maintenance of biodigester units. Pre-fabricated 6 m^3 biodigester units were installed in all the households. After continuous feeding, production of biogas increased and six out of the ten households recorded that 80% of their cooking needs were achieved in summer while in winter biogas production was minimal. Challenges faced included non-adherence to feeding regime resulting in biodigester blockage, and lack of feeding. Overall, there was high appreciation of biodigester technology in the study area as echoed by beneficiaries of the project.

Introduction

Agriculture in developing countries needs to undergo a significant transformation in order to meet the related challenges of food security and climate change (FAO, 2010) and as basis of a green economy, which is the driver of economic development in rural areas. To address food security, environmental integrity, ecosystem services and the effects of climate change and variability simultaneously and effectively, climate-smart agriculture is called for which is described as agriculture that sustainably increase productivity and resilience (adaptation), reduces greenhouse gas emissions and strengthens national food security FAO (2010).

Biogas technology is one of the renewable energy opportunities that are well accepted worldwide (APCAEM, 2007). Biogas is produced when organic matter (e.g. abattoir waste, animal manure, kitchen waste, agricultural residues) is decomposed in an anaerobic environment by a chain of micro-organisms (Warget, 2009). The attributes of the biogas technology go beyond the production of gas with added benefits like conversion of organic waste to high-quality fertilizer and sanitation improvements (APCAEM, 2007; Bensah and Brew-Ammond, 2010).

In this study, an integrated crop-livestock-bioenergy system was introduced to a farming community in the Maluti-a-Phofung Municipality, Free State Province, South Africa, in order to improve the livelihoods of rural households in an environmentally sustainable manner. In this initiative (Fig. 1), crop production was supported by the use of climate information and conservation agricultural practices. Mixed cropping of maize, leguminous crops and hay was promoted. The crop residues of maize and leguminous crop were used to feed the animals and some of the residues acted as a mulch for the next cropping season. Manure from livestock were utilised as input to the bio digester to produce bio gas that was used for cooking. The other bi-product of bio gas generation is bio slurry that was applied to the fields as fertilizer. The study therefore aimed at augmenting the rural farming community's adoption of the system by combining biogas generation with conservation agriculture and mixed farming.

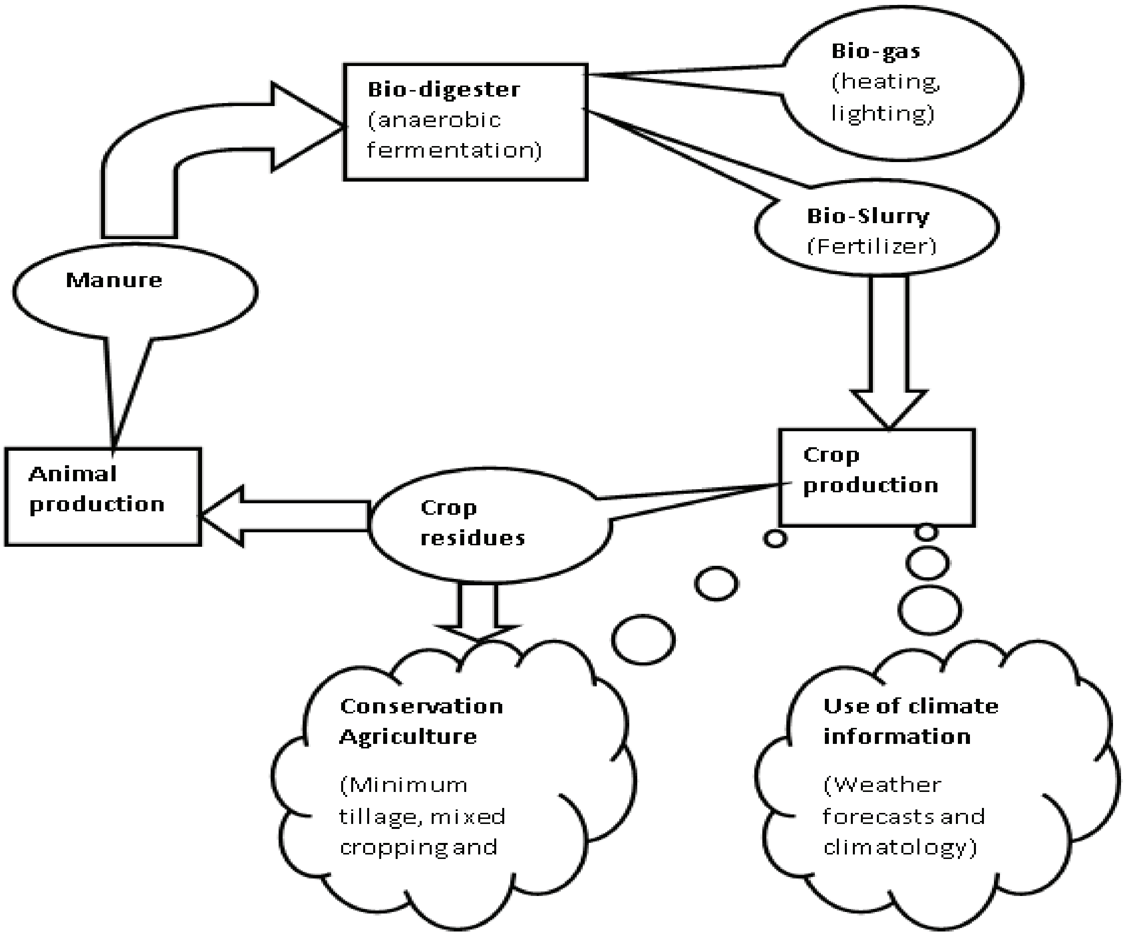

Figure 1. *Integrated crop-livestock-bioenergy system in the Maluti-a-Phofung Municipality, Free State, South Africa.*

Materials and methods

The study was undertaken through four stages: situational analysis, consultation and training, implementation, and monitoring and evaluation.

Situational analysis

Before introducing a biogas project into the farming community, it is imperative to conduct a diagnostic survey in the study area, since an inadequate understanding of the community dynamics could lead to inappropriate interventions, which could lead to resource wastage (Owusu, 2008). Situational analysis was undertaken in and around the farms of the Maluti-a-Phofung Municipality during the study (August to October 2012).

Consultation and training

A number of capacity-building exercises took place during the study's life cycle (September 2012 to June 2015). Table 1 shows a number of capacity-building initiatives that were accomplished by the project implementers from Agricultural Research Council.

Table 1. *Training and capacity-building initiatives for the integrated crop-livestock-bioenergy project in the Free State, South Africa*

Title	Target group
Introduction to bioenergy and climate change	Farmers
Introduction to conservation agriculture principles	Farmers
Introduction to use of climate information for agriculture	Farmers
Rainfall measurement and recording	Farmers
Biodigester installation training	Farmers and youths
Maintenance of biodigesters	Farmers and youths

Implementation

Two types of digesters were considered: pre-fabricated and brick and mortar on site constructed ones. The factors considered during selection of the biogas digester type are shown in Table 2.

Table 2. *Factors considered when determining the type of digester*

Selection parameter	Floating tank biogas digester (Brick and Mortar)	Pre-fabricated fixed dome digester
Daily biogas production	Dependant on size	0.5 - 2 m^3 day^{-1}
Material requirements	High: bricks, cement, sand, stone, plaster, paint, reinforcing steel, steel drum, plumbing fixtures and gas pipes	Low: cement, sand, plumbing fixtures and gas pipes
Quality guarantee	Low: dependant on the skill levels of available labour and is variable. High chance of gas leakage due to poor workmanship	High: factory manufactured LPG biogas tank with quality control measures in place
Cost	Dependant on size: approximately R60 000 for a 6 m^3 plant	Dependant on size: approximately R35 000 for a 6 m^3 plant
Time to construct	21 days	4 days
Labour required	2 skilled bricklayers, 1 plumber, 3 general labourers	1 plumber, 3 general labourers
Supervision requirements	High	Low
Maintenance	High: painting of steel drum to prevent rusting	Medium: clean out of digester chamber

Two types of pre-fabricated digesters developed by South African companies were used. The digesters had different sizes, one was a 3 m^3 unit and the other a 6 m^3. The biogas digester installation was done with the following process: site selection; proper demarcation of the pit size; excavation; bedding; tank placing; gas pipe installation and fitting; valve and desulfurizing unit fitting; leaks identification and cooking equipment fitting.

With regard to crop and livestock farming, simple rain gauge was installed at all the farm sites. Weather forecasts were also disseminated to the farmers throughout the growing season. During pre-season, seasonal forecast information and recommendations of the upcoming season were distributed to the farmers through annual farmer forums. The farmers were introduced conservation agriculture techniques through on-farm trials. The project was more focused in the reduced tillage principle of conservation agriculture in a maize-bean cropping system; two-row no-till planter was used for the demonstration of the no-till planting. Maize stover was used to feed cattle in the farms.

Monitoring and evaluation

Monitoring and evaluation in this study was undertaken in two ways. Firstly, project implementers monitored the performance of system through unarranged household visits. Secondly, end-user questionnaires were used.

Results

To determine the biogas digester volume at each of the farms, energy demand questionnaire was undertaken at the inception of the project. This was done in parallel with the diagnostic survey. Most of the households had between 5 and 9 family members. Based on the research on available resources like the feedstock, water, labour concerns and biogas need per household it was decided to choose the pre-fabricated tank biogas digester technology. The farmers interviewed were a mixture of subsistence and emerging small-scale farmers. The farm sizes ranged from 146 to 462 hectares with less than a quarter of total area dedicated to crop farming. All households keep cattle as the main livestock with herd size between 15 and 115.

The household energy analysis focused on determining the household energy needs, energy use prioritization and investigating the type and cost of the energy that is currently in use. This helped identify energy uses that can be replaced by biogas and to assess ease of adoption of the new technology. From the results, household energy demand can be divided into two groups, namely domestic needs and farming activities. For domestic purposes energy is mainly used for cooking, lighting, water heating, space heating and to a lesser extent cooling, 3 out of the 9 households have gas refrigerators. Cooking was cited as the main energy need followed by lighting, both of which are used throughout the year. Cooking is mostly done using firewood (48%) followed by LPG gas (31%) and lastly cow dung (21%). In all the farms, energy for refrigerators and lighting was entirely on LPG gas and candles respectively.

Both beef and dairy cattle are kept; however dairy cattle are most common. Suitable digester feedstock was any organic material such as animal dung, human waste and plant material. For the project, cattle dung was used as feedstock. With this number of cattle, amount of dung produced was enough to feed 6-12 m_3 digester. All households have access to clean water throughout the year.

The number of biodigester units (Fig. 2) installed at a homestead was based on two factors: the size of the family, which has a direct bearing on the total household biogas demand, and the minimum amount of biogas that can be generated daily by a single 3 m_3 biodigester, which is 0.5 m_3 per day. A 6 m_3 biodigester unit can produce around 1 m_3 of biogas a day. All the homestead chosen for this study had enough cow dung and water available to feed the biodigesters daily.

Figure 2. *Biodigester installed at one of the sites in Free State, South Africa*

Rainfall forecasting in agriculture is essential to assist the farmers in their planning activities. The skills score tests of the forecast confirmed that the forecasted precipitation events coincided with the observed events. This shows confidence in the forecast information that the project had been sending to the farmers. Farmers stated that the forecast information was crucial in their agricultural operations.

Land preparation for the implementation of conservation agriculture was mostly carried out successfully in all the years with few challenges. It is expected that the outputs of the project will go a long way in filling in some of the knowledge gaps that exist in the mitigation and adaptation to climate change in South Africa.

The results of the individual questionnaire showed that majority of the farmers (9 out of 12) were satisfied with the installed biogas digesters units in the farms, while 3 were not content with the technology. Seemingly, in all the three households, which were not satisfied with the technology, the project team realized that their biogas digesters were not functioning well because of negligence and high blockage of the plants. In addition, 5 out of the 12 were not satisfied with the biogas digesters' technical aspect due to high blockage.

Conclusions

The project managed to achieve its principal objective of promoting the adoption of biogas digesters among rural farmers in Thabo Mofutsanyana District, Free State Province. To determine the biogas digester volume at each of the farms, energy demand questionnaire was undertaken at the inception of the project. This was done in parallel with the diagnostic survey. Most of the households had family members of between 5 and 9. Based on the research on available resources like the feedstock, water availability, labour concerns and biogas need per household, it was decided to choose the pre-fabricated tank biogas digester technology.

References

APCAEM. 2007. Recent Developments in Biogas Technology for Poverty reduction and sustainable development. United Nations Economic and Social Commission for Asia and the Pacific (ESCAP). Available at (last viewed 18/07/2015) http://www.un-csam.org/publication/F-Biogas.PDF

Bensah, E.C. and A. Brew-Hammond. 2010. Biogas technology dissemination in Ghana: History, current status, future prospects, and policy significance. *International Journal of Energy and Environment* 1(2): 277-294.

FAO. 2010. An international consultation on integrated crop-livestock systems for development: The way forward for sustainable production intensification. FAO, Rome.

Owusu, G. 2008. Social effects of poor sanitation and waste management on poor urban communities: a neighborhood-specific study of Sabon Zongo Accra. *Journal of Urbanism* 3(20): 145-160.

Warget, D. 2009. Biogas in developing rural areas, LTH, Lund University. Available at (last viewed 31/07/2015) http://www.davidwargert.net/docs/Biogas.pdf

Measuring land degradation: A quantitative approach for better understanding of the problem in Thar Desert

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Abstract

Quantitative assessment of the biophysical and socio-economic variables of land degradation through a Driving force (D) - Pressure (P) - State (S) - Impact (I) - Response (R) model that can be implemented in a GIS environment, has been found to provide the best unbiased assessment of factors leading to desertification. We successfully tested the D-P-S-I-R model in a small sand-dominated area in the eastern Thar, where we found too much pressure on croplands causing land degradation than an open grazing system. Unfortunately, upscaling of the procedure for regional-scale assessment and mapping became risky due to the problems in correctly estimating the sand-reactivated areas in a complex terrain, using the satellite-derived Colour Brightness Index (CBI). We, therefore, developed an Aeolian Sand Reactivation Index from MODIS surface reflectance and emissivity data (ASRI_bbe), which was found to perform very well on many different types of landforms. Analysis of the spatio-temporal changes in ASRI_bbe for the years 2000 to 2015 revealed distinct changes in the seasonal pattern of sand reactivation related to global warming. The study also filtered out the areas of persistent increase in sand reactivation due to cultivation pressure.

Introduction

The concept and focus of land degradation has changed vastly since the first UN Conference on Desertification (1977) when the term was used to mean diminution of the biological potential of land in any ecosystem (Anon., 1977). The 1992 UN Conference on Environment and Development (UNCED) negotiated a more acceptable definition as 'land degradation in arid, semi-arid, and dry sub-humid areas, resulting from various factors, including climatic variation as well as human activities' (Anon., 1992), which was accepted by the UN Convention to Combat Desertification (UNCCD) for all practical purposes, but with the inclusion of some typical non-dryland areas in the developing countries that are subject to high land degradation, lack enough skill and resources to control it, and need international assistance through UNCCD (Anon., 1995).

Conventionally, desertification is assessed and mapped through visual interpretation of land features for different kinds of land degradation, especially from satellite imagery in hard copy or digital format, but the reliability of the method is often questioned. Dregne (1983) and FAO (1984) described some of the most useful early methodologies for quantification of field indicators to assess several bio-physical indicators of degradation, like wind and water erosion, salinization, vegetation degradation, as well as some socio-economic factors. The identified sites for quantification were considered as 'benchmark' locations for repeated monitoring. Kharin *et al.* (1985) and Babaev *et al.* (1993) emphasized on the importance of technogenic factors in desertification. While most of the biophysical variables are amenable to direct measurement, analysis of the socio-economic variables is largely based on informed opinions, and hence more subjective in nature (Kar and Takeuchi, 2003).

With time, there is a gradual shift towards developing and adopting unbiased quantitative measurement techniques to get spatially more reliable datasets without relying much on the very sparsely located individual observation sites. Towards this end a conceptual model of Driving force - Pressure– State - Impact– Response (D-P-S-I-R) was developed in the 1970s for the African situation (Anon., 1979), and was found useful for assessing the land degradation problems in the drylands of Europe (Enne and Zucca, 2000). Several variants of the D-P-S-I-R model have since been successfully implemented in GIS (Kar and Takeuchi, 2003; Kar, 2018). Digital techniques for satellite image interpretation have now almost totally replaced the need for 'benchmark' field sites, because the pixels in an image can serve as a benchmark location. Proper interpretation of the changes in a pixel's radiance values over time and space in different wavelength bands provides an unbiased assessment of the degradation or otherwise of the land surface condition (Kar, 2018). Grunblatt *et al.* (1992) showed a novel way of using such quantified information in a Geographic Information System (GIS) framework. A selection of the case studies, and the indicators on which the quantifications are based, is provided in the two successive editions of the World Atlas of Desertification (Middleton and Thomas, 1997; Cherlet *et al.,* 2018). In fact, digital remote sensing and GIS are now fast replacing the rigorous field methods for assessing the status of several biophysical indicators (Claessens *et al.,* 2009; Anon., 2009; Nachtergaele *et al*., 2010; Santini *et al.,* 2010).

There is now a growing feeling among researchers that proper implementation of the D-P-S-I-R model and making the land users active participants in remedial processes may ultimately show the pathways to 'land degradation neutrality'. The Global LAnd Degradation Information System (GLADIS, hosted in FAO website), which explores the links between population pressure, poverty, land degradation, etc., through derivation of indices on ecosystem service status, land degradation parameters, biophysical degradation and land degradation impact, is so far the best small-scale example of the new approach, but is currently too coarse for any policy strategy at local to regional levels.

First implementation of a D-P-S-I-R model in Thar Desert

Thar Desert is located between the denuded Aravalli hill ranges in India and the Indus River in Pakistan, where the mean annual rainfall varies from 500 mm in the east to ~100 mm in the west (Fig. 1). It is largely a sand-dominated desert, where wind erosion during the hot summer months is a major environmental problem. To test the performance of the D-P-S-I-R model in assessment and monitoring of wind erosion, we carried out a study in a cluster of villages in the sandy terrain between Jodhpur and Churu in the eastern part of the Desert (Kar, 2011). The study involved analysis of the following variables in contiguous village polygons of the region: human and livestock population densities (as driving forces, D), quantification of cultivation and grazing pressures (P), digital analysis of the ortho-rectified, and geo-referenced and atmosphere-corrected Landsat data for January, 1971 and January 2001, as a measure of sand reactivation (a state variable, S). Signatures of sand reactivation were analysed from Landsat-derived Soil Brightness Index (SBI), Principal Component Analysis (PCI) and Colour Brightness Index (CBI), and were evaluated with results from a supervised classification (maximum likelihood).

SBI values were calculated using the following formulae (Kauth and Thomas, 1976, for MSS; Huang *et al.*, 2001, for ETM+):

SBI (MSS) = 0.406(MSS4) + 0.600(MSS5) + 0.645(MSS6) + 0.243(MSS7);

SBI (ETM) = 0.356(ETM1) + 0.397(ETM2) + 0.390(ETM3) + 0.697(ETM4) + 0.229(ETM5) + 0.160(ETM7),

Where MSS4 to MSS7 are Landsat-1 Multispectral Scanner wavelength band numbers (path 159, row 041 for 09 January 1973; 70 m pixel resolution, re-sampled to 57 m resolution), while ETM1 to ETM7 are Landsat-7 Enhanced Thematic Mapper wavelength band numbers (path 148, row 041 for 22 January 2001; 30 m pixel resolution). To convert the SBI values into sand reactivation categories, the Digital Number ranges of some known sand-reactivated areas were measured from the images, and their corresponding SBI values were found out for calibration. PCI was calculated using the procedures in ERDAS (1997). CBI values for both MSS and ETM data were calculated using Mathieu *et al.* (1998) formulae:

CBI = SQRT ((B^2 + G^2 + R^2)/3)

where B is blue wavelength band (MSS4; ETM1), G is green band (MSS5; ETM2), and R is red band (MSS6; ETM3).

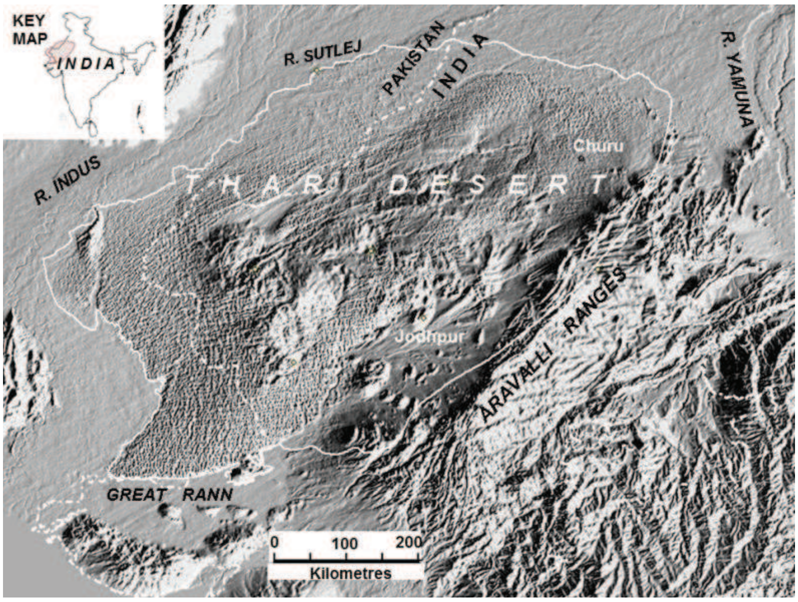

Figure 1. *The Thar Desert.*

We found that the CBI values represented the field patterns of sand reactivation very well, but the signatures got overlapped in the areas of river sand and gypsiferous soil. Therefore, we masked the aeolian sand reactivated areas using results from the Supervised Classification (Kar, 2011).

Cultivation pressure was measured through intensity of cropland use between 1970-71 and 2000-01. Grazing pressure was calculated from optimum carrying capacity of grazing lands in the area vis-a-vis adult cattle units. Using village as a mapping unit for driving force and pressure variables, and CBI pixel for state variable, we carried out a spatio-temporal analysis under GIS, which revealed good agreement between the moderate and high cultivation pressures with moderate and high sand reactivation, but the agreement was poor for grazing pressure despite the poor condition of grazing lands. We also found good spatial agreement between sand reactivation and groundwater irrigation, via land levelling and deep ploughing, which possibly impacted the atmospheric dust load over time. Multi-criteria evaluation of the D, P and S variables using Ordered Weighted Average technique and fuzzy set membership function revealed that 3% area had severe risk of desertification, 20% moderate and 62% slight. Analysis of sequential *rabi* season AVHRR-NDVI images for 1983-2001 showed how greenness and land productivity shifted from E to W with groundwater irrigation, and hinted that the sandy landscape here needed 2-3 decades to stabilize after irrigation had started. We argued that continuation of high cultivation pressure and depletion of aquifers due to overuse of water for irrigation would result in a return to the state of high sand reactivation (Kar, 2011).

A new digital method for assessing aeolian sand reactivation

Although the D-P-S-I-R exercise provided a broad framework for local-scale assessment, its successful implementation at regional level depended on error-free sand reactivation mapping over diverse terrain of the desert. In our previous study in Churu district, Rajasthan, India we had noticed that the CBI worked very well on the exclusively aeolian sand-dominated landscape, but in a complex terrain it failed to discriminate the aeolian sand-reactivated areas from other bright surfaces like riverine sand, silica-rich rocky or gravel-dominated surfaces, dry gypsiferous surfaces, etc. This put severe restriction on the use of CBI for assessing sand reactivation, which is the most important S factor in Thar Desert. To overcome the limitation we, therefore, experimented with several other complimentary methods to fortify the CBI output.

For the new exercise we decided to use long and continuous data strings on surface reflectance to calculate sand reactivation in the whole of Thar Desert during a season and to attempt understanding of the yearly changes in such data strings. The desired data was available from the Moderate-resolution Imaging Spectroradiometer aboard the Terra satellite (MODIS Terra). Instead of using the daily data, however, we opted for the 8-day summaries of the surface reflectance in different wavelength bands, available at 500 m pixel resolution. We accessed the NASA/USGS repository for the basic data from early-March to mid-June during the years 2000 to 2015. Thus, the proposed analysis involved surface reflectance data for thirteen 8-day periods over sixteen years.

Calculation procedure

We first calculated CBI for each of the 8-day periods, using Mathieu *et al.* (1998):

$$CBI = SQRT((Bm^2 + Gm^2 + Rm^2)/3),$$

where Bm is MODIS blue band (band-3), Gm is MODIS green band (band-4) and Rm is MODIS red band (band-1). The wavelength range in all the above bands is narrower than in the Landsat bands.

Since CBI values failed to represent well the aeolian sand reactivation areas, we used a 'top-soil grain size index' (GSI) that was developed by Xiao *et al.* (2006):

GSI = (Rm-Bm) / (Rm+Bm+Gm).

GSI values increased in the quartz-rich fine sand (i.e., mainly aeolian sand), but declined with the increase in the silt and clay contents in the surface sediments. Areas rich in coarse sand and gravels and the rocky surfaces also had lower GSI values. Thus GSI could discriminate the aeolian fine sand from other surfaces.

We multiplied the CBI values with the GSI values to produce a Sediment Type and Brightness Index (STBI). Since CBI values were in four digits and GSI in single digit, we normalised the two datasets before multiplication. STBI could discriminate aeolian sand reactivated areas over a large part of the desert. The major exceptions were found in the large megabarchan fields to the southwest of Jaisalmer and in other mobile dune areas in the west where silt and clay content in the surface soils is high due to the very high contributions from the Indus-Sutlej alluvium.

To overcome the limitations of STBI we used the GLASS broadband emissivity (GLASS_bbe) data at 1 km pixel resolution that was derived from the MODIS albedo products (Ren *et al.,* 2013). Typically the emissivity of a loose sandy surface is much lower than a water body or a well vegetated surface. Emissivity values of other natural surface lie in between the values for loose sand and the water body. We inversed the GLASS_bbe values and integrated them with the STBI values to produce an Aeolian Sand Reactivation Index using the broadband emissivity values (ASRI_bbe) as:

ASRI_bbe = (STBI/10) * inv_BBE,

where inv_BBE is the inverse of GLASS_bbe values, and calculated as:

(10000 - Measured BBE value).

Results and discussion

The final product, ASRI_bbe, was tested extensively across the Indian part of the desert, using ground information on the visually-apparent sand reactivation categories at sample locations, as well as by matching the ASRI_bbe values with the apparent image patterns of reactivated sand on satellite FCCs. This helped us to categorise the ASRI_bbe values in the 8-day products into the following five units: Insignificant = 1-4000, Low = 4001-4500, Moderate = 4501-5000, High = 5001-6000, and Very high = 6001 and above. The assignment was found to match well with the intuitively worked out aeolian sand reactivation categories.

We then carried out a time-series analysis of the derived maps on STBI and ASRI_bbe. Stacking of the graphs showing total sand reactivated area (as % of total area) during each 8-day period over a year (i.e., 8-day periods on the X axis) revealed a gradual increase in sand reactivated area from early March to the fourth week of April, after which a slight decline took place, but a second peak appeared by the fourth week of May (Fig. 2). Over the years, the saddle between the two peaks became prominent, as sporadic rainfall events linked to the strong Western Disturbance became more frequent during May, and temporarily stabilised the sandy landscape. This evolving phenomenon is a result of the Global Warming.

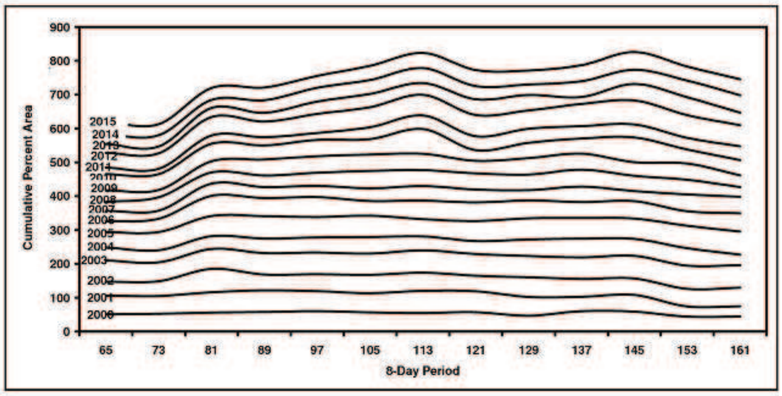

__Figure 2.__ ASRI_bbe graphs for the years 2000 to 2015, stacked one over the other as percentage of total Thar Desert area under sand reactivation with time from early March to mid-June. Numbers 65 to 161 denote the first day of the 8-day periods concerned according to Julian calendar.

When we stacked the individual 8-day sand-reactivated area graphs over the different years (i.e., years on the X axis), we found a rhythmic behaviour of all the 8-day periods over the years, such that ASRI_bbe values peaked in the years following a below-normal rainfall year. For example, a major drought year, 2002, did not record high ASRI_bbe, but 2003 did, as the summer wind speed during the drought year was not very high. A drought-related decline in natural vegetation in 2002, especially of the small shrubs, and an increase in wind strength in the summer of 2003, encouraged higher sand mobilization. An opposite situation was noticed after the high monsoon rainfall event of 2010 (Fig. 3). The total sand reactivated area declined sharply in 2011 as natural vegetation cover increased after the 2010 rainfall.

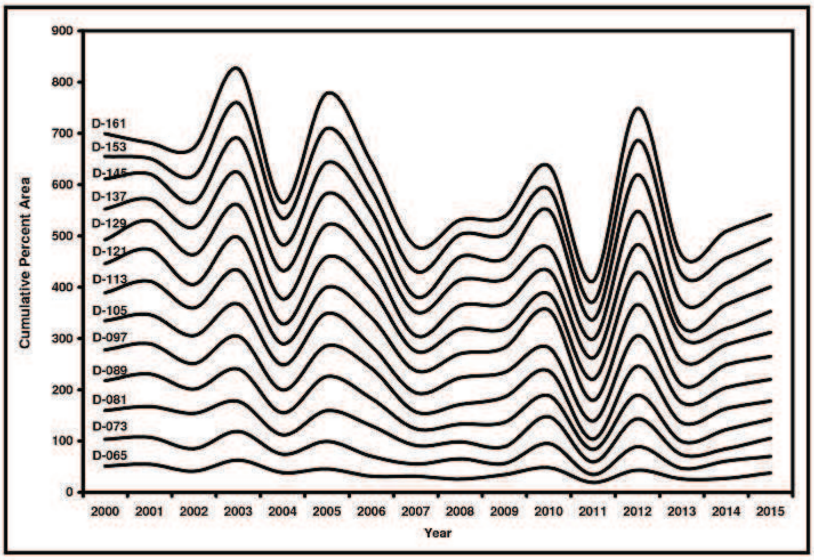

__Figure 3.__ ASRI_bbe graphs for the 8-day periods from early March to mid-June, stacked one above the other as percentage of total Thar Desert area under sand reactivation in different years (year 2000 to 2015).

Despite the relationship of mean ASRI_bbe values with the rainfall deviation from normal in a year, however, a consistent pattern of gradual decline in sand reactivation with time has taken place, as the mean summer wind speed has gradually declined (Fig. 4). The spatial data on sand reactivation, when subjected to a robust, non-parametric Theil-Sen median trend analysis, also showed a strong negative trend across the desert. Other studies have shown a declining trend in the atmospheric dust load during the period (Pandey *et al.,* 2017). In fact, Thar Desert witnessed a much higher wind regime in the mid-20th Century than during the beginning of this Century (Kar, 2013; Jaswal and Koppar, 2013). Whether the pattern will continue in future needs to be monitored properly, as this will influence the specificity of the land management needs. Kar (2012) suggested from an analysis of the GCM data that wind erosivity in the desert may increase from the 2020s, but there is also a possibility that the summer rains due to Western Disturbances will also increase during May, which may restrict the sand mobilization. If the time-span of Western Disturbance in a year increases, this may delay the onset of SW monsoon rains to mid- or late-July. Under such circumstances, Thar Desert may expect a strong bi-modal distribution of aeolian sand mobilization. The proposed remote-sensing-based monitoring system will help in deciphering the trend.

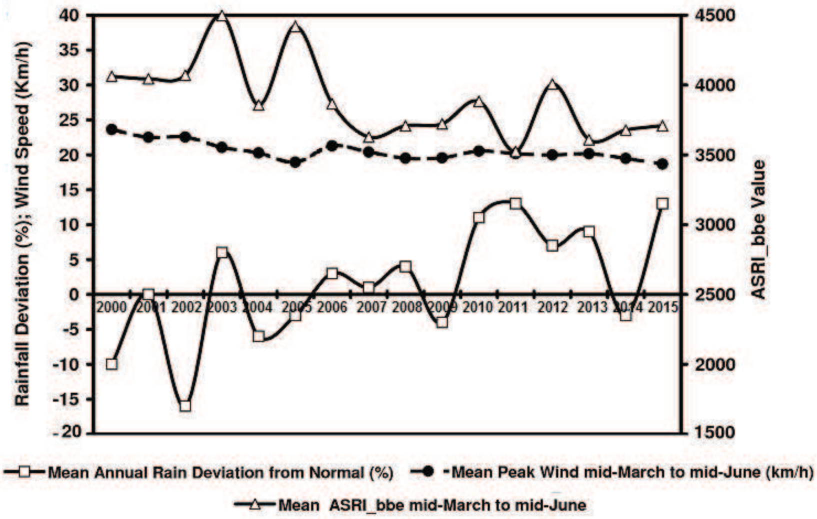

Figure 4. *Relationship between mean annual rainfall deviation from normal (%) during the year 2000 to 2015, mean peak wind speed for mid-March to mid-June (km h-1), and mean ASRI_bbe values for mid-March to mid-June.*

Our studies have shown that presently deep ploughing of sandy terrain for cropping is a major cause of the localised increase in sand reactivation despite a falling wind regime (Kar, 2011; 2014). If more sandy area gets destabilised through deep ploughing and the land is kept without a bare minimum plant cover during the dry summer months, more land parcels may become vulnerable to wind erosion. This is now happening in the central Thar, especially in the Phalodi-Bikaner tract, as also in the tail-end of the Indira Gandhi Canal network, where many new sand streaks have appeared in the wake of deep-ploughed fields. The Bahla-Sultana area, now under irrigated cropping, has become a major deflation area as deep ploughing of the sandy terrain in this very high wind energy zone has loosened the sand to a greater depth. As the summer wind begins to peak, the strong vortex in the wake of the Jaisalmer-Ramgarh Hamada carries a huge load of loose sand from the ploughed fields. In the process, the fields lose the precious soil micro-nutrients also.

Presently, the slowing down of the pre-monsoon summer wind and the sporadic showers during May, especially in the western part, are blessings in disguise for the desert, and need to be utilised for agricultural growth. The falling wind speed is beneficial for conserving the fine sand and silt in the crop fields, while the sporadic summer rains can hugely benefit the growth of trees and shrubs. Possibly this is the most opportune time to strike a balance with Nature again, by adopting a more realistic paradigm that gives some space to and improves upon the traditional sustainable practices of the crop-tree/shrub-livestock mix.

Investing in the core competence of the local livestock sector as an industry may provide a much higher dividend under the evolving climatic uncertainties. The sector has a vast market potential, but somehow the White Revolution was not given a serious thought here. If promoted, the gains may encourage stakeholders to take care of the degraded rangelands, manage water judiciously, and at the same time lessen the pressure on the croplands. Traditional land conservation practices in the dry farming area, and creation of wind brakes and soil mulching in the irrigated areas, especially during the peak summer months, remain the best strategies.

Conclusion

Proper identification of the areas affected by aeolian sand reactivation is important for implementation of any D-P-S-I-R scheme to model desertification in the sand-dominated Thar Desert. We found the satellite-derived CBI as very useful for areas dominated by aeolian sand only, but in a complex terrain it became inadequate. A robust aeolian sand reactivation index that can perform in all kinds of terrain in Thar Desert could be developed using the MODIS surface reflectance and emissivity data. Called ASRI_bbe, this index accurately mapped the different categories of sand reactivated areas at 1 km pixel resolution. Analysis of the time-series data on aeolian sand reactivation from year 2000 to 2015 revealed gradual replacement of a unimodal distribution of sand reactivation pattern to a bi-modal one, in which the month of May now experiences a short period of comparative lull due to sporadic rains from the Western Disturbance. If the pattern continues, it will benefit the regeneration of natural vegetation, especially in the open rangelands that are currently in a highly degraded state. If animal husbandry, the traditional strength of the region, is given adequate infrastructural and market support, especially for dairy milk, meat, etc., the farmers may adopt it for assured economic returns and gamble less on the croplands. This will not only lessen the pressure on croplands, but will also help in developing the degraded rangelands, which in turn will encourage sustainable land management practices for the growth of the crop-tree/shrub-livestock mix.

References

Anonymous 1977. Round-up, Plan of Action and Resolutions. United Nations Conference on Desertification, Nairobi, Kenya.

Anonymous 1979. Mastering the Probable and Managing the Unpredictable. Inter-Futures Study Team, Organisation for Economic Cooperation and Development and International Atomic Energy Agency, Paris, France.

Anonymous 1992. Managing fragile ecosystems: Combating desertification and drought. Pages 46-66 *in*United Nations Conference on Environment and Development, Rio de Janeiro, Chapter 12, Agenda 21. A/CONF.151/4 (Part II), United Nations, New York, USA.

Anonymous 1995. United Nations Convention to Combat Desertification. Interim Secretariat for the Convention to Combat Desertification, Geneva, Switzerland.

Anonymous 2009. Land Degradation Assessment in Drylands Project (LADA) Final Report: Compilation of Selected Global Indicators of Land Degradation. PR. No. 39701, International Institute of Applied Systems Analysis, Laxenburg, Austria.

Babaev, A.G., N.G. Kharin and N.S. Orlovsky. 1993. Assessment and Mapping of Desertification Processes: A Methodological Guide. Desert Research Institute, Academy of Sciences of Turkmenistan, Ashkabad, Turkmenistan.

Cherlet, M., C. Hutchinson, J. Reynolds, J. Hill, S. Sommer and G. von Maltitz (eds.). 2018. World Atlas of Desertification. Publication Office of the European Union, Luxembourg, Belgium.

Claessens, L., J.M. Schoorl, P.H. Verburg, L. Geraedts and A. Veldkamp. 2009. Modelling interactions and feedback mechanisms between land use change and landscape processes. *Agriculture, Ecosystems and Environment* 129: 151-170.

Dregne, H.E. 1983. Desertification of Arid Lands. Harwood Academic Publishers, Chur, Switzerland, 242 p.

Enne, G. and C. Zucca, 2000. Desertification Indicators for the European Mediterranean Region: State of the Art and Possible Methodological Approaches. ANPA - National Environmental Protection Integrated Strategies, Promotion, Communication Department, Rome, and NRD - Nucleo di Ricerca sulla Desertficazione, Universita degli Studi di Sassari, Sassari. 260 p.

ERDAS. 1997. ERDAS Field Guide. ERDAS, Inc., Atlanta, USA, 656 p.

FAO. 1984. Provisional Methodology for Assessment and Mapping of Desertification. Food and Agriculture Organisation of the United Nations, Rome, Italy.

Grunblatt, J., W.K. Ottichilo, and R.K. Sinange, 1992. A GIS approach to desertification assessment and mapping. *Journal of Arid Environments* 23: 81-102.

Huang, C., B. Wylie, L. Yang, C. Homer and G. Zylstra. 2001. Derivation of a Tasseled Cap Transformation based on Landsat-7 at-satellite reflectance. U.S. Geological Survey. 10 p.

Jaswal, A.K. and A.L. Koppar. 2013. Climatology and trends in near-surface wind speed over India during 1961-2008. *Mausam* 64: 417-436.

Kar, A. 2011. Geoinformatics in spatial and temporal analysis of wind erosion in Thar Desert. Pages 39-62 *in* Geoinformatics in Applied Geomorphology (S. Anbazhagan, S.K. Subramanian and X. Yang, eds.). CRC Press, Boca Raton, USA.

Kar, A. 2013. Quantification of aeolian bedform and process parameters in Thar Desert for earth surface dynamics. *Annals of Arid Zone* 52: 181-207.

Kar, A. 2014. Agricultural land use in arid western Rajasthan: Resource exploitation and emerging issues. *Agropedology* 24: 179-196.

Kar, A. 2018. Desertification: Causes and effects. Pages 159-205 *in* Exploring Natural Hazards - A Case Study Approach (D. Bartlett and R.P. Singh, eds.). CRC Press, Boca Raton, USA.

Kar, A. and K. Takeuchi. 2003. Towards an early warning system for desertification. Pages 37-72 *in* Early Warning Systems. UNCCD Ad Hoc Panel, Committee on Science and Technology. UN Convention to Combat Desertification, Bonn, Germany.

Kauth, R.J. and G.S. Thomas. 1976. The Tasseled Cap - A graphic description of the spectral-temporal development of agricultural crops as seen by Landsat. Pages 4B41-4B51 *in* Proceedings of the Symposium on Machine Processing of Remotely Sensed Data, Purdue University, Indiana, USA.

Kharin, N.G., N.T. Nechaeva, V.N. Nikolaev, T. Babaeva, L.G. Dobrin, A. Babaev, N.S. Orlovsky, K. Redzhepbaev, B.T. Kirsta, O.N. Nurgeldyev, A. Batyrov, and I.P. Svintsov. 1985. Methodological Principles of Desertification Processes Assessment and Mapping (Arid lands of Turkmenistan taken as example). Desert Research Institute, Turkmen SSR Academy of Sciences, Askhabad, Turkmenistan.

Mathieu, R., M. Pouget, B. Cervelle and R. Escadafal. 1998. Relationships between satellite-based radiometric indices simulated using laboratory reflectance data and typic soil color of an arid environment. *Remote Sensing of Environment* 66: 17-28.

Middleton, N. and D.S.G. Thomas (eds.). 1997. World Atlas of Desertification (second edition). UNEP and Arnold, London. 182 p.

Nachtergaele, F., M. Petri, R. Biancalani, G. van Lynden and H. van Velthuizen. 2010. Global Land Degradation Information System (GLADIS), Beta Version: An Information Database for Land Degradation Assessment at Global Level, Land Degradation Assessment in Drylands. Technical Report No. 17, FAO, Rome.

Pandey, S.K., V. Vinoj, K. Landu and S. Babu. 2017. Declining pre-monsoon dust loading over South Asia: Signature of a changing regional climate. *Nature Scientific Reports* 7: 16062. doi:10.1038/s41598-017-16338-w.

Ren, H., S. Liang, G. Yan and J. Cheng. 2013. Empirical method to map global broadband emissivities over vegetated surfaces. *IEEE Transactions on Geoscience and Remote Sensing* 51: 2619-2631.

Santini, M., G. Caccamo, A. Laurenti, S. Noce, and R. Valentini. 2010. A multi-component GIS framework for desertification risk assessment by an integrated index. *Applied Geography* 30: 394-415.

Xiao, J., Y. Shen, R. Tateishi and W. Bayaer. 2006. Development of topsoil grain size index for monitoring desertification in arid land using remote sensing. *International Journal of Remote Sensing* 27: 2411-2422.

Managing dryland salinity for food and environmental security: Issues and options

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Extended Summary

Salinity caused by natural (*i.e.*, primary salinity) or anthropogenic factors (secondary salinity) is a severe impediment to sustainable farming on about 1000 mha land area globally (FAO and ITPS, 2015). Although natural salinity is known to have adversely affected agricultural production since ancient days (Houk *et al*., 2006), anthropogenic salination, slowly attaining alarming proportions in both irrigated and dryland regions across the world, poses a severe threat. Irrigation-induced salinity often receives more research and policy attention than dryland salinity, particularly in the countries/regions where public financed irrigation schemes are the mainstay of food security. However, regardless of the cause and asset affected, salination is invariably a triple whammy: diminishing the land value, necessitating unwarranted expenditure on reclamation and curtailing farm incomes to varying extents.

Drylands cover about 40% of the global area (UNEP, 2011) of which nearly 60% is either desertified or prone to desertification (Lal, 2004). Unabated degradation of drylands, caused by factors like unsustainable land management, fresh water scarcity and of late, climate change impacts, has increased the livelihood risks of about 2 billion global population dependent on them (UNEP, 2011). Climatic warming and increasing aridity are projected to expand drylands to nearly 50% of the global land surface by the end of 21st century (Huang *et al*., 2016).

Factors like scarce precipitation, excessive evapo-transpiration, low organic carbon and wind erosion make dryland soils highly vulnerable to various kinds of degradation. In addition to impeding soil development, these factors also subject the poorly formed dryland soils to multiple stresses like salinity and drought. Like irrigated lands, pedogenic processes are the main driver of primary salinity in drylands (McFarlane *et al*., 2016). However, unlike irrigated lands where excessive irrigation and neglect of drainage contribute to secondary salinity, clearing of native vegetation is the main cause of human-induced salination in drylands.

Replacement of native perennial vegetation for growing annual crops and pastures allows a considerable portion of the rainfall to leak to the groundwater, resulting in the development of shallow saline watertables and salt accumulation in the surface; especially where groundwater is salty. While only a meagre fraction of total rainfall reaches the groundwater in areas with natural vegetation, deep drainage could be several folds higher in annual crop and pasture-based systems (Cocks, 2003). In some cases, irrigation with salty groundwater for preventing crop failures may further increase the salinity and sodicity risks.

Besides Australia, where over 2 mha area is currently affected and another 15 mha is at high risk (George and Bennett, 2004), extent of dryland salinity has steadily increased in other regions like China (Zhang *et al*., 2018), India (Mandal *et al*., 2010), Central Asia (Toderich *et al*., 2013), Africa (Burgan *et al*., 2010), North America (Bakker *et al*., 2010; Wiebe *et al*. 2007) and South America (Giménez *et al*., 2015). Immense economic value of drylands in terms of food and livestock production provides ample justification for overcoming the stresses plaguing their productivity. For example, drylands produce nearly 40% of the total food grains and support two thirds of the livestock population in India (Haileslassie and Craufurd, 2012). Similarly, dryland areas roughly constitute 60% of the total wheat area in China (Zhang *et al*., 2018).

Remedial measures developed for managing irrigation-induced salinity may be less effective, or sometimes inappropriate, in dryland areas. Land use changes at the regional scale coupled with site-specific interventions are considered necessary for the productive use of dry saline lands. Revegetation of both groundwater recharge (relatively deep water tables) and discharge (shallow saline water tables) zones, though considered necessary for controlling the rising water tables and restoring the water balance (George *et al*., 1999), may not always be economically viable and may warrant substantial changes in the cropping practices (Cocks, 2003; George and Bennett, 2004).

Significant reductions in water table depth occur only if considerable areas of the catchment are vegetated. Again, watertable depth recedes only in those parts of discharge areas where salinity is mild-to-moderate (George *et al*., 1999). In spite of this, tree plantings in discharge areas are often preferred by the land owners as such arrangements do not encroach on the farmland (Archibald *et al*., 2006). Some engineering interventions like salt interception, drainage and groundwater pumping also provide relief; but are less appealing due to their capital-intensive nature as, in order to be effective, pumping or drainage need to be implemented on a large scale (Bakker *et al*., 2010). Moreover, difficulties in safe disposal of saline drainage effluent render such drainage options environmentally unsound (Clarke *et al*., 2002). Under such conditions, preventing and reducing the extent of surface waterlogging seems to be more effective (McFarlane *et al*., 2016).

Aforementioned problems with vegetation-based and drainage solutions have enhanced the interest in other options including ley framing, crop-livestock integration, replacing annual pastures with perennial pastures and the inclusion of salt tolerant crops and cultivars in the cropping systems. Perennial pastures in rotation with crops can provide multifarious benefits like reduced watertable and salinity, increased soil nutrient availability and fodder supply to livestock (Bell *et al*., 2014). Integration of salt tolerant crops like lucerne (Humphries and Auricht, 2001) and *desi* cotton (Nikam *et al*., 2016) in the existing cropping sequences can provide assured returns to the land owners while also mitigating recharge-induced salinity to a good extent (Humphries and Auricht, 2001). It is seen that some potential crops (*e.g*., lucerne) recommended for remediating dryland salinity have limited salt tolerance, indicating the need for evolving high yielding cultivars capable of coping with high salinity and associated problems. Some site-specific agronomic techniques worth consideration for reducing the salt hazard include surface and sub-surface plastic mulching (Zhang *et al*., 2018), bed-furrow technique (Bakker *et al*., 2010) and flexible cropping schemes involving water-saving and water-intensive crops in alternation (Giménez *et al*., 2015). Over reliance on water-saving techniques and crops may turn out counter productive in years of excess rainfall, inducing heavy deep drainage. Similarly, water-intensive cropping systems though relatively safe from deep drainage standpoint may be more prone to failure.

References

Angus, J.F., R.R. Gault, M.B. Peoples, M. Stapper and A.F. Van Herwaarden. 2001. Soil water extraction by dryland crops, annual pastures, and lucerne in south-eastern Australia. *Australian Journal of Agricultural Research* 52: 183-192.

Archibald, R.D., R.J. Harper, J.E. Fox and R.P. Silberstein. 2006. Tree performance and root-zone salt accumulation in three dryland Australian plantations. *Agroforestry Systems* 66: 191-204.

Bakker, D.M., G.J. Hamilton, R. Hetherington and C. Spann. 2010. Productivity of waterlogged and salt-affected land in a Mediterranean climate using bed-furrow systems. *Field Crops Research* 117: 24-37.

Bell, L.W., A.D. Moore and J.A. Kirkegaard. 2014. Evolution in crop-livestock integration systems that improve farm productivity and environmental performance in Australia. *European Journal of Agronomy* 57: 10-20.

Bugan, R.D.H., N.Z. Jovanovic, W.P. De Clercq, W-A Flügel, J. Helmschrot, M. Fink and S. Kralisch. 2010. Dryland salinity management in the semi-arid Western Cape (South Africa). Pages 1-15 *in* Proceedings of XXV IUGG General Assembly Earth on the Edge: Science for a Sustainable Planet. 28 June-7 July 2011. Melbourne, Australia.

Clarke, C.J., R.J. George, R.W. Bell and T.J. Hatton. 2002. Dryland salinity in south-western Australia: its origins, remedies, and future research directions. *Soil Research* 40: 93-113.

Cocks, P.S. 2003. A revolution in agriculture is needed if we are to manage dryland salinity and related natural resource issues. Pages 1-7 *in* Proceedings of the 11th Australian Agronomy Conference, 2-6 February, 2003. Horsham, Australia.

FAO and ITPS. 2015. Status of the World's Soil Resources (SWSR)- Main Report. Food and Agriculture Organization of the United Nations and Intergovernmental Technical Panel on Soils, Rome, Italy.

George, R.J. and D.L. Bennett. 2004. Impact of farm forestry systems on dryland salinity- a modelling case study. Pages 26-28 *in* Proceedings of the Australian Forestry Conference. 26-28 July, 2004, Melbourne, Australia.

George, R.J., R.A. Nulsen, R. Ferdowsian and G.P. Raper. 1999. Interactions between trees and groundwaters in recharge and discharge areas- A survey of Western Australian sites. *Agricultural Water Management* 39: 91-113.

Giménez, R., J.L. Mercau, J. Houspanossian and E.G. Jobbágy. 2015. Balancing agricultural and hydrologic risk in farming systems of the Chaco plains. *Journal of Arid Environments* 123: 81-92.

Haileslassie, A. and P. Craufurd. 2012. Challenges in the dryland agricultural production systems of south Asia: Research priorities and strategies. *Annals of Arid Zone* 51: 1-8.

Houk, E., M. Frasier and E. Schuck. 2006. The agricultural impacts of irrigation induced waterlogging and soil salinity in the Arkansas Basin. *Agricultural Water Management* 85: 175-183.

Huang, J., H. Yu, X. Guan, G. Wang and R. Guo. 2016. Accelerated dryland expansion under climate change. *Nature Climate Change* 6: 166-171.

Humphries, A.W. and G.C. Auricht. 2001. Breeding lucerne for Australia's southern dryland cropping environments. *Australian Journal of Agricultural Research* 52: 153-169.

Lal, R. 2004. Carbon sequestration in dryland ecosystems. *Environmental Management* 33: 528-544.

Mandal, A.K., R.C. Sharma, G. Singh and J.C. Dagar. 2010. Computerized Database on Salt Affected Soil in India. Technical Bulletin No.CSSRI/Karnal/2/2010. pp. 28.

McFarlane, D.J., R.J. George, E.G. Barrett-Lennard and M. Gilfedder. 2016. Salinity in dryland agricultural systems: challenges and opportunities. Pages 521-547 *in* Innovations in Dryland Agriculture. Springer, Cham.

Nikam, V.R., G.G. Rao, A. Chinchmalatpure and D.K. Sharma. 2016. Cultivating desi cotton for securing livelihood of farmers in dryland saline areas of Gujarat. *Indian Farming* 66: 31-33.

Toderich, K.N., E.V. Shuyskaya, T.F. Rajabov, S. Ismail, M. Shaumarov, K. Yoshiko and E.V. Li. 2013. Uzbekistan: Rehabilitation of desert rangelands affected by salinity, to improve food security, combat desertification and maintain the natural resource base. Pages 249-278 *in* Combating Desertification in Asia, Africa and the Middle East (Heshmati G., Squires V. eds). Springer, Dordrecht.

UNEP. 2011. Global Drylands: A UN system-wide response. The United Nations Environment Management Group.

Wiebe, B.H., R.G. Eilers, W.D. Eilers and J.A. Brierley. 2007. Application of a risk indicator for assessing trends in dryland salinization risk on the Canadian Prairies. *Canadian Journal of Soil Science* 87: 213-224.

Zhang, M., B. Dong, Y. Qiao, H. Yang, Y. Wang and M. Liu. 2018. Effects of sub-soil plastic film mulch on soil water and salt content and water utilization by winter wheat under different soil salinities. *Field Crops Research* 225: 130-140.

Desertification and interventional effort

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Abstract

Desertification and its control have been on the international scene for the past more than four decades. Initial efforts at global and national platforms to understand underlying causes, manifestations, consequences and extent of the problem have been followed by development of technologies and plans of action to reduce the environmental damage and to improve the livelihoods of the affected population. The progress has been reviewed from time to time and, despite awareness and concerns, the success has been partial only - a fraction of the physical targets has been achieved. Besides natural impediments of terrain and vicissitudes of climate, the need for efforts to control is maximum in poor or developing countries and these find the cost of developmental effort unaffordable, while the pressure of people on land is already high and further mounting. Poverty, social harmony, political stability and involvement of locals are other pre-requisites. Yet, there are some notable achievements. A case of arid zone of Rajasthan has been described to show how, through development of irrigation, infrastructure, service sector and industrialization, the environmental load on land could be reduced and causes of desertification minimized. Of course, nature also helped in that, for as yet unknown reason: the ferociousness of wind regime has come down. Though globally, the problem of land degradation remains under-addressed, the commitment of the nations to achieve land degradation neutrality targets and rising concerns of climate change and biodiversity loss will insure greater action and international co-operation in the near future.

Introduction

Desertification is a problem that affects current as well as long term productivity of the drylands, besides decreasing several ecosystem services. Though, some countries in the world had realized the gravity of the situation and even undertaken some efforts to fight the menace long back, the problem came on national and international arena as a prelude and sequel to the UN Conference on Desertification at Nairobi in 1977. At this conference several of the affected nations and international experts on the subject deliberated upon the causes, manifestations and consequences of the problem. The term "desertification" at this UN Conference was defined as "diminution of biological productivity of land in arid, semi-arid and sub-humid environments due to over-exploitation of land resources by human use and management, ultimately leading to appearance of desert-like conditions". The process was considered self-accelerating and feeding on itself. The follow up comprised attempts to assess the extent and severity of the problem and an emphasis to develop technologies for its control. The concerns regarding desertification initially were focused on arid zones but in the course of time it was realized that the problem of land degradation was equally serious, and even more consequential, in semi-arid and sub-humid climate zones. However, following the experiences of Sahel region in Africa, where a succession of drought years caused not only a huge human suffering but also a major ruination of land, the 1992 Rio Conference justifiably included climate variability as a causative factor in the above-noted definition. It has also been shown that as a result of desertification, some 12 mha of land are lost every year, which means a loss in production worth 20 million tons of grain.

The control efforts have been reviewed and discussed at local, national and international levels and even at the United Nations. Thus, the United Nations Conference on Sustainable Development (Rio+20) in Rio de Janeiro, Brazil, in 2012, called for a political outcome document with practical measures for implementing sustainable development. And a formal commitment came into being in UN General Assembly that aims at rehabilitating/restoring degraded land, including land affected by desertification, drought and floods, and strive to achieve a land degradation neutral (LDN) world by the year 2030 (United Nations General Assembly, 2015). As of today, 121 countries have already committed to set LDN targets and required actions.

Experience has shown that desertification is a very complex phenomenon comprising multiple interactions between human and environmental systems (Warren and Olsson, 2003). It is also variable over time and space and calls for plans and measures that are appropriate, durable for a given situation and duly supported by adequate funds as well as expertise. The present paper briefly provides overview of experiences gained in this process in arid zone of Rajasthan, India, that is known for its huge human and livestock pressure, vulnerable landforms and a history of technology development and desertification control efforts.

Desertification control and issues involved

As said above, desertification is essentially an outcome of an exploitative use of land and its resources under a greatly increased and ever-rising regime of human needs for food, feed, water, timber, mining, recreation and so on. Common manifestations of the process are soil erosion by wind and water, waterlogging with or without soil salinization, acidification, reduction in vegetative cover in quantity and quality, land pollution by mining or industry and urbanization. There is also an increasing realization of the difficulty in discerning natural and human activity-related manifestations of land degradation or establishing secular trend in severity of desertification in a situation of highly inter-annual or short duration climate perturbations. Therefore, desertification term, the processes and the consequences have continued to be reassessed for long with some even questioning the science and euphoria behind desertification (Thomas and Middleton, 1994).

Droughts are a common occurrence in drylands, where these are a conspicuous part of the natural climate variability. These both impact and get impacted by land degradation. Likewise, livelihood security, socio-economic equity, political instability are causes as well as outcome of land resource depletion (Mortimore, 2003). Experiences over the decades in conservation and improvement of lands have shown that whereas degradation of land is easy, the reclamation or restoration is far more complicated, expensive and tedious. Putting in place several of the amelioration measures has also long gestation period and hence has vulnerability, despite the claims that technologies are proven and viable. Trade amongst the countries in commodities, industrial goods and technology-based services has greatly increased in recent times but the outcome or balance is generally negative for nations with primary, natural resource-based industry and where the problem of desertification is most consequential.

Assessment of the extent and type of degradation

Estimates on the magnitude of a problem are basic to planning, allocation of resources and implementation of restorative measures. Therefore, one of the major activities at the beginning of the campaign was on data generation regarding forms and spatial distribution of desertification. An outcome of this was the statistics and maps in the form of an atlas that was first printed in 1992 and second edition appeared in 1997 (Middleton and Thomas, 1997). This and later updated information showed that worldwide the land degradation and desertification were a serious problem on ~2 billion ha area globally and besides, this showed also that 52% of all agricultural land was moderately to severely affected. At the same time the problem was worsening each year (Low, 2013). The situation is a threat to livelihood of some 1.5 billion people, most of whom were already poor. The problem is most consequential in developing countries in Africa and Asia. Two-thirds of the African continent is desert or under drylands and within these, 74% of its agricultural drylands are already seriously or moderately degraded.

The areas with the biggest dynamics of desertification are concentrated in the Sahelian region, in the Kalahari in the south and in the Horn of Africa. It is estimated that the problem is affecting some 500 million people here. According to Olagunju (2015), Nigeria is losing about 0.35 million ha of land every year to desert. Whereas in Ghana 35% of the land is prone to desertification, in drylands of Kenya and Ghana it is 70 and 80%, respectively. The belt of land running through the West African Sahel region and the Sudan to northeast Ethiopia and Kenya is particularly vulnerable. Around 90% of rangelands and 80% of rain-fed farmlands in the area are affected by degradation - including soil erosion, deforestation, and loss of woody vegetation, making them less able to bear crops and pasture. In China, the land affected by desertification is 264 mha nationwide, which amounts to 27% of its geographic area. Wind erosion and encroachment by drift sands is a major problem in China. The area so affected was ~14 mha in year 1955 and the same had increased to 38 mha by year 2000 (Wang, 2014). Vegetation cover deterioration is another serious problem.

Regarding India, investigations show that nearly half of the country is affected by one or the other form of land degradation, within which water erosion, wind erosion, water logging, soil salinity and soil acidity constitute 63.9, 6.3, 9.7, 4.0 and 10.9%, respectively (Samra and Sharma, 2005; Anonymous, 2010). The problem is generally moderately severe to severe and affects nearly 40% of rural population. Likewise, estimates exist for most of the other countries across the world. Several have questioned the degree of reliability of these data on the grounds that the situation is highly variable spatially and over the years (Grainger, 2000; Abahussain *et al*., 2002). Therefore, it must be admitted that the data carry elements of judgment and should be taken as such. Further, the environmental impacts are not the sole outcome of physical changes but are tied to the ability of a society or culture to adapt to those changes as also to the coping ability of individual farmers. Mortimore (2003) and Darokh (2003) have highlighted several such ambiguities in functioning of complex human-environment relationships.

Human population, through activities related to land use and management, is a major driving force in desertification. An increase in its pressure impacts through enhanced need for food and feed and reduction in size of land holdings. Both amount to an intensification of land use as well as expansion of cropping into areas that are marginal in nature. Thus, population growth has been considered all along an accelerator of the desertification problem. However, there have been regions where developments in economy such as urbanization, industrialization, mining of bountiful minerals and fossil fuels, infrastructure have not only been able to absorb the load of surplus population but have helped in reducing dependence on traditional livelihoods. Jiang (2002) cites the case of Inner Mongolia, where the human population has tripled in four decades but the income per capita through various developments, including irrigation, has increased fifty fold. Thus, the relationship of population growth to desertification is not simple and depends on collateral and independent economic developments (Darkoh, 2003).

A brief review of efforts at desertification control and successes achieved

The process of rehabilitation of degraded lands is complex, time-taking and multi-dimensional. For all these, a trained manpower, subject matter specialists and appropriate machinery are needed. The scale of operation is large, necessitating creation of settlements, roads and other infrastructure. Maintenance requirements of developed lands are equally critical, exacting and variable, depending upon whether the lands are community or individually owned. Though in the past developing a technology was a constraint but over time the situation has improved a great deal and the past 4-5 decades are marked by planning and implementation of a gamut of activities. The approaches have varied from a purely land rehabilitation effort to a more comprehensive content that included also measures for public welfare like meeting or strengthening of basic societal needs. However, implementation of the activities was not smooth because of multiplicity of activities, lack of co-ordination, organizational and funding inadequacies and natural causes like failure of rainfall. However, notable successes have been achieved. In China, the lands degraded by wind erosion and sand encroachment had been increasing all the time but during the decade from year 2000 for the first time not only the growth of the problem has been stopped but there is noticeable decrease. In the Loess Plateau an area of 15 mha has been treated for wind erosion control and this has reduced also the annual silt and sediment influx into the Yellow River by more than 300 million tons (Gao *et al.,* 2009). A big project namely "Grain for Green Program" has been completed with the object to withdraw 3.67 mha of dry farmland and re-vegetate another 5.13 mha of aeolian desertified tract (see companion paper of Tao Wang in this volume). Likewise in India, soil and water conservation on rainfed agricultural lands has been a major activity, which started in 1950's. As of now, nearly 11 mha area has been treated under field/contour bunding, gully control, check dams and so on (Anonymous, 2012).

Afforestation of degraded forest and rehabilitation of grazing lands have been other major activities. Sand dune stabilization has been achieved over 0.25 mha.

In desertification-affected countries of Africa, despite realization of the seriousness of the problem, progress has been slow. This is not so much for lack of technology but because of local social and political issues and paucity of funds. In fact, Agnew and Warren (1996) concluded that the plans of action were not working and the problem was actually intensifying. But for the past more than a decade situation has improved, particularly after the launch of the 'Great Green Wall' in 2007 that is spread across 20 countries of West and North Africa. The aim is to rehabilitate 100 mha of land by year 2030. More notable achievements have been improvement of 15 mha of degraded lands in Ethiopia and another 5 mha in Nigeria.

Experiences gained and lessons learnt

Drought and desertification

Droughts are a part of the normal climate regime in drylands and their frequency and intensity increases in direction from dry sub-humid to arid. These cause failure of crops, reduce availability of utilizable biomass for livestock, create fuel wood scarcity and shortage of water for drinking and domestic needs. As a result, the pastoralists and farmers need to buy food and fodder or undertake distress migration, shed livestock holding, incur debts etc. The impact of droughts from desertification viewpoint is particularly deleterious. The seasonal rainfall paucity increases manifold the pressure on the already famished vegetation because of increased incidence of overgrazing and fuel wood exploitation (Saxena, 1993). Therefore, it is no surprise that major advancement of desertification happens during such periods of severe and extended drought. As a corollary, a strategy and preparedness to cope up with drought situation is a big step not only in relief to local population but also in reducing its impact on long term sustainability of natural endowments and in protecting the vegetation cover improvements already undertaken as part of control efforts. Hence, approaches based on early warning, monitoring, impact assessment and appropriate relief effort assume critical importance in reducing misery and deprivation of the affected populations.

There is also another side of this relationship in the sense that desertification also enhances the impact of droughts. It depletes the vegetation cover, particularly its more critical perennial component, which leads to a great reduction both in the quantity and duration of biomass availability on a long term basis. Thus, this weakened resilience of ecosystem leads to a poor recovery of the vegetation even after the rainfall has become normal (Smith and Reynold, 2003; Bradley and Grainger, 2004). This deteriorates inter-community relations and leads to violent conflicts amongst the dependent populations. Both, desertification and drought over large tracts have a potential to affect climate stability. Enhanced bare surface increases albedo, which is an important variable in General Circulation Models and can produce atmospheric subsidence and reduction of rainfall (Fuller and Ottke, 2002).

Economics of rehabilitation effort and sustainability issues

Even though a very complex and interdisciplinary task, planners and policy makers often insist on cost-benefit analysis in decision making. Exercises have been done to find out as to what land degradation means in economic terms. UNEP estimated in 1980's that the direct cost of desertification at global level was $26 billion per year. The direct cost was derived from decrease in crop area, reduction in crop yields, poor response to input use and decline in profitability of enterprise. Collection of the data with a level of reliability and scientific rigor has been very challenging even at local scale. For example, crop yields under rainfed farming suffer from a large degree of inter-annual as well as inter-field variation that arises from quantum and distribution of rainfall, farm management, level of skill, and incidence of diseases and pests. Further, the estimation is made based on extrapolation from few, pre-existing data from limited field experiments. The same is even truer of indirect costs such as siltation of reservoirs, effect on public health, costs in infrastructure maintenance and others. Yet, out of bare necessity efforts continue to be made (Dregne *et al.,* 1991; Bojo, 1996). A large amount of data has been generated for China. Cheng *et al.* (2013) show that the average direct and indirect cost of degradation was ~1% of GDP of China. In India, Reddy (2003) showed that direct costs of land degradation alone in various States varied from 0.2 to 1.9% of GDP with a national average of 0.89%.

Regarding benefits of control effort, the information is equally inadequate for above-mentioned reasons and also that several of the interventions are more for social or environmental objectives and the income is not easily measurable or that the gestation period is long, as for example for afforestation or grassland development, to add to the uncertainty. However, in most cases benefits outweigh the cost involved, particularly so in areas like control of waterlogging, reclamation of salt-affected or acid soils and plant nutrient applications. Fleskens *et al.* (2012) developed a "Desertification Mitigation Cost Effectiveness" model and showed that cost-benefit analysis varied across situations depending on the responsiveness to technology. They found that use of a technology across cereal growing area was profitable only in one-third of the area (Fleskens *et al*., 2013). The situation further worsens if cost of maintenance is also included as several of the measures do not have stability and require sustained effort for maintenance. Therefore, in marginal areas, attention needs to be given to subsidies, since gains can be marginal as compared to the cost of restorative effort.

Some countries have tried successfully to link the desertification control effort with the much needed employment generation, poverty alleviation or famine relief. Besides the above, globalization of trade and inability of weak economies to have fair terms of trade have affected land degradation. The price differential in agricultural and industrial products constrains the economy of the developing World. Rise in demand, and hence the prices, leads to overstocking and accelerate desertification in several central African countries (Rocheleu *et al*., 1995). However, where the naturally handicapped regions form a part of much larger geographic area and of the national economy, situation is different. Despite their inability to payback, such drylands here are able to get funds and expertise as part of a bigger national objective. As described later in this paper, Thar Desert has seen a lot of development in irrigation, much of it from externally sourced water.

Politico-social strife and desertification

Political instability, ethnic or communal disharmony, social disparities and inequity in livelihood assets, like drought, are both a cause and an outcome of land degradation. The problem is particularly serious in parts of Africa (Low, 2013). As an example, the cattle corridor in Eastern Africa has been a time-tested mechanism aimed to cope with spatial climate variability, distribution of livestock pressure and minimize local conflicts. But, over time with increased local population-driven demand, the competition for pasture and water has increased greatly. There has also been a high level of individualization or privatization of the open access rangelands or their conversion to arable lands in corridor in Uganda (Mugerwa, 2018). This situation has caused frequent and terrible ethnic and communal clashes, large scale displacement of populations to neighboring countries accompanied by lawlessness (USAID, 2011; Osinubi and Osinubi, 2006). Political instability also leads to similar outcomes. Such situations promote degradation of natural resources and hinders program development and implementation or protection of the assets already built (Eriksen, 2003; Darokh, 2003). To minimize these disturbances and loss of life and livelihoods, solutions are being thought in creation of more 'green jobs' for young and displaced populations, in reduction of pressure in Cattle Corridor, in improved management of droughts and in investments in the restoration andsustainable land management of 10 mha of degraded lands (UNCCD, 2018).

Poverty/livelihoods and desertification

Poverty and build up of unsustainable biotic pressure arising from increase in population are so intimately related with land degradation that it becomes difficulty which one is the cause or the effect. But, whether the poor are major agents of desertification or not, they certainly suffer from its consequences, as their livelihoods greatly depend on the productivity of land (Hazell *et al*., 2002; Stringer, 2009). It is no surprise, therefore, that three-fourth of world poor are found on degraded lands (Abdi *et al*., 1993) and they certainly suffer the most from desertification and droughts (Sandford, 1993; Stringer, 2009). Scarcity conditions that prevail in environmentally vulnerable situations accentuate economic disparities all the more as the job opportunities shrink, food and other essential items get costly and hunger and disease take over. The vicious circle can be broken only by State-level interventions in the form of value addition to local produce, alternate livelihoods and improvements in infrastructure (Low, 2013). China, India and a few other countries have adopted such an approach. An example of this is the plantation of native acacia trees over 13000 ha in Sahel region to produce gums and resins and undertake value addition mainly for securing livelihood of the local population.

Peoples' participation

The areas affected by desertification are large, comprise both privately owned and community lands and are settled for decades by communities who practice a land use and management based on traditional knowledge. To control desertification under these situations, most countries resort to use of technologies developed top down. Developments that do not consider the stakes, genuine needs, and aspirations of the local society often fail once the tight control is withdrawn. Therefore, the resource development programs need to evolve by active participation of the dependent populations. Such an approach not only gets high acceptance from the communities but also the upkeep and maintenance of the developed assets becomes much easier. Unfortunately, the importance of local participation (Mortimore, 2003) and society-desertification linkages as a whole (Smith and Reynolds, 2003) remains still underappreciated.

Desertification, climate change and biodiversity degradation

Besides a convention on desertification (UNCCD), the outcome of the 1992 Earth Summit was launching of two more conventions, namely the UN Framework Convention on Climate Change (UNFCCC) and the UN Convention on Biological Diversity (UNCBD). All the three have been in operation since then and have environment and human society's long term wellbeing as their core concern with several commonalities in their goals and operational approaches. For example, the build up of greenhouse gases in atmosphere is the main cause of climate change and, after burning of fossil fuels, agricultural activity is one of the major causes of global warming, having contributed as much as 50-70 giga tons (Gt) of carbon (C) over the course of human history of land use. But this points also to the possibility of the potential inherent in soils to sequester C through appropriate management practices. For example, Lal (2000) has shown that globally soils of drylands contain 1462-1548 Gt of C, largely in organic form in their top 1-meter depth and these lands have a capacity through appropriate management to sequester C at a rate of 0.7 to 1.43 Gt per year, an equivalent of 10% of all global fossil fuel emissions in late 1990's (Lal, 2001). To supplement this, the vegetation component, associated with soil and water conservation on degraded lands has the potential to sequester C in above ground biomass at a rate of 3-15 t ha^{-1} in arid situation and up to 80 t ha^{-1} in dry sub-humid region. Both climate change and land degradation have a common cause in climate variability, particularly droughts. Reed and Stringer (2016) have described other multiple relationships and feedbacks that exist between land and climate. Thus, land degradation has a common cause and its appropriate management has co-benefits for climate change mitigation and adaptation, and biodiversity conservation, in addition to enhancing food security and stainable livelihoods (Cowie *et al.,* 2007; Hulme and Kelly, 2013). Therefore, a commonality of interest in concept and practice of UNCCD and UNFCCC does exist (Hulme and Kelly, 2013, Stringer *et al.,* 2012). Biodiversity on land and in water bodies and oceans is a vital resource and outcome of evolution over the millennia. The genetic material contained in these holds an immeasurable promise in improving plants and animals and in strengthening the wellbeing of society and nature in the future. But, there are areas where conflict of interest does come into play amongst the three conventions. Therefore, there is need to minimize the areas of conflict, develop common ground or aim at striking a balance, and still better, seek synergies in concepts, objectives and practices amongst the UNCCD, UNFCCC and UNCBD (Cowie *et al.,* 2007; CBD, 2010; Grainger, 2015; Akhtar-Schuster *et al.,* 2017).

Rajasthan arid zone - A case of desertification and development

The Rajasthan arid zone with an area of ~0.2 million km^2 is located in the northwestern part of India and much of it is known as the Thar Desert that extends further west into Pakistan up to the eastern bank of river Indus. The physio-geographical details, climatic variability, weather conditions, status of natural resources of land, water, vegetation and general biodiversity existing in the area, have been described in detail by Yadav *et al.* (2019) in a companion chapter in this volume.

Socio-economic background

The region has been well settled for the past two millennia by diverse ethnic and social groups but the population all along was rather thin and concentrated in better-off eastern half with an established arable farming. Besides, human population growth was sluggish and the numbers increased only three-fold in the period of 230 years, to the year 1890. This growth situation continued up to 1921, the causes being high maternal and infant mortality, famines and epidemics of diseases like cholera, malaria and typhoid. However, from then on the growth has been continuous and large: population tripled in fifty years to year 1971 and tripled again in forty years to year 2011 (Dhir *et al.,* 2018). With present density of 140 persons km^{-2}, the region is one of the most densely populated arid zones in the World. Like human population, arable farming has also shown large growth in recent years. The arable lands occupied 10-30% across much of the desert in 1930, increased to 36.3% in 1956, to 45.7% in 1980 and 57.4% in 2010 (Dhir *et al.,* 2018). Other main categories of land use are culturable wastelands (17.6%), unculturable waste lands (4.6%) and designated grazing lands (3.8%).

Agriculture, animal husbandry and traditional management practices

With 50-60% of population dependent on it, agriculture is the major source of livelihood in the region. Currently, the region has ~12 mha under cultivation, 74% as rainfed and the rest under irrigation. Nearly half of the irrigated area gets water brought from West Himalayan river system and the rest from local groundwater sources. Under rainfed farming, pearl millet, pulses and oilseeds are the crops. But over time, the rainfed cropping pattern has shown some commercial dimension: a large increase in area of clusterbean and some medicinal plants. On irrigated lands, groundnut, cotton, mustard and a variety of condiments and spices, fodder and fruit trees have become principal crops. Animals are an important source of economy. Of over 30 million animal population, cattle, buffalo, goat, sheep and camel account for 20, 13, 23, 43 and 1%, respectively. In the past four decades, there has been considerable increase in the proportion of goat, sheep and buffalo.

Local people have developed, over the generations, management practices and strategies, particularly for rainfed farming and in livestock rearing, which remain relevant even today. Agroforestry and mixed cropping with a combination of short and medium duration crops, in order to cope with uncertainties of rainfall amount and distribution, are specifically important. Millet, pulses and clusterbean are hardy, generally with short duration and yet they have an ability to take advantage of a good rainfall year. They are also multipurpose, providing both food grains and fodder. Fallowing, crop rotations, and choice of crops in relation to onset of rain are the other highlights. Farming based on rainwater harvesting has been an old practice in the driest parts of Thar.

In the field of animal husbandry, mixed flock has been a strategy to make best use of multi-storey vegetation. Breeding practices, ethno-veterinary and migration of heards are the other well-developed practices. The change in livestock composition in recent years, in response to ecological compulsions or market forces, shows that livestock rearing is viable. In regard to the total livestock load, nearly 2/3rd of the adult cattle units in the region are with farmers, the rest being with the pastoralists. The mixed farmers find animal component an asset as they are able to make use of the residual crop biomass and give in turn milk and manure, prolong duration of gainful employment, minimize the adverse effect of drought and lead to women empowerment as most of the animal rearing operations are carried out by women.

Causes, manifestations of desertification in arid Rajasthan

One of the main contributing factors promoting desertification is the expansion of arable farming. Even the dune-affected lands (Fig. 1) have been brought under cultivation. Replacement of the earlier bullock-drawn ploughs by tractor mounted disc plough, which disturbs soil to a greater depth, removing standing vegetation and its soil binding roots, greatly increases wind erosion. The number of tractors has increased from just 698 in 1956 to 160,000 as of now. This has adversely affected also the agroforestry system. Shrubs, like *Zizyphus* which is hardy and produces feed of outstanding quality, were numerous in agricultural fields in the past. Tractor cultivation has hugely damaged such shrubs and their present productivity is just 10 to 25% of the past (Dhir *et al.,* 2018). The dominance of the multipurpose tree, "*khejri"* (*Prosopis cineraria*), in agricultural fields was an outcome of a conscious, selective management. Despite this, its stand has suffered a great deal all over, partly because of insect pests/disease and inadequate replacement of the aging trees. The accelerated wind erosion generates masses of drift sands that pile up against obstacles and field boundary or create shrub-coppice dunes or hummocks, disturbing the level of the land and necessitating a leveling operation (Fig. 2). Furthermore, the loose sand comes in the way of obtaining a uniform and adequate crop plant population.

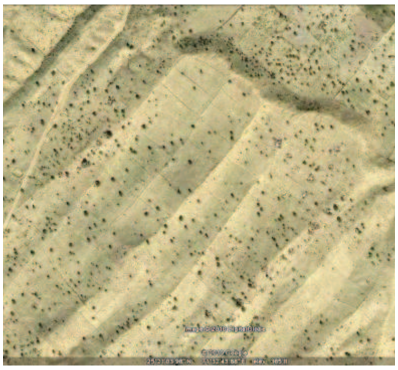

Figure 1. *Satellite imagery of an area in ~250 mm rainfall tract in Thar Desert showing that even the dunes flank with highly erodible soils are under cultivation right up to the crest. This has been a cause of accelerated wind erosion.*

Figure 2. *Overview of agricultural lands severely eroded by erosion. This necessitates land leveling every 3-4 years*

The grazing lands have been the main plank of animal husbandry in the past and these also provided fuel, thatch and other useful biomass, including medicinal plants. But during the last 5-6 decades the area has shrunk because of expansion of cropping. Even more grievous has been the depletion of useful vegetation cover because of persistent overgrazing (Suresh Kumar, 1997). Perennial, high yielding grasses have suffered the most. They have virtually disappeared, replaced by low yielding, short-lived annual grasses and herbs (Saxena, 1977; Shankarnarayan, 1988) and the of unpalatable invasive shrubs such as *Calotropis, Aerva* and *Haloxylon.* As a consequence, the quantity of grazable biomass is decreasing (Saxena, 1977, 1993; Shankar and Kumar, 1988). Major degradation of vegetation occurs during the drought period when over-grazing greatly intensifies and the clumps of grasses are grazed to the ground level (Saxena, 1993). The young sprouts that appear after any rainfall are also grazed to the ruin of the vitality of surviving perennial grasses. For people, drought means personal misery, death or distress sale of livestock, increased debt and migration.

Severity, extent and consequences of the problem of land degradation

The assessment of desertification in arid Rajasthan has been an ongoing activity at the Central Arid Zone Research Institute (CAZRI) adopting various methodologies. As per the latest information, the area affected by wind erosion is 76%, 18% being severely affected (Kar *et al.,* 2009). Water erosion, water logging in irrigated areas, and salinization together form 8%. However, this does not include the degradation of grazing lands of various revenue categories, which constitute ~26% of the region. Over 95% of these common access lands are severely degraded.

An estimate of enhancement of management costs and reduction of output of useful services is a promising method of assessing the impact of land degradation. Wind erosion reduces land productivity through impoverishment of soil. Sandy soils, upon erosion by an extraordinary dust storm, lose their productivity by ~25% (Dhir, 1995). This loss is, however, not permanent and land is able to recover in 2-3 years period. The disturbance of land level is a more serious problem and calls for control effort, although costly. However, this potential damage from wind erosion is far more grievous in canal command area in the south-west.

The grazing lands are a different case as they have got seriously depleted over the past 4-5 decades. In the western drier part, where the coverage of grazing lands is also much larger, the degradation process started later but today over 90% of these lands are severely degraded also. Though, the problem is indeed serious and the same is manifest in the large decline of cattle as per cent of livestock and an increase in that of goat, a state of crisis in animal husbandry has not happened because alternate sources have become available to supplement needed biomass. Goat is far more versatile and can freely browse on thorny and other shrubs not suitable for cattle and sheep. Besides, irrigated farms generate a lot of by-produce, which finds its way to the market for animal holdings of pastoralists and rainfed farmers.

Though waterlogging and soil salinization was becoming a menace in the canal irrigated areas in the past, control on water supplies, de-watering and change in cropping pattern has been able to contain the problem. However, dwindling of ground water resources that sustain the vitally important irrigation is indeed serious. Aquifers with acceptable quality of water are few and these are undergoing decline in water table by 1-3 meters annually, in some areas already exhausted. The irrigated area has, however, not suffered a setback because of shifting to under-exploited sites or by adoption of sprinkler irrigation system. This situation will, however, sustain for another 5-10 years only, after which irrigated agriculture will start dwindling considerably.

Desertification control effort and its analysis

The Government of India, concerned with the plight of farmers in climatically disadvantaged regions of the country, launched a nationwide "Drought Prone Area Program" (DPAP) in 1974-75. Little later (in 1977-78), "Desert Development Program" (DDP)" was started, exclusively for desert region. For some time both operated concurrently in Thar Desert, but from early 1980's only the DDP has continued. The coverage has been expanded to arid areas in the southern part and to cold desert area in the north. Besides, the technical content of the activity has also been broadened. Some non-governmental organizations (NGOs) are undertaking natural resource regeneration activities as part of their rural development activity. In the initial stages of the program, development of surface water resources through construction of small to medium sized reservoirs and drinking water supply sectors were also components of this activity. Over time, main focus has been on desert afforestation, sand dune stabilization, pasture land improvement and soil and water conservation.

Afforestation was one of the major areas of activity and it covered the canal irrigated areas also, where protective of vegetation was critical to the successful functioning of the infrastructure. The total area so afforested is 0.35 mha. A technology was developed quite early for stabilization of sand dunes, using *Acacia tortilis*, which is fast growing yet hardy plant. As of now an area of 0.33 mha has been treated, much of it in IGNP command and along its water distribution system. However, this activity expanded only to some extent in other parts because the local people did not want exclusion of the land from their use.

Pasture development has been another major activity. A technology for rehabilitation based on fencing to prevent damage during establishment period, land preparation and reseeding with appropriate perennial grasses with an element of shrubs and trees already existed with CAZRI. The grasses are hardy, efficient utilizers of moisture in terms of biomass production and are highly palatable. The same applies to chosen shrubs and trees. The technology had also been demonstrated successfully for varied ecological settings in the Thar Desert. As of now this development has taken place over ~0.20 mha.

Desertification and development

Desertification in Rajasthan in 1970's and 1980's was considered as a problem that had all the potential to turn the lands barren and devastate the settled populations therein. But today, the human population, which is ~2.5 times more than that existed then, is not only surviving but has a higher human development index, about 2 times higher life expectancy, low infant and maternal death rate, and enjoying a distinctly better quality of life. This is only partly due to desertification control efforts as several other activities have played significant role. Most important amongst these has been the development of irrigation. Today, this 26% of the irrigated area in the total cropped area is contributing 180 billion rupees worth of crops, which account for 62% of all agricultural produce of the region. Other socio-economic benefits of irrigation are rural employment generation, enterprise diversification, and growth of agro-based industries. Rural drinking water supplies, infrastructure, service sector, urbanization and industry have grown considerably (Dhir, 2003). In fact, labour wages, both in urban and rural areas, in Thar Desert are much higher than the State and national-average. However, the smooth running of canal system has been possible only by protective afforestation that was carried out with considerable zeal and efforts.

Severity of erosion-causing wind has come down greatly in recent years for reasons as yet poorly understood. However, deterioration of grazing lands remains as serious as in the past. The efforts made to rehabilitate these lands failed not because of lack of the technology but due to difficulty in regulating grazing that is so critical for their upkeep. Neither the government nor the people's self-governance institutions could remedy the situation. However, the impact has been moderate so far due to biomass available from irrigated areas. Of course during famines, the relief provided by State agencies in the form of fodder imports from outside the region helps avert crisis (Dhir, 2003). As the wages in Thar Desert today are higher than those in other parts of Rajasthan, the region is attracting labor from outside. The stress due to drought has got greatly reduced due to the ability of the State to provide necessary relief. A very significant development has been interest in renewable sources of energy. Abundant land at affordable cost and promotional efforts of the Government has made the region a hub of solar power plants in the country.

Global warming has added a new dimension in the destiny of environmentally marginal areas. Most studies conclude that rainfall may not decrease but it is certainly going to get more erratic and torrential in character. Further, rise in potential evapo-transpiration of crops is going to increase their water requirement. This, along with rise in temperature, is going to reduce the length of growing season during winter and thus adversely affect the yield potential of winter season crops, which are a major contributor to economy of the region.

Conclusions

Despite the availability of appropriate technologies, progress in control of desertification has been low. Harshness of climate with high incidence of droughts, less than satisfactory societal organization and lack of co-operation with the proposed exclusion of lands from traditional user rights, and high costs are some of the major constraints. Best results have been obtained in situations where the people's livelihoods and welfare are taken care of in the process of desertification control; and in situations where such lands form a part of bigger economy that can afford alternate enterprises and job-absorbing infrastructure and service sector. Solar power generation is one such activity. Renewed commitment in the form of UNCCD-promoted 'land degradation neutrality' program lends a hope in this direction.

References

Abdi, A.E. Glover and O. Luukkanen. 2013. Causes and impacts of land degradation and desertification: Case study of the Sudan. *International Journal of Agriculture and Forestry* 3(2): 40-51.

Abuhussain, A.A., A. Abdu, W.K. Al-Zubari, N.A. El-Deen and M. Abdul-Raheem. 2002. Desertification in the Arab Region: analysis of current status and trends. *Journal of Arid Environments* 51: 521-545.

Agnew, Clive and Andrew Warren. 1996. A framework for tackling drought and land degradation. *Journal of Arid Environments* 33(3): 309-320.

Akhtar-Schuster, M., L.C. Stringer, A. Erlewin, G. Metternicht, S. Minelli, U. Safriel and S. Sommer. 2017. Unpacking the concept of land degradation neutrality and addressingits operation through the Rio Conventions. *Journal of Environmental Management* 195(1): 4-15.

Anonymous. 2010. Degraded and Wastelands of India: Status and Spatial Distribution. Indian Council of Agricultural Research New Delhi and National Academy of Agricultural Sciences New Delhi. 76 p.

Anonymous. 2012. Elucidation of 5th National Report Submitted to UNCCD Secretariat, Ministry of Forests and Environment, Govt. of India, New Delhi. 45 p.

Bojö, J. 1996. The costs of land degradation in Sub-Saharan Africa. *Ecological Economics* 16: 161-173.

Bradley, D. and A. Grainger. 2004. Social resilience as a controlling influence on desertification in Senegal. *Land Degradation and Development* 15: 451-470.

CBD. 2010. Decision Adopted by the Conference of the Parties to the Convention on BiologicalDiversity at its Tenth Meeting. X/2. The Strategic Plan for Biodiversity 2011-2020 and the AichiBiodiversity Targets. (UNEP/CBD/DEC/X/2). Available from:https://www.cbd.int/decision/cop/?id=12268.

Cheng, L., X. Cui, L. Gong and Gi, Lu. 2013. Methodologies for Valuating Desertification Costs in China - Case Study 1. Pages 57-60 *in* "Economic and Social Impacts of Desertification, Land Degradation and Drought, White Paper I". UNCCD 2nd Scientific Conference. United Nations Convention to Combat Desertification (UNCCD) Ed. Low, P.S. Bonn, Germany.

Cowie, A., U.A. Schneider and L. Montanarella. 2007. Potential synergies between existing multilateral environmental agreements in the implementation of land use, land-use change and forestry activities. *Environmental Science & Policy* 10: 335-352.

Darokh, M.B.K. 2003. Desertification in the drylands: A review of the African situation. *Annals of Arid Zone* 42: 289-308.

Dhir, R.P. 1995. Problem of desertification in arid zone of Rajasthan-A view. *Desertification Control Bulletin* 27: 45-52

Dhir, R.P. 1999. Natural resources and desertification: Need for refinement of behavioral interpretations. Pages 1-4, *in* "*Management of Arid Ecosystem*" (Eds. A.S. Faroda, N.L. Joshi, S. Kathju and A. Kar. Arid Zone Research Association of India and Scientific Publishers, Jodhpur.

Dhir, R.P. 2003. Thar Desert in retrospect and prospect. *Proceedings of Indian National Science Academy* 69 Part A: 167-184.

Dhir, R.P., D.C. Joshi and S.K. Kathju. 2018. *Thar Desert in Retrospect and Prospect* Scientific Publishers, Jodhpur. 404 p.

Dregne, H. 1983. *Desertification of Arid Lands*. Harwood Academic Publishers. New York. 203 p.

Dregne, H., M. Kassas and B. Rozanov. 1991. A new assessment of the world status of desertification. *Desertification Control Bulletin* 20: 6-18.

Eriksen, H.S. 2003. Biophysical processes and livelihood interactions in the drylands. *Annals of Arid Zone* 42: 231-254

Fleskens, L., B. Irvine, M. Kirkby and D. Nainggolan. 2012. Desertification Mitigation and Remediation of Land (DESIRE) - A global approach for local solutions: Deliverable. 5.3.1. Model outputs for each hotspot site to identify the likely environmental and social effects of proposed remediation strategies. 156 p.

Fuller, D.O. and C. Ottke. 2002. Land cover, rainfall and land-surface albedo in West Africa *Climate Change* 54: 181-204.

Gao, Z.L., Y.H. Li, J. Xu, Z.Z. Wang, J. Zhao, W. Guo and K.S. Peng. 2009. Research on eco-construction and control measures of soil and water loss in the Loess Plateau. *Science Technology and Industry* 9(10): 1-12.

Grainger, A. 2015. Is Land Degradation Neutrality feasible in dry areas? *Journal of Arid Environments* 112: 14−24.

Hulme, M. and M.K. Kelly. 2013. Exploring the links between desertification and climate change. *Environment* 35: 439-451.

Jiang, H. 2002. Culture, ecology and nature's changing balance: Sandification on Mu Su sand land, Inner Mongolia, China. Pages 181-196 *in* "Global *Desertification: Do humans cause deserts* ? (J.F. Reynolds and M.S. Smith eds.), Dahlem University Press, Berlin.

Kar. A, P.C. Moharana, P. Raina, M. Kumar, M.L. Soni, P. Santra, A.S. Arya, and P.S. Dhinwa. 2009. Desertification and its control measures. Pages 1-47 *in* Trends in Arid Zone Research in India (A. Kar, B.K. Garg, M.P. Singh and S. Kathju, eds.), Central Arid Zone Research Institute, Jodhpur.

Lal, R. 2000. Carbon sequestration in drylands. *Annals of Arid Zone* 38: 1-11

Lal, R. 2001. Potential of desertification control to sequester carbon and mitigate the greenhouse effect. *Climate Change* 15: 35-72

Low, P.S. (ed.). 2013. Economic and Social Impacts of Desertification, Land Degradation and Drought. White Paper I. UNCCD 2nd Scientific Conference, prepared with the contributions of an international group of scientists. United Nations Convention to Combat Desertification (UNCCD). Bonn, Germany. 62 p.

Middleton, N.J. and D.S.G. Thomas. 1997. World Atlas of Desertification. 2nd Edn. Arnold, London

Mortimore, M. 2003. Is there a new paradigm of dryland development *Annals of Arid Zone* 42: 459-482.

Mugerwa, K.W. 2018. Capacity Building and Criticality of People's Participation in Drought Management and Desertification Control in Uganda, East Africa. Pages 185-206 *in* Drought Management and Desertification Control: Still Miles to Go. Daya Publishing House, New Delhi.

Olagunju, T.E. 2015. Drought, desertification and the Nigerian environment: A review. *Journal of Ecology and Natural Environment* 7(7): 196-209.

Osinubi, T.S. and O.S. Osinubi. 2006. Ethnic conflicts in contemporary Africa: The Nigerian experience. *Journal of Social Sciences* 12(2): 101-114. DOI: 10.1080/09718923.2006.11978376

Reddy, V.R. 2003. Land degradation in India: Costs and determinants. *Economic and Political Weekly* XXXVIII(44): 4700-4713.

Reed, M.S. and L.C. Stringer. 2016. *Land Degradation, Desertification and Climate Change-Anticipating, Assessing and Adapting to Future Change*. Rutledge, London. 184 p.

Rocheleau, D.E., P.E. Steinberg and P.A. Benjamin.1995. Environment, development, crisis crusade. *World Development* 23: 1037-1051.

Samra, J.S. and P.D. Sharma. 2005. Quality of soil resources in India. Pages 1-29 *in* "Souvenir International Conference on Soil, Water and Environment Quality-Issues and Priorities" Indian Society of Soil Science, New Delhi.

Sandford, H. 1993. Towards Global Food Security: Fighting against hunger. Towards Earth Summit, Social Briefing No.2.

Saxena, S.K. 1977. Desertification due to ecological changes in the vegetation of Indian desert. *Annals of Arid Zone* 16: 367-373.

Saxena, S.K. 1993. Impact of successive droughts on the natural flora of Indian Arid Zone. Pages 159-168 *in* Desertification and Its Control in the Thar, Sahara and Sahel Regions (A.K. Sen and A. Kar, eds.). Scientific Publishers, Jodhpur.

Shankar, V. and S. Kumar. 1988. Vegetation ecology of Indian Thar Desert. *International Journal Ecology and Environment* 14: 131-155.

Shankarnarayan, K.A. 1988. Ecological degradation of Thar Desert and eco-regeneration. Pages1-14 *in* Desert Ecology (I. Prakash, ed.). Scientific Publishers, Jodhpur.

Smith, M.S. and J.F. Reynolds. 2003. Interactive role of human and environmental dimensions in the desertification debate. *Annals of Arid Zone* 42: 255-270.

Spooner, B. 1982.Rethinking Desertification: the social dimension. Pages 1-25 *in* Desertification and Development. Academic Press, London.

Stringer, L.C., A.J. Dougill, A.D. Thomas, D.V. Spracklen, S. Chesterman, C. IfejikaSperanza, H. Rueff, M. Riddell, M. Williams, T. Beedy, D.J. Abson, P. Klintenberg, S. Syampungani, P. Powell, A.R. Palmer, M.K. Seely, D.D. Mkwambisi, M. Falcao, A. Sitoe, S. Ross and G. Kopolo. 2012. Challenges and opportunities in linking carbon sequestration, livelihoods and ecosystem service provision in drylands, *Environmental Science and Policy* 19-20: 121-135. doi: 10.1016/j.envsci.2012.02.004

Stringer, L.C., J. Dyer, M.S. Reed, D.J. Dougill, C. Twyman, D. Mkwambisi. 2009. Adaptations to climate change, drought and desertification: insights to enhance policy in southern Africa. *Environmental Science and Policy* 12(7): 748-765.

Suresh Kumar. 1997. Vegetation of the Indian Arid Ecosytem. Pages 71-79 *in* Desertification Control (S. Singh and A. Kar, eds.). Agro Botanical Publishers (India), Bikaner.

Thomas, D.S.G. and N.J. Middleton. 1994. Desertification: Exploding the Myth. Willey New York. 248 p.

UN General Assembly (UNGA). 2015. Transforming Our World: the 2030 Agenda for SustainableDevelopment. Resolution adopted by the UNGA on 25 September 2015 (A/RES/70/1 Available from: http://www.un.org/ga/search/view_doc.asp?symbol=A/RES/70/1&Lang=E

UNCCD. 2018. A Rising Africa in a Fragile Environment-The Initiative to Sustainability, Stability and Security. UNCCD Bonn, Germany. 25 p.

USAID. 2011. Climate Change and Conflict in Uganda: The Cattle Corridor and Karamoja, U.S. Agency for International Development 1300 Pennsylvania Ave, NW Washington, DC 20523. 60 p.

Wang, T. 2014. Aeolian desertification and its control in Northern China. *International Soil and Water Conservation Research* 2(4): 34-41.

Warren, A. and L. Olsson. 2003. Desertification: loss of credibility despite evidence. *Annals Arid Zone* 42: 271-289.

A century of climate variations in the Horn of Africa drylands: Implications on soil erosion and flood hazard

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Abstract

A major proportion of the Horn of Africa is dryland. Though the population of this area has the highest growth in Africa, the traditional, low yield, rain-fed agriculture is unable to meet a constantly growing demand of primary goods. In this insecure situation, climate variability plays an important role, resulting in a worsening of land degradation and flood hazard. Analysis of the main climatic parameters over 1901-2015, using gridded data, showed the most striking change is temperature; it increased, particularly after the 1960s, in all the studied countries, i.e. Eritrea, Djibouti and Somalia. By contrast, rainfall trends were not so evident. Rainfall erosivity, expressed through the R-factor of the USLE, showed a moderate decrease in Eritrea, stability in Djibouti and a slight increase in Somalia. Aridity is a common condition in all the three countries. The De Martonne aridity index values indicate irrigation as indispensable for all the three, but particularly in Eritrea. The Horn of Africa is affected by several climate-related disasters, such as droughts and floods, whose frequency and effect on people have remarkably increased in the last two decades. Though the recent climate variations are evident, it seems they are not the only reason for the onset of such worrying situations, which are analysed with a focus on the Wabe Shebelle river for the flooding hazards.

Introduction

Climate change is occurring globally and some of the observed changes have established new records in recent years (EEA, 2012). Climate change has already led to a wide range of impacts on environmental systems and society and further impacts are expected in the future. Climate related natural disasters have increased and damage costs are expected to increase, as well. Climate change can exacerbate the socio-economic imbalances of communities, especially in highly vulnerable areas such as drylands, in developing countries that already find major constraints to their development in land degradation (ELD Initiative and UNEP, 2015), recurrent droughts and devastating floods (Billi *et al.,* 2015: Tadesse *et al.,* 2018). According to the current projections of climate change in African drylands, also agriculture will be severely affected. Yields from rain-fed crops could be halved by 2020 insome countries, leading to a worsening food security and increase in the number of people at risk from hunger (UNFCCC, 2007). The drylands of the Horn of Africa (Eritrea, Djibouti and Somalia) do not escape and are even more vulnerable to such negative impact and hazards. An insight into the climate variability throughout the last century can provide basic information to enhance the knowledge base for adaptation and to design scientifically based mitigation strategies in these countries. That is the main aim of this study.

Study area and data

The countries considered in this study are Eritrea, Djibouti and Somalia. They were selected because the majority of their territory is subjected to arid and semi-arid climatic conditions and they are already experiencing severe land degradation (ELD Initiative and UNEP, 2015). For this study, gridded country averaged mean monthly temperature and precipitation data were used. Data were obtained from the Climate Change Knowledge Portal of the World Bank Group (https://climateknowledgeportal.worldbank.org/), which are based on Gridded data by the Climatic Research Unit (CRU) of University of East Anglia (UEA), UK, and cover a long interval from 1901 to 2015. These data were also processed to obtain time series of the USLE rainfall erosivity R-factor by means of the Renard and Freimund (1994) relation:

$$R = 0.0483P^{1.61} \quad [1]$$

in which P is annual rainfall (in mm) and the units of R is MJ mm ha^{-1} h^{-1} yr^{-1}.

In order to check about trend in aridity, the De Martonne (1925) aridity index was used:

$$I_a = P/(T+10) \quad [2]$$

in which P is annual precipitation in mm and T is mean annual air temperature in °C. This aridity index is very old but it was selected because it requires only temperature and precipitation data, whereas other more accurate and popular methods, such as the UNEP (1992) aridity index, need detailed data that are not available for the study area. Moreover, the specific values of the Aridity Index are related to the specific needs for irrigation (Baltas, 2008; ARPAV, 2019) as shown in Table 1.

Table 1. *Relationship between the De Martonne (1925) Aridity Index and irrigation requirement (Baltas, 2008; ARPAV, 2019)*

I_a	Condition	Irrigation
<5	Arid	Indispensable
5-10	Semi-arid	Indispensable
10-20	Dry sub-humid	Very useful
20-30	Sub-humid	Often useful
30-50	Humid	Not required

Data about natural disasters in the study countries were obtained from the EM-DAT, the International Disaster Database, managed by the Centre for Research on the Epidemiology of Disasters (CRED, 2019).

Results

Temperature

The time series of mean temperature in Figure 1 shows a marked temperature increase, especially after 1965, in Djibouti and Somalia with an increase of about 1°C in the last 50 years. The situation of Eritrea is more complex; there is a clear increase in temperature but the time series is broken into two portions (Fig. 1a), both showing a marked increasing trends, but between 1940 and 1943 there is a sharp drop of 2°C that cannot be interpreted as a natural phenomenon.

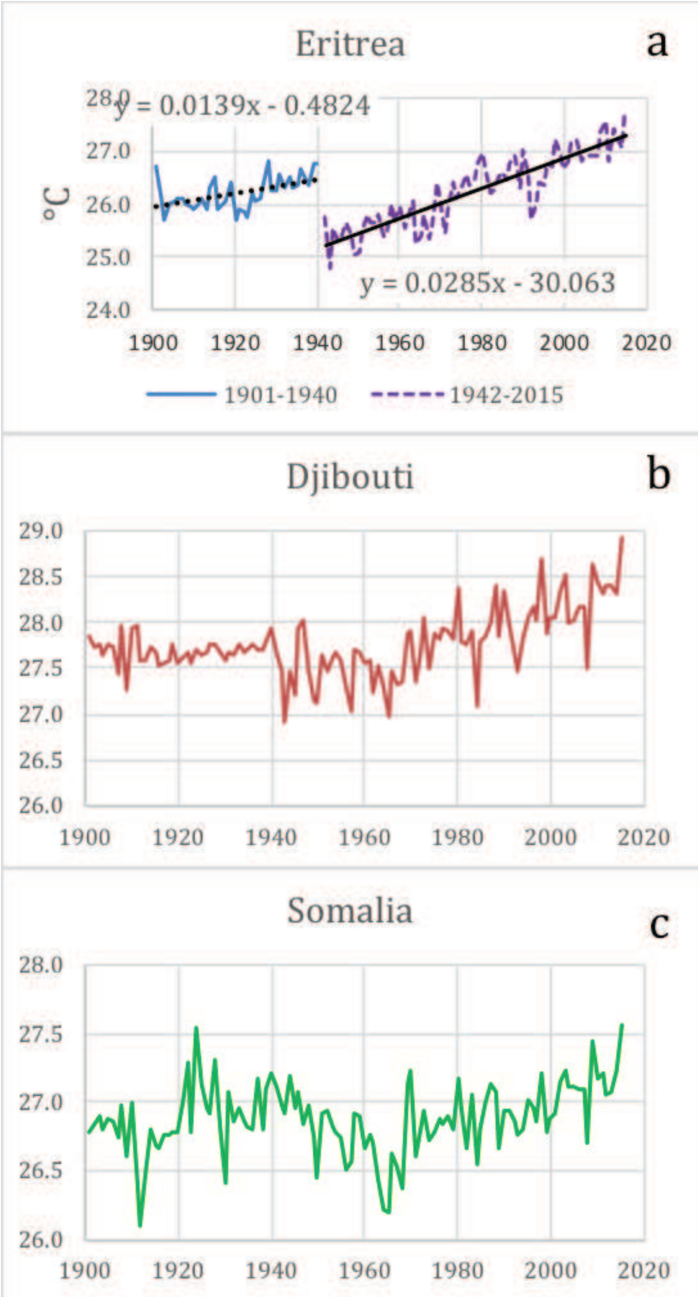


Figure 1. *Variation of mean temperature in the study countries.*

The most likely explanations can be a change of position of the reference meteorological stations or a change of the measuring devices. Nevertheless, both portions of the time series indicate a marked increasing trend, the one after 1942 shows a higher rate of change of about 2°C in the last seven decades. This pattern is comparable with that of Djibouti, whereas in Somalia the 1901-1940 period is characterized by an increasing trend, followed by a decreasing trend from 1940 to 1965 (Fig 1c).

An average temperature time series was constructed for the studied countries and the distribution of temperature anomalies was compared with those of the whole planet across the 1901-2015 interval (Fig. 2). The two curves have a similar general pattern, though the inter-annual variability in the studied countries is higher, as it would be expected given the influence of local factors such as the strength of the ENSO and the position of the ITCZ. Also in the world curve there is a substantial increase starting around the early 1960s and after this date the interpolating trending lines are almost parallel. They are parallel also in the 1901-1940 interval, but the rate of increase is half of that after 1965. From 1940 to 1964, both series show a decreasing trend, which is more marked in the studied countries.

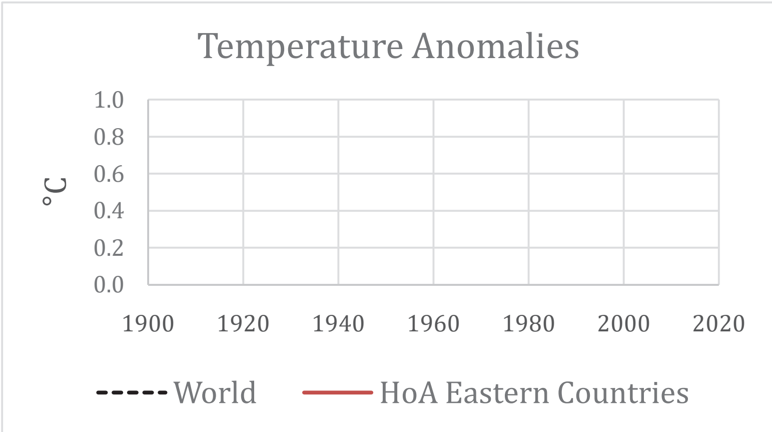


Figure 2. *Temperature anomalies recorded in the entire planet and in the Horn of Africa Eastern Countries.*

Precipitation

Unlike temperature, annual rainfall time series shows different trends for the three countries (Fig. 3). In Eritrea there is a substantial decrease of about 0.3 mm yr^{-1}, leading to an average reduction in annual rainfall of about 37 mm over the period 1901-2015 (Fig. 1a), about 13% of mean annual precipitation (287.2). In Djibouti there is no change over the same time interval (Fig. 1b), but this country experienced the largest inter-annual variability with a coefficient of variation of 0.40 (mean annual precipitation is 246.1 mm) compared to 0.24 and 0.20 of Eritrea and Somalia, respectively. By contrast, the long-term trend of Somalia annual rainfall shows a moderate increase (Fig. 1c), an increase of about 13 mm over the period 1901-2015 (about 5% of mean annual precipitation 270.1 mm). Unlike temperature, in the three countries there is no evidence of any particular pattern, other than wavy, non-cyclic, patterns as pointed out by the 10-year mobile average of Fig. 3.

Rainfall erosivity

Though the long term trends and the inter-annual variations of rainfall are important parameters in water resources, soil moisture and agriculture productivity, rainfall intensity and erosivity are a crucial factor in soil erosion and, hence, in determining crop yield.

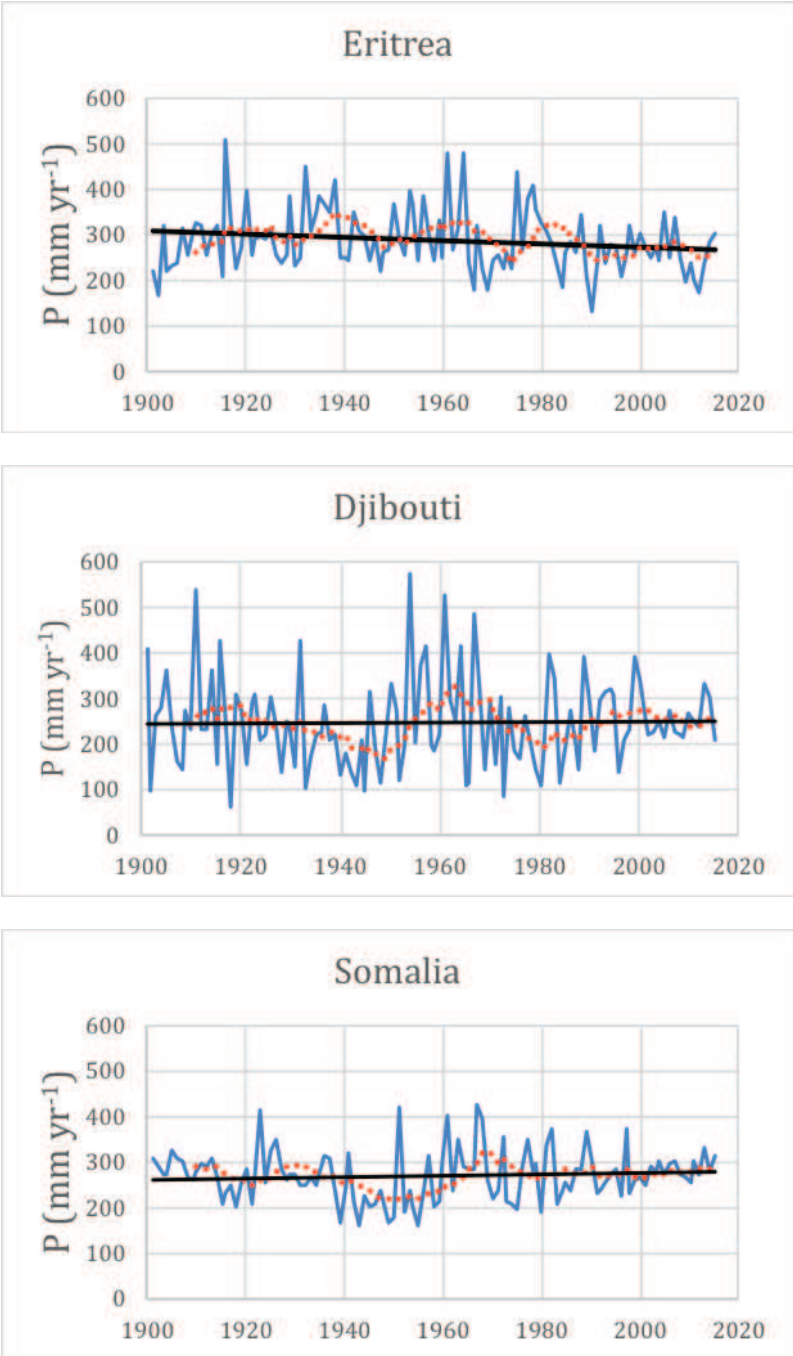


Figure 3. *Variation of annual precipitation and trend lines. The dotted line is the 10 year moving average.*

Unfortunately, no generalized information of rainfall intensity is available for these countries, but the USLE R-factor can be calculated for each year using Eq. 1 and its variability throughout the 1901-2015 period can be analysed. Since this parameter is calculated by means of a power equation based on annual precipitation, the results obtained and their trends and inter-annual variations follow a pattern similar to that of precipitation. In fact, in Eritrea erosivity tends to decrease, in Djibouti there is no evidence of a clear trend, whereas in Somalia the R-factor tends to increase (Fig. 4).

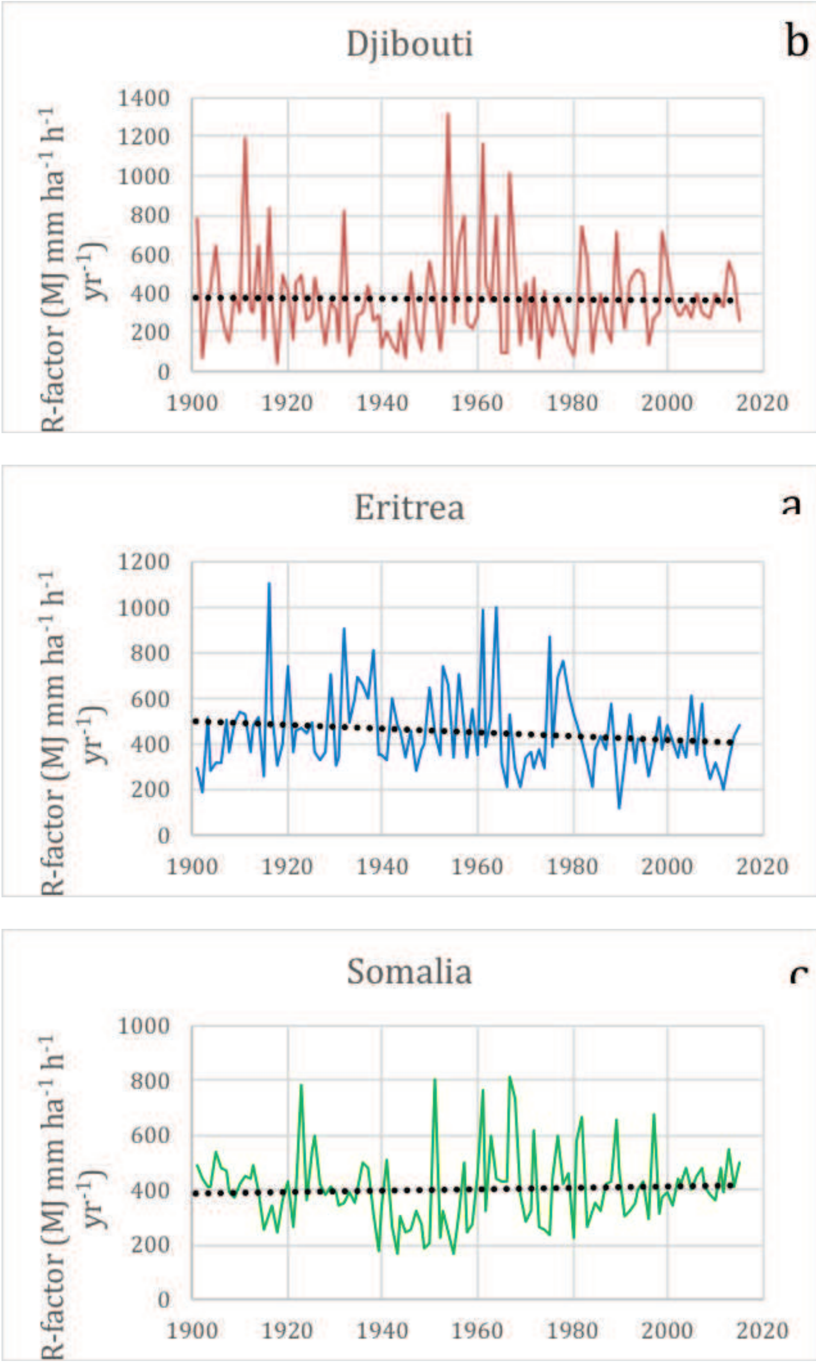


Figure 4. *Erosivity R-factor variation through time. Trend lines indicated by dotted lines.*

Average values of R-factor are 434, 395 and 419 MJ mm ha^{-1} h^{-1} yr^{-1} for Eritrea, Djibouti and Somalia, respectively. These values are comparable with those measured for north-western drylands of China (Yin *et al.,* 2013 in Yin *et al.,* 2017), but they are four time smaller than those observed in the semi-arid/sub-humid southern Italy (Yin *et al*., 2017). In southern Italy, in fact, annual rainfall is twice that in the studied countries. In the countries under study, though the rainfall is lesser than in Italy, it is likely to be more intense, and with the poorly developed soils and cultivation practices, even a small increase in erosivity may exacerbate land degradation.

Aridity

Aridity is an important factor in sustainable agriculture. An increase of aridity, especially in drylands, may lead to a decrease in soil moisture, soil quality degradation, diminished soil fertility and less opportunities for irrigation. Aiming to shed some light on aridity trends, time series of the De Martonne aridity index (I_a) were constructed using Eq. 2 (Fig. 5).

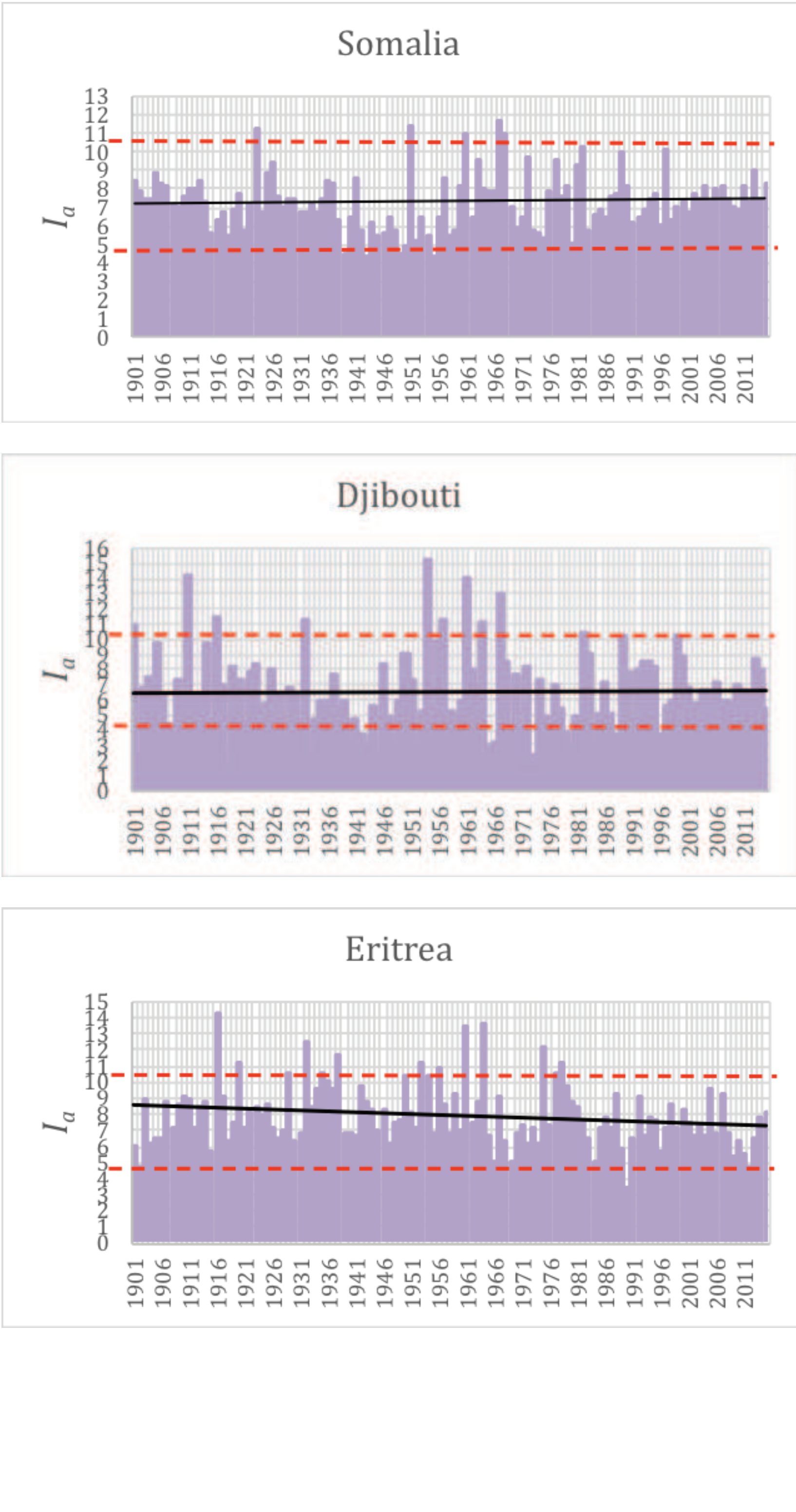
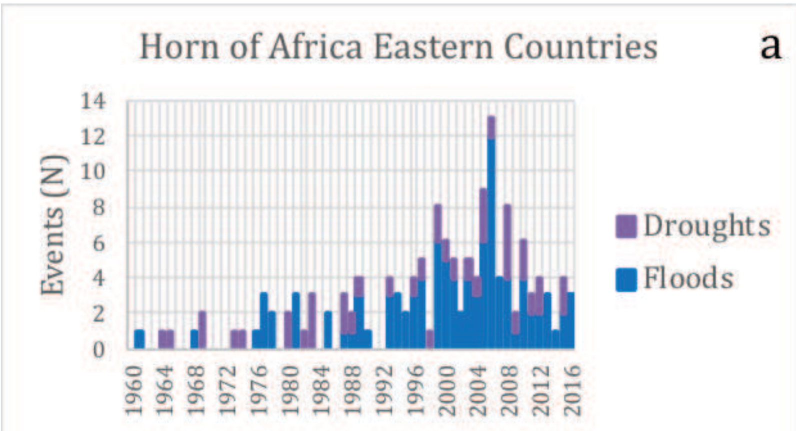


Figure 5. Time variation of the De Martonne (1925) aridity index. The dashed lines indicate the range of aridity values for which irrigation is indispensable (see text for explanation and Table 1). Trend is indicated by the solid lines.

In the three countries, the aridity index ranged between 5 and 10 (in Fig. 5, this range is marked with two dashed lines), confirming that irrigation is indispensable here for agriculture. In Eritrea, the index shows a decreasing trend, in Djibout no detectable change and in Somalia an increasing trend, although the rate of increase is very low and, at the current rate, it would be virtually possible to go beyond the critical irrigation conditions (i.e. $I_a > 10$) only after one thousand years. Eritrea has distinct annual precipitation according to elevation. In the highland, the annual rainfall is around 500 mm, whereas on the coast and in the Danakil lowlands it reduces to 170 and 50 mm, respectively.

Climate change and natural disasters

It is well known that climate change is propelling a substantial increase in frequency and intensity of natural disasters all over the world, and the studied countries are not an exception. The number of events and of affected people for the two major climate-related disaster, floods and droughts, in the studied countries between 1960 and 2016 is shown in Fig. 6. Both numbers have substantially increased in the last two-three decades. This reflects the intrinsic vulnerability of drylands to natural disasters, the lack of warning systems and the inability (for many and varied reasons and constraints) of the local land managers to deploy effective mitigation measures.



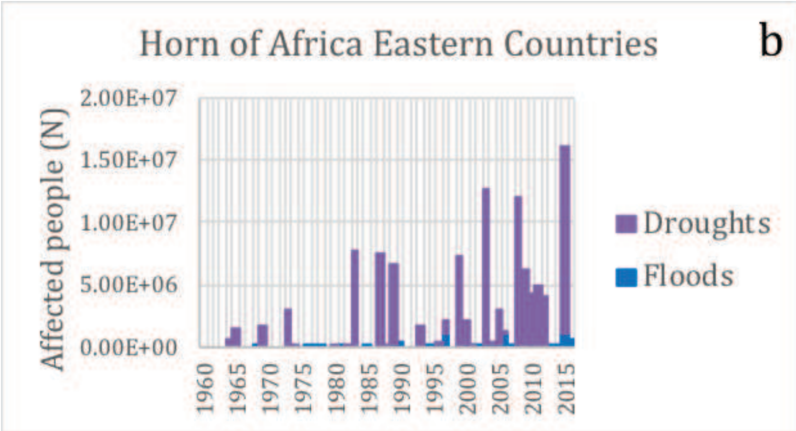


Figure 6. *Total number of disasters and people affected in the Horn of Africa Eastern countries. A marked increase is evident in the last five decades.*

In the Horn of Africa Eastern Countries, floods are the most frequent disaster, whereas droughts are affecting the largest proportion of people. Floods are more common in Somalia whereas the frequency of droughts is higher in Somalia and Djibouti and their occurrence has become a serious menace also in Eritrea after the early 1990s. Somalia is the country where the largest number of people has been affected by both floods and droughts. In many cases, however, the negative impacts of climate change are exacerbated by human activities, such as land use change (Billi *et al.,* 2015), land mismanagement, inappropriate design of infrastructures (Demissie *et al.,* 2016) or overgrazing (Gabriels and Cornelis, 2019). An interesting example of that is given by the Wabe Shebelle river (Fig. 7) daily discharge and floods frequency intensity of which has markedly increased in the last two-three decades.

In the previous section, it has been pointed out that Somalia is characterized by an increasing trend in the annual precipitation (Fig. 3). The rainfall time series maps for the 2000-2017 interval of FSNAU-FAO (2017) also indicate that, in the last two decades, a substantial rainfall increase occurred, with an increased frequency of heavy rains on the lower reaches of Juba and Shebelle river, that often are associated with devastating floods. Though in this flat area drainage is poor, such high floods cannot be accounted for only by the increase in local rainfall.

Suspended sediment transport measurements on the Wabe Shebelle river (Omuto *et al.,* 2009) revealed that during floods the sediment concentration could reach as high as 30-40 mgl_{-1}, whereas during lower flows normal values are in the 10-20 mgl_{-1} range, which are still notable.

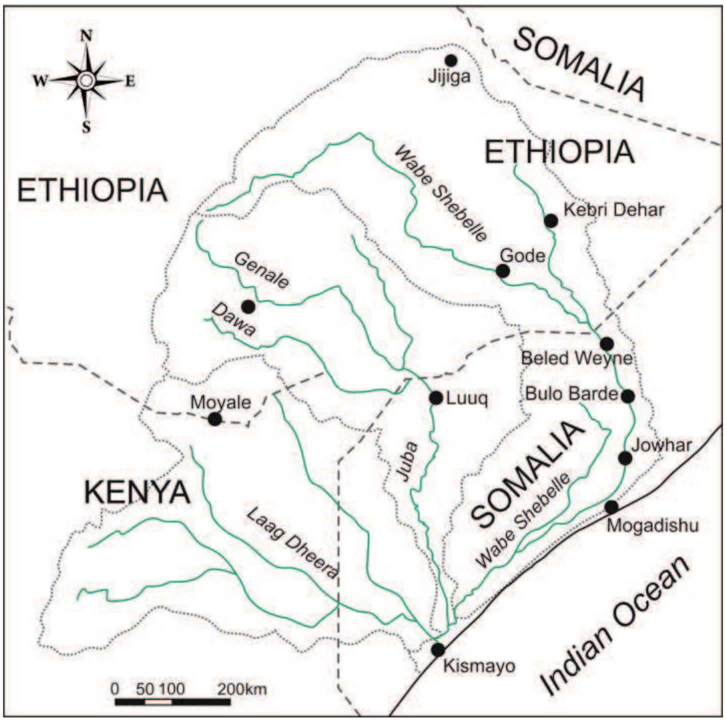


Figure 7. *The drainage basins of the Wabe Shebelle-Juba river system.*

A peculiar characteristic of the Wabe Shebelle river is that from Beled Weyne, near the Somalia-Ethiopia border, to Afgoye (a small town near Mogadishu) its runoff and mean discharge decrease substantially from 2580 x10^6 m^3 to 126 x10^6 m^3 and from 83 m^3s^{-1} to 47 m^3s^{-1}, respectively, within a river length of about 500 km (Fig. 8). Such a loss of water is due to many factors, including a natural infiltration through the stream bed to the water table. However, in the whole river reach between Beled Weyne and Afgoye many water diversions schemes (official and unofficial) for irrigation are present. They substantially contribute to decrease in the runoff along the river, mainly during intermediate or lower than bankfull flows.

Though during high floods, a decrease in peak discharge due to water withdrawal by diversion schemes may be not so evident, it would be useful to reduce the flood risk in the downstream lowland. During lower than bankfull flows, however, a downstream decrease in stream power may result in high sedimentation rates, which, given the high sediment concentration, may be a main cause of streambed aggradation. Using the field data measured by Omuto *et al.* (2009) it was possible to calculate in Afgoye an average streambed aggradation ranging from 1 to 13 cm yr^{-1}. This high rate of aggradation, combined with an increase of local rainfall, may account for the increased frequency of devastating floods in the lower reaches of the Wabe Shebelle river and points out the role of human impact in exacerbating the risk of climate-related disasters.

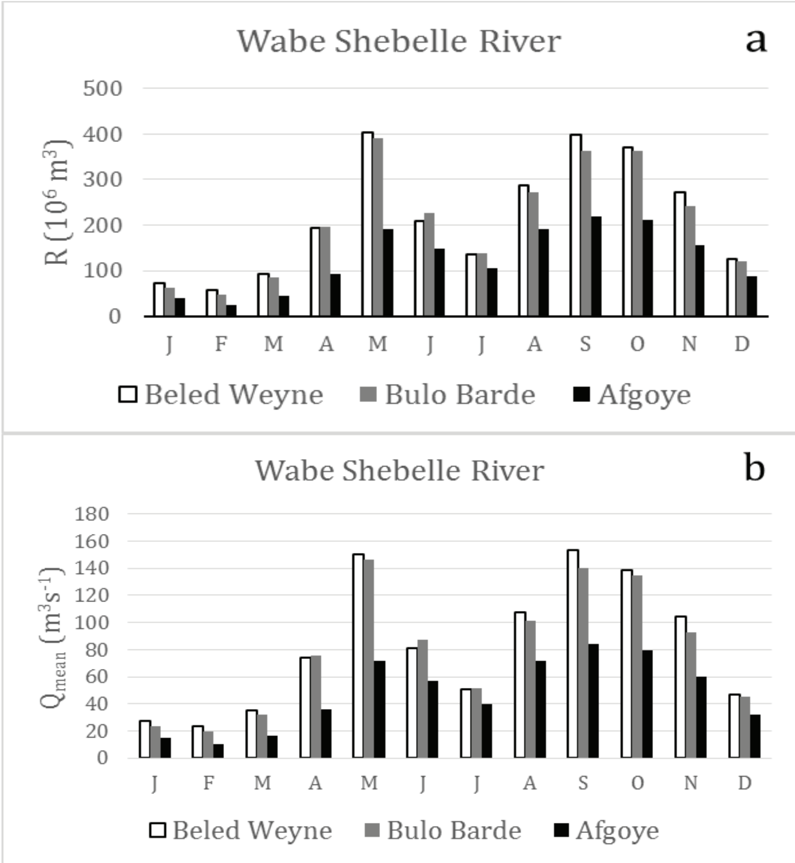


Figure 8. *Downstream decrease in (a) runoff and (b) mean discharge of the Wabe Shebelle river.*

Conclusions

In the Horn of Africa Eastern Countries, there is an increasing trend in the temperature in the period 1900-2015. The rate is comparable with the global rate. Annual precipitation does not show a clear trend, but there is a small decreasing trend in Eritrea, no trend in Djibouti and an increasing trend in Somalia. The USLE erosivity factor (Renard and Freimund, 1994) shows similar patterns as precipitation since it is based on a power function of annual rain. The De Martonne aridity index shows worsening conditions in the investigated period, with irrigation becoming increasingly indispensable, particularly for Eritrea. The frequency of climate-related disasters, such as droughts, famine and flooding, have remarkably increased in the last few decades, but the local human impact factor is often accelerating this process.

References

ARPAV. 2019. http://www.arpa.veneto.it/temi-ambientali/agrometeo/dati/cartografia/de-martonne

Baltas, E.A. 2008. Climatic conditions and availability of water resources in Greece. *International Journal of Water Resources Development* 24(4): 635-649

Billi, P., Y. Alemu and R. Ciampalini. 2015. Increased frequency of flash floods in Dire Dawa, Ethiopia: change in rainfall intensity or human impact? *Natural Hazards* 76(2): 1373-1394.

CRED. 2019. International Disaster Database. https://www.emdat.be/emdat_db/.

De Martonne, E. 1925. Traitede Geographie Physique. A. Colin, Paris. 1519 p.

Demissie, B., P. Billi, A. Frankl, M. Haile and J. Nyssen. 2016. Excess river sedimentation at bridges in the Raya Graben (Northern Ethiopia). *Land Degradation and Development* 28: 946-958.

EEA. 2012. Climate change, impacts and vulnerability. *In* Europe 2012. An indicator-based report. Report No 12/2012, European Environment Agency, Copenhagen. 300 p.

ELD Initiative and UNEP. 2015. The Economics of Land Degradation in Africa: Benefits of Action Outweigh the Costs. ELD Initiative, Bonn. 155 p.

FSNAU-FAO. 2017. Somalia rainfall performance, 2000-2017: Deviation from long term mean. https://reliefweb.int/sites/reliefweb.int/files/resources/Somalia-Rainfall-Time-Series-for-2000-2017.pdf

Gabriels, D. and W.M. Cornelis. 2019. Human-induced land degradation. *In* Land Use, Land Cover and Soil Sciences - Vol. III (W.H. Verheye, ed.). Encyclopedia of Life Support Systems, UNESCO-EOLSS,

Omuto, C.T., R.R. Vargas and P. Paron. 2009. Soil erosion and sedimentation modelling and monitoring framework of the areas between rivers Juba and Shabelle in southern Somalia. FAO-SWALIM Technical Report No. L-16. Nairobi, Kenya.

Tadesse, Y., A. Amsalu, P. Bill and M. Fazzini. 2018. Drought magnitude and frequency in the region of Dire Dawa, eastern Ethiopia. *Journal of Water and Climatic Change* 9(3): 624-630.

UNEP. 1992. World Atlas of Desertification. Edward Arnold, London, UK.

UNFCCC. 2007. Climate change: impacts, vulnerabilities and adaptation in developing countries. United Nations Framework Convention on Climate Change. Bonn. 60 p.

Yin, S., M.A. Nearing, P. Borrelli and X. Xue. 2017. Rainfall erosivity: An overview of methodologies and applications. *Vadose Zone Journal* 16(12). DOI: 10.2136/vzj2017.06.0131

Innovative 'Green Grassroots Plantation Technique' for combating desertification

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Abstract

Drylands are an important resource for sustaining the livelihoods of millions of people the world over. However, they are being degraded, even desertified, by anthropological pressures and climate change. Afforestration of degraded drylands and introduction of agroforestry in the water scarce areas, based on the traditional knowledge wedded to modern scientific practices, can be a potential solution to enhance the resilience of dryland people against the adverse impact of above changes. This paper presents a novel technique for establishing trees for agroforestry systems in very dry areas where the vegetation essentially thrives on moisture conserved in the soil from the scanty rainfall events in western Rajasthan. The technique is called 'One Litre Water Technique of Agroforestry', developed by one of the Grassroots Progressive Farmers from Rajasthan. It has been used extensively for planting trees under the 'Greening the Desert' initiative. The technique utilizes only one litre of water at the time of transplanting the tree saplings, which then survive and grow on the conserved moisture from the preceeding monsoon rains. Conserving water in the active root zone of the developing trees, through suitable tillage and other agronomic operations, is the key factor in the success of this method of agroforestry in the arid and semi-arid regions of western Rajasthan. Using this technique, over 50,000 trees have been planted in the districts of Sikar and Jodhpur. Apart from local plants and trees of desert region like Prosopis cineraria (Khejri), Tecomella undulata (Rohida) and Ziziphus jujuba (Ber), several shrubs and trees of medicinal and therapeutic value like Azadirachta indica, Ailanthus exelsa, Phyllanthus emblica, Moringa, and Eucalyptus have been planted through this technique at various locations of Rajasthan that have provided the people with fuel, fodder and timber and helped them in increasing their incomes.

Introduction

Drylands are home to nearly one-third of the world population, mainly in the developing world, and are the center of origin of many cultivated plants and livestock. Their rich biodiversity provides high-value niche-specific products that are of immense economic importance to the local communities. Drylands are also endowed with rich heritage of traditional knowledge and culture (Ben-Gal *et al.,* 2006; Barakat, 2009) that have contributed to the resilience of the communities to harsh environments. However, the drylands are under threat due to anthropological pressures (urbanization, over exploitation of natural resources, intensive monoculture of a few selected crops, etc.) and climate change. These changes are leading to wide-scale loss of biodiversity and desertification in the harsher parts of drylands, where there is scarcity of water and the soils are marginal. Tailored policy and conservation strategies for combating desertification are needed that benefit from the traditional knowledge.

Arid drylands are the regions of prolonged dryness where evaporation is higher than precipitation and the production of agricultural crops is limited. Little water that is available from rainfall in the arid zones may not be available to crop plants as the amount may be too small to penetrate soil sufficiently, or it may run off too quickly. Furthermore, weedy species may be so adept at utilizing scarce water that they rob the water from crops (Creswell and Martin, 1998). Water management in the arid regions can effectively be achieved by the combined use of indigenous knowledge systems (IKS) and modern scientific technologies, opening opportunities for enhancing the use efficiency of the scanty rainfall in an eco-friendly manner and protecting soil from damage.

We describe here a unique technique for establishing the plantation of trees for agroforestry system in the arid zone of Rajasthan, India, which combines the modern scientific theory and farmer's knowledge in conserving moisture by reducing evaporative and other losses of water received from rains. This technique has been utilized for the last two decades for agroforestry and is creating an impact, with the plantation success rate of over 80%.

The "One litre water plantation technique" and its implementation

For combating the livelihood problems of the dryland communities due to scarce rains and high evapotranspiration, the technique was developed and standardized by one of the authors (Sundaram Verma) through efforts spanning over a period of 10 years, tackling two major problems of moisture conservation:

- Preventing the capillary rise of water in the soil to prevent loss of moisture due to evaporation, and
- Contolling weeds that rob the trees of their moisture supply conserved in the root zone in the rainy season.

The technique involves breaking of capillaries to prevent soil water loss due to evaporation and conserving groundwater in the root zone and removal of weeds to prevent water loss due to transpiration (Fig. 1). First, the selected site of the plantation is levelled before monsoon, to prevent rainwater run-off, followed by one or two deep ploughings to facilitate percolation of water and removal of weeds a fortnight after rains. A deep ploughing is then repeated just before the end of monsoon. This operation also creates a dust mulch on the surface and breaks the capillary connection between the subsurface and surface, preventing further loss of conserved moisture by surfave evaporation. On the hilly or slopy lands, manual digging of the soil up to 60-90 cm is required.

Pits of about 15 cm diameter and 45 cm deep are prepared on the marked sites at the end of monsoon. The tree saplings are planted in the pits such that all the roots remain in the soil at 20-30 cm below the surface and the surface is further covered with soil up to about 5-10 cm with the remaing top space of about 10-15 cm left empty for watering. Immediately after planting the saplings each pit is irrigated with one litre of water once. The sapling is then left to grow with out any additional irrigation. The complete procedure is completed within a few minutes to minimize the moisture loss. Post planting operation comprises creating the dust mulch and weed control through appropriate tillage (harrowing by tractor or manually).

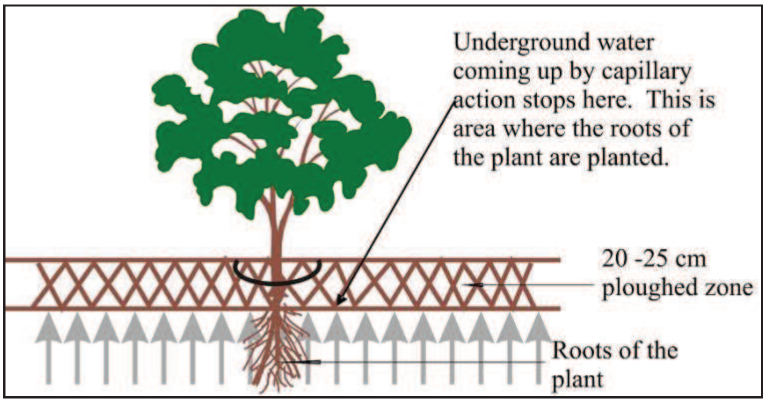

Figure 1. *The one litre water plantation technique.*
(Source: www.gian.org/north/files/Dry%20Land%20Agro%20Forestry-Case%20Study.pdf)

Based upon the technique, plantation of over 50,000 trees was undertaken in the region. The trees planted included species well adapted to the arid regions of western Rajasthan, namely *Holoptelea integrifolia, Prosopis cineraria, Tecomella undulata, Azadirachta indica, Acacia tortilis, Eucalyptus globulus, Ziziphus mauritiana/jujuba, Vachellia nilotica, Leucaena leucocephala, Adhatoda vasica, Dalbergia sissoo, Jatropha curcas, Moringa oleifera* and *Phyllanthus emblica.* These trees are not only the source of food, fiber, fodder, fuel, timber, medicines, shade and shelter but also promising for desert afforestation. With the combined efforts of the innovator, state and central government agencies, including the forest department, and the local people, the planting was done on the deforested areas, community lands and on-field bunds.

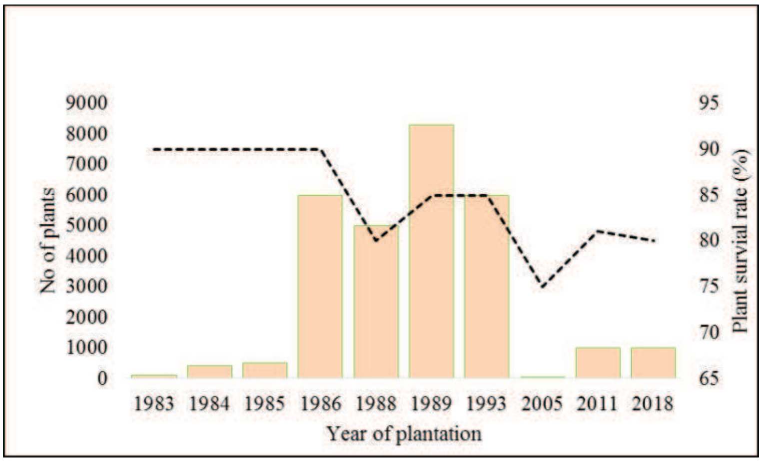

Figure 2. *Pilot projects during 1983-2018 on plantation of different trees and their survival rates using one litre water technique.*

The technique was found to be very successful and the survival rate of plants ranged between 75-90% (Fig. 2), as compared to less than 50% in the general methods adopted for agro-forestry in arid lands. The technique is more productive, low cost and sustainable with higher survival rates of planted saplings and can be used for planting all types of trees. During the trials it was also observed that even if the sapling shoot was damaged by frost, the new shoot germinated from the stumps and roots present in the soil. This technique not only provides opportunities for better income generation from the produce of different trees for the people inhabiting these arid areas, whose incomes from agricultural activities are very low as compared to their counterparts living in other zones, but also ensures environmental sustainability by combating desertification.

Conclusions

The one litre water plantation technique provided the farmers and other stakeholders of arid regions low-cost tool to fight the climate change and desertification but with the prospects of generating incomes through planting trees for food, fodder, fuel, timber, medicines etc. on the arable lands, fallow lands and community pastures, and degraded lands. Despite being a frugal and beneficial method capable of combating deforestation and providing sustainable livelihood, the mass dissemination and adoption of this technique could not be achieved due to lack of awareness and limited resources and support for popularization. There is a need fora policy level intervention that encourages the adoption ofthis techniques in the afforestation and other land management schemes in the arid zones.

References

Barakat, H.N. 2009. Arid lands: Challenges and hopes. Earth system: history and natural variability Vol. III. EOLSS publishers.

Ben-Gal, Alon, Alon Tal and Noemi Tel-Zur. 2006. The sustainability of arid agriculture: Trends and challenges. *Annals of Arid Zone* 45(2): 1-31.

Creswell, R., and F.W. Martin. 1998. Dryland farming: Crops and techniques for arid regions. Educational Concerns for Hunger Organization (ECHO), N. Fort Meyers, FL, 23 p.

Theme 3: Soil Health Management, Carbon Sequestration and Conservation Agriculture

Lead Lectures and Rapid Presentations

Soil organic matter, soil health and sustainability

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Extended Summary

Soil degradation is a major global concern and it results in impaired soil health. Poor soil health leads to low input use efficiency and decreasing factor productivity. Continuous reduction in soil organic matter levels is the principal cause of poor soil health and diminished biodiversity in agricultural soils. This sets up a cascade of events - poor soil biology in turn leads to low ability to build soil organic matter and sequester carbon, loss of soil structure, hard-setting of soils, poor water holding capacity and poor aeration, all of which then feedback into creating further adverse conditions for soil organisms and soil biodiversity. Imbalanced fertilizer usage, intensive tillage, no return of organic materials to soil etc., further accentuate these effects, which all finally lead to loss of soil resilience and soil degradation. Thus, reversing soil biological degradation requires improving the soil's biology. The most important drivers of soil biology are those imposed by climate (temperature, moisture), soil conditions (pH, habitat structure) and resource quality (type of vegetation/management practice).

Knowledge of the modern concepts of soil organic matter formation and the underlying soil biochemistry are important for a critical appreciation of their linkages to soil biological health and its degradation. A major portion of soil organic matter (SOM) is aliphatic in source and largely attributed to root input. Most soil N is composed of proteinaceous-tissue derived materials and cell wall constituents. Amino sugars are important C and N constituents of SOM and comprise 20-35% of soil organic carbon (SOC). A significant proportion of organic nitrogen in soils arises from dead or living soil microbes. In undisturbed soils, 82 biochemical compounds were identified in soil organic matter (Kallenbach *et al.*, 2016); the principal ones were protein and polysaccharides that made up half of the composition of SOM. The most currently accepted pathway is that soil microbes are the principal agents of SOM formation (Cotrufo *et al.,* 2015) because microbial-derived carbon compounds are the primary constituents of stable, long-term organic matter store.

Soil microbes consist mainly of proteins and homo-and hetero-polysaccharides (e.g. chitin, peptidoglycan and lipopolysaccharides). Peptidoglycan accounts for 90% of the weight of gram positive bacteria, is resistant to many chemical and biological processes and is found in the most refractory components of SOM. Lipids are hydrophobic and stabilized considerably in non-living SOM. So, SOM should actually be considered a synonym for all the various forms of microbial biomass in soil (smaller active live portion to greater amounts of necromass). SOM chemical heterogeneity is attributed to microbial metabolism of relatively simple C components (Kallenbach *et al.,* 2016); variations in SOM chemistry, hitherto attributed to soil mineralogy, may also arise due to divergent microbial communities and their metabolic products. Soil microbial biomass is the "eye of the needle" since all plant and

animal carbon inputs compounds are processed through them. Microbial physiological processes that regulate microbial biomass production and turnover strongly relate to SOM accumulation. Organic cropping has been reported to have higher organic carbon, microbial biomass and microbial community, with higher metabolic growth rates, which lead to more rapid incorporation of new carbon inputs into microbial biomass (higher carbon utilization efficiency) and to greater retention of C inputs in the clay fraction of soil, than in the conventional cropping (Kallenbach *et al.,* 2015). So, biologically active and fertile soils will continue to have a high production of microbial biomass and its turnover, leading ultimately to improved SOM content (and greater soil carbon sequestration) since the latter arises from the activity of the former.

A large, diverse, and active population of soil organisms is the most important indicator of a "healthy" soil. Soil microbiome (the entire array of microorganisms in a particular environment) is a sensitive indicator of soil health as it provides an indication of the direction and magnitude of the changes in ecosystem structure and function, earlier and better than other indicators. The ability of organic biodynamic fertilizers to improve soil quality was evaluated in arid loamy sand soils in farmers' fields in Rajasthan, India in cowpea cropping and citrus orchards. Water holding capacity, organic carbon and ammoniacal nitrogen improved significantly in organic farming. Microbial community was evaluated using both a culture dependent and independent approach. Actinomycetes increased significantly in organic cropping and in orchard by 92 and 100%, respectively, compared to conventional management. Bacterial populations increased significantly on nutritionally diverse media in organic farm soils over conventional, both copiotrophs (+52-119%) as well as oligotrophs (+25-79%). The arbuscular mycorrhizal protein, glomalin increased by 56-82% in organic farms. Nitrogen fixers, ammonifiers, nitrifiers and sulfur oxidizers did not show significant differences. There was a consistent increase in soil enzymatic activities in organic farms - acid phosphatase (1.5× in cropping; 3× in orchard), fluorescein diacetate hydrolysis (1.8×; 3.3×), dehydrogenase (2.4×; 3.5×) and β-glucosidase (2.2×; 6.3×). Quantification of 16S rDNA abundance in soil using qPCR showed a clear 1.8 fold increase in both organic cropping and organic orchard soils. The abundance of amoA gene decreased by 22 and 11 folds in organic cropping and orchards. The culture independent analysis of eubacterial 16S rRNA gene showed that organically cropped farms and orchards had more diverse bacterial community compared to the conventional.

The distribution of bacterial species observed in organic cropping is more even. Representation of Proteobacteria among the eubacterial species was 20% lesser in organic as compared to conventional cropping. Good soil biological health is thus directly reflected in high numbers and activity of Actinobacteria, which were higher by 10% in organic cropping. Overall, the results demonstrated unequivocally that organic amendments improved the biological quality through an alteration of the microbial community structure and function. We concluded that organic manures selectively modify the environment and make soil ecosystems more sustainable and have thus designated organic amendments as `ecosystems engineers' (Aparna *et al.*, 2014).

Ecological and agricultural interventions like residue addition, mulching, minimum or no-tillage agriculture, organic farming, integrated nutrient management, agro-forestry practices improve soil biological activity and promote production of microbial biomass and soil organic matter. This implies that soils with the high microbial activity not only give a good indication of its soil biological health but also its long-term potential to sequester carbon. In further work, selected microbial consortia (*Arthrobacter* sp., *Streptomyces* sp., and *Bacillus* sp.) were inoculated in a Bhopal Vertisol (pH: 8.15; EC: 0.26 mS cm^{-1}, organic carbon 0.72%) to assess the formation of SOM in the presence of added organic materials (cereal straw and legume residues) and N fertilizer. Results showed (Table 1) that carbon mineralization (C_{min}) from added residues increased from 19.6% in uninoculated unfertilized soil to 22.4% in treatment where mixture of inoculants was used (a 14.3% increase). Due to addition of N, C_{min} increased from 19.6% to 27.5% (a 40.3% increase). Microbial inoculation did not increase C_{min} further in the N amended soil. Further, C_{min} from FYM amended soils increased by 120% whereas in unamended soils it increased by 260% owing to priming effect of added N. The SOC content at 3 and 6 months of incubation showed progressive decrease due to microbial activity. However at 6 months, among the various treatments, SOC was built up over unamended control (0.63%) by crop residues (0.71%), FYM (0.82%) and vermicompost (0.79%) amendments (Rao *et al.,* 2019). Microbial inoculation increased the organic C in crop residue amended soils to 0.83%. The organic carbon and labile carbon content were highest in soils inoculated with microbial consortium. Other soil properties like carbohydrate and extracellular protein content and soil dehydrogenase activity also indicated improvement of soil biological health by microbial inoculation. Amendment with farm yard manure (FYM) was at par with microbial inoculants in improving the soil biological properties. The effects of inoculation tapered off at 9 months. Results pointed to the value of mixed microbial inoculation in promoting carbon mineralization, SOM formation (soil C sequestration) and biological activity.

Table 1. *Carbon mineralization from added organic materials in a Vertisol at 120 days and soil properties at 180 days of incubation as affected by inoculation with a selected microbial consortium (MC)*

Treatment	**Cum. CO_2-C evolved (mg 100g^{-1} soil) (120 d)**	**% added C_{min} (120 d)**	**pH**	**OC (%)**	**Labile C (mg kg^{-1})**	**Labile C/OC (%)**	**Carbo-hydrate content (mg g^{-1} soil)**	**Extra-cellular protein (mg g^{-1} soil)**	**DHA (µg TPF g^{-1} $24h^{-1}$)**
Control	9.7	0	8.10	0.63	303	4.85	1.77	0.18	21.4
Cereal residue	85.7	12.6	8.10	0.76	477	6.24	2.29	0.20	43.6
Legume residue	98.0	21.9	8.00	0.71	378	5.31	2.86	0.24	35.1
C + Lresidues	110.8	19.6	8.06	0.71	385	5.41	2.73	0.20	31.9
FYM	34.6	12.2	8.03	0.82	497	6.02	2.91	0.28	25.8
Vermicompost	18.2	8.6	8.15	0.79	437	5.53	2.83	0.23	20.3
C + L + MC inoculum	126.6	22.4	7.76	0.83	841	9.88	2.93	0.27	32.5

SOM is the main stay of soil health and the studies all over India have shown that integrated nutrient management systems involving a combination of chemical fertilizers and organic manures are the best for nutrient supply and for building up SOM and maintaining soil health in the long run. Aparna *et. al.* (2016), in a study in semi-arid zone vertisols in Guntur, India, showed that cultivation of legumes improved soil biological health and protected the soils from adverse effects of very high chemical inputs. There was a dramatic increase in β-glucosidase activity (325%), alkaline and acid phosphatase activities (27% and 105%) and decrease in labile carbon mineralization quotient (qMLC) by 37%, indicative of the beneficial effect of legume cultivation even under intensive chemical farming. The deterioration of soil health was obvious in chilli cultivation under intensive chemical farming, where qMLC increased by 49%.

In a long-term experiment on pearl millet conducted for 21 years at Central Arid Zone Research Institute, Jodhpur, India (Saxena *et al.,* 2018), the highest yield sustainability was obtained with combined application of 2.5 t ha^{-1} organic manure and 20 kg urea-N ha^{-1}. However, highest yield and buildup of organic carbon (2.9 g kg^{-1}) and microbial biomass (67.2 μg g^{-1}) as well as dehydrogenase activity were observed when 5 t ha^{-1} manure + 40 kg urea-N ha^{-1} were applied. The labile and highly labile fractions of SOM (due to high microbial activity) as also the least labile fraction (implying more C sequestration) were also highest with 5 t manure + 40N.

Based on a review of global and Indian literature, Rao (2013) concluded that easy-to-measure soil biological parameters that give a good idea of soil health include i) organic C and labile C, ii) soil respiration, iii) population of diazotrophs (N fixers), iv) soil dehydrogenase activity, v) soil enzymes viz., β-glucosidase and acid phosphatase, and vi) glomalin content. All these are inter-related and are of the 'more is better' type. Parameters like microbial biomass carbon, dehydrogenase activity and potentially mineralizable N (PMN) are very important soil biological indicators but their measurements are time consuming. Soil organic C has a high relationship with biological quality parameters like microbial biomass and soil enzymes. Microbial quotient, i.e. the ratio of microbial C to organic C (Cmic/Corg ratio), gives a good indication of ecosystem efficiency i.e., how efficiently the microbes are in breaking down the available carbon to build up their population and biomass.

The proportion of microbial biomass carbon to total organic carbon varies from 2-4% in agricultural soils. A decrease of this proportion over time or with a particular treatment implies a reduction in microbial transformation and intensity. Microbial metabolic quotient (qCO_2) or biomass specific respiration (CO_2-C evolved/Cmic) gives an excellent indication of the eco-physiology of the microbes with lower values indicative of ecosystem equilibrium or maturity. Based on our previous experimental work (Aparna *et al.,* 2014, 2016; Malhotra *et al.,* 2015) and the currently on-going work, it is felt that many of the parameters are well correlated to each other and are good surrogates. Soil enzyme activities are often well correlated to each other, especially as all the four are hydrolases.

A summary of the most important parameters that reflect soil health is shown in Table 2. They constitute a good minimum data set for research laboratories.

Table 2. Minimum data set for soil biological quality

#	Function	Attribute	Notes
1	Organic matter	SOC	Compound indicator of soil health; Microbially derived product of organic matter breakdown and formation of biomolecules. Well correlated with other indices
2	Microbial biomass	Labile C	Easily available carbon source for microbes; good indicator of soil C sequestration; well correlated to microbial biomass
3	Microbial activity	CO_2 evolution	Best indicator of overall soil biological activity; well correlated to soil microbial biomass and N mineralization
		β-glucosidase	Significant correlations between soil enzymes and soil microbial biomass, soil bulk density and soil aggregation. Most sensitive indicator of SOM dynamics, biogeochemical cycling and management influence on soil health
4	Available Nitrogen	Soil protein	Largest source of organic N derived from plant roots, animals and microbes; key source of N for mineralization and driver of the growth of microbes

Conclusion

Soils with the high microbial activity not only indicate good soil health but also their longterm ability to sequester carbon. Microorganisms are the principal agents for the formation of the mixture of organic molecules that is soil organic matter (SOM). Any agricultural intervention that improves microbial biomass formation and provides conditions for its rapid turnover, translates into higher amounts of soil organic matter. Microbial inoculation promotes carbon mineralization, soil organic matter formation and biological activity. Microbial inoculants thus have a high potential to induce carbon sequestration in soils. Soil microbial biomass (active as well as necromass) and SOM are thus two sides of the same coin and represent a continuum. SOM is well correlated to all the crucial soil quality indices. The active fraction of SOM that is easily decomposable, viz. labile C, is well correlated to microbial biomass. The soil organic matter content and labile C as quantitative parameters and soil respiration as an activity parameter are the best integrated indices of soil health that are easy to determine and can be adopted on a large scale for routine use in soil testing laboratories.

References

Aparna, K., M.A. Pasha, D.L.N. Rao and P.U. Krishnaraj. 2014. Organic amendments as ecosystem engineers: Microbial, biochemical and genomic evidence of soil health improvement in a tropical arid zone field site. *Ecological Engineering* 71: 268-277.

Aparna, K., D.L.N. Rao and D. Balachandar. 2016. Microbial populations, activity and gene abundance in tropical vertisols under intensive chemical farming. *Pedosphere* 26: 725-732.

Cotrufo, M.F., J.L. Soong, A.J. Horton, E.E. Campbell, M.L. Haddix, D.H. Wall and W.J. Parton. 2015. Formation of soil organic matter via biochemical and physical pathways of litter mass loss. *Nature Geoscience* 8: 776-779.

Kallenbach, C.M., A.S. Grandy, S.D. Frey and A.F. Diefendorf. 2015. Microbial physiology and necromass regulate agricultural soil carbon accumulation. *Soil Biology and Biochemistry* 91: 279-290.

Kallenbach, C.M., S.D. Frey and A.S. Grandy. 2016. Direct evidence for microbial-derived soil organic matter formation and its ecophysiological controls. *Nature Communications* 7: 13630.

Malhotra J., K. Aparna, A. Dua, N. Sangwan, N. Trimurtulu, D.L.N. Rao and Rup Lal. 2015. Microbial and genetic ecology of tropical vertisols under intensive chemical farming. *Environmental Monitoring and Assessment* 187(1): 4081 DOI: 10.1007/s10661-014-4081-2.

Rao, D.L.N. 2013. Soil Biological Health and its Management. Pages 55-83.*in* Soil Health Management: Productivity-Sustainability-Resource Management (H.L.S. Tandon, ed.), FDCO, New Delhi.

Rao, D.L.N., K. Aparna, and S.R. Mohanty. 2019. Microbiology and biochemistry of soil organic matter, carbon sequestration and soil health. *Indian Journal of Fertilisers* 15(2): 124-138.

Saxena, A., Praveen-Kumar, D.V. Singh, N.R. Panwar and N.L. Joshi. 2018. Deciphering yield sustainability of high yielding pearl millet varieties in arid environment. *National Academy Science Letters* 41*:* 75-79.

Conservation agriculture vis-a-vis climate smart agriculture: What can be learnt from South Asia?

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Extended Summary

South Asia, particularly its agriculture, is highly vulnerable to climate change and has emerged as Global Hotspot. Among the world's nearly seven billion people, 1.7 billion live in South Asia. By 2050, that number is expected to rise to 2.4 billion people. Having predominantly smallholder systems, the farming in the region is challenged with mounting pressure on natural resources compounded with growing uncertainties and risks of global climate change. Hence, 'business as usual farming practices' will not be able to help us attaining Sustainable Development Goals (SDGs).

Climate change is real and increasing climatic variability affects most of the biological, physical and chemical processes that drive productivity of agricultural systems. Moreover, since most of arable land in the region is already under cultivation, there is no scope left for horizontal expansion of farming; yet we need to produce 70% more food to feed the projected population by 2050. Nonetheless, having high risks of climate change induced extreme weather events, the crop yields in the region are predicted to decrease from 10 to 40% by 2050, with risks of crop failure in several highly vulnerable areas. Increase in mean temperature, increased variability both in temperature and rainfall patterns, changes in water availability, shift in growing season, rising frequency of extreme events such as terminal heat, floods, storms, droughts, sea level rise, salinization and perturbations in ecosystems have already affected the livelihood of millions of people.

Studies show that there would be at least 10% increase in irrigation water demand in arid and semi-arid region of Asia with a 1°C rise in temperature. Thus, climate change could result in the increased demand for water, further aggravating resource scarcity. Moreover, climate change can intensify the degradation process of natural resources, which are central to meet the increased food demand. On the other hand, changing land use pattern, natural resource degradation (especially land and water), urbanization and increasing pollution could affect the ecosystem in this region directly and also indirectly through their impacts on climatic variables (Lal, 2016).

For example, the research has revealed that by 2050 about 51% of the Indo-Gangetic Plains may become unsuitable for wheat crop, a major food security crop of region, because of increased heat-stress (Lobell *et al.*, 2012). Therefore, adaptation to climate change is no longer an option but a compulsion to minimize the loss due to adverse impacts of climate change and reduce vulnerability (Jat *et al.*, 2016). Moreover, while maintaining a steady pace of development, the region would also need to reduce its environmental footprint from agriculture to meet the Paris Agreement commitments.

This warrants a paradigm shifts in agronomic management optimization not only to produce more but with higher efficiency of production inputs while sustaining natural resource base and reducing environmental footprints of food production. Conscious efforts are, therefore, needed to shuffle the unsustainable elements of conventional tillage based monoculture production paradigm with temporally and spatially more productive, profitable and adapted sustainable production farming. Conservation Agriculture (CA) - based management system, with elements of site-specificity of component technologies that aim to achieve production intensification, same/higher yields and high profitability, while improving the efficiency of external production inputs and natural resource base, is one of the ways for attaining sustainable intensification and continued food and livelihood security. With local adaptations and situation-specific refinements, the CA-based practices have shown tremendous potential to attain sustainable intensification across the ecologies, production systems, soil types and farm typologies around the world. No wonder, the global adoption of CA systems has now passed 180 mha mark (Kassam *et al.*, 2018).

In South Asia, CA technologies have been developed, adapted and promoted since past 2 decades primarily to increase farm income and conserve resources. A meta-data analysis of large number of on-station as well as on-farm studies on CA-based management optimization in cereal-based systems across South Asia has shown tremendous potential to increase/sustain crop productivity, increase input-use efficiency as well as economic profitability (Jat *et al.*, 2019).

CA-based management, under different cropping systems, has also shown tremendous potential to improve soil health and build soil carbon across the production systems in South Asia. Increased intensity of challenges in agriculture, specially increasing food demand from shrinking natural resources with emerging threats of climate variability and risks, therefore, has led to redefining the scientific research and development priorities. Accordingly, the technologies that help increase productivity and efficiency, promote sustainable intensification, and contribute to the adaptation to emerging climatic variability yet mitigating GHG emissions, termed as climate smart agriculture practices (CSAPs), are central to scientific research and development priorities in the region (Jat, 2017; Jat *et al.*, 2018).

Recent evidence across diverse production systems and ecologies in South Asia reveled that CA- based management practices are not only helping in conserving resources and addressing the issues of water, labour, energy etc. but also have the potential to increase adaptive capacity of production system to climate risks, reduce GHG emissions or enhance carbon storage, yet increasing food production (Jat, 2017; Kakralikya *et al.*, 2018). Our recent study on cost-effective climate change mitigation opportunities in Indian agriculture, based on a pan India analysis of large datasets, revealed significant GHG mitigation opportunities with adoption of CA (Sapkota *et al.*, 2019). Based on a decade and half-long intensive research by CIMMYT, NARS and other partners in the region, there is ample evidence which supports that CA-based management practices contribute to climate smart agriculture (CSA). Hence, the science-backed evidence reveals that there is a good story from South Asia to tell other regions that CA delivers to CSA and SDGs.

References

Jat, M.L., J.C. Dagar, T.B. Sapkota, Yadvinder-Singh, B. Govaerts, S.L. Ridaura, Y.S. Saharawat, R.K. Sharma, J.P. Tetarwal, H. Hobbs and C. Stirling. 2016. Climate change and agriculture: Adaptation strategies and mitigation opportunities for food security in South Asia and Latin America. *Advances in Agronomy* 137: 127-236.

Jat, M.L. 2017. Climate Smart Agriculture in Intensive Cereal Based Systems: Scalable Evidence from Indo-Gangetic Plains. Pages 147-154 *in* Agriculture under Climate Change-Threats, Strategies and Policies (Belavadi, VV *et al.,* eds.). Allied Publishers Pvt Ltd.

Jat, M.L., D. Chakarborty, D.S. Rana, M.K. Gathala, J.K. Ladha, *et al*., 2019. A meta-analysis of impact of conservation agriculture on the performance of predominant cropping systems of South Asia. (Under preparation)

Jat, M.L., H.S. Jat, H.S. Sidhu, Naveen Gupta, P.C. Sharma, L.K. Rolaniya, R.K. Jat, K.M. Choudhary, Deepak Bijarniya, K.S. Saini, S.K. Kakraliya and Yadvinder Singh. 2018. New Horizons of Sustainable Intensification in Maize Systems in South Asia. Pages 38-46 *in* Book of Extended Summaries (B.M. Prasanna, Aparna Das and Kelah K. Kaimenyi, eds.). 13th Asian Maize Conference and Expert Consultation on Maize for Food, Feed, Nutrition and Environmental Security. Ludhiana, India, October 8-10, 2018. CIMMYT, Mexico D.F.

Kakraliya, S.K., H.S. Jat, Ishwar Singh, T.B. Sapkota, L.K. Singh, J.M. Sutaliya, P.C. Sharma, R.D. Jat, M. Choudhary, S.L. Ridaura and M.L. Jat. 2018. Performance of portfolios of climate smart agriculture practices in a rice-wheat system of western Indo-Gangetic plains. *Agricultural Water Management* 202: 122-133.

Kassam, A., T. Friedrich and R. Derpsch. 2018. Global spread of Conservation Agriculture. *International Journal of Environmental Studies*. https://doi.org/10.1080/00207233.2018.1494927

Lal, R. 2016. Feeding 11 billion on 0.5 billion hectare of area under cereal crops. *Food and Energy Security* 5: 239-251.

Lobell, D.B., A. Sibley and J. Ivan Ortiz-Monasterio. 2012. Extreme heat effects on wheat senescence in India. *Nature Climate Change* 2: 186-189.

Sapkota, T.B., S.H. Vetter, M.L. Jat, S. Sirohi, P.B. Shirsath, Rajbir Singh, H.S. Jat, P. Smith, J. Hillier and C.M. Stirling. 2019. Cost-effective opportunities for climate change mitigation in Indian agriculture. *Science of Total Environment* 655: 1342-1354.

Concept of negative emission of CO_2: Role of agriculture and forestry

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Extended Summary

Although the value of a single global-average temperature threshold to represent hazardous impacts of climate change has long been discussed and debated, but the 2°C threshold representing serious implications of climate change has endured in science (Minx *et al.,* 2018). In the recent agreements in Paris, a more aggressive target of 1.5°C was also considered. If it could be met, this target would protect about 2 million km^2 of permafrost from melting, lower ocean acidification, significantly prevent incidences of extreme weather events and also improve chances for species adaptation.

The last decade has seen global CO_2 emissions tracking the upper limit of Representative Concentration Pathways considered in the last Intergovernmental Panel on Climate Change report. Further, number of other studies has suggested that even short mitigation delays in current scenario would necessitate much more rapid de-carbonization, later in the century to achieve even the 2°C target. Results of such studies have depended crucially on two assumptions: (i) it is difficult to make the maximum feasible rate of de-carbonization as binding clause in any global agreement because it is implicitly tied to complex questions of geopolitics and economics and (ii) uncertainties in estimates of net potential removal of C from all biological and chemical approaches.

Recent integrated assessment simulations have achieved 7% yr^{-1} reductions by massive transformation of the global energy system in the near term. This involved rapid phase-out of existing infrastructure for de-carbonization of the global energy sector and decoupling of carbon emissions from economic growth. Both have practical limitations in real terms. Thus, the negative emissions technologies (NETs) like bioenergy (BE), direct carbon capture & storage (CCS), biochar, enhanced weathering, ocean fertilization, artificial down-welling etc. will have to be used at large scale even to achieve the 2°C goal. In the Paris Agreement of 2015, development and large scale deployment of NETs came out as an important solution to reduce GHGs. NETs reduce the net carbon content of the atmosphere and preferably permanently lock in the geosphere. Some of the NETs are perceived as speculative and resource consuming today but would acquire practical use with rapid technological development.

Current estimates state that we are emitting 35 Gt CO_2 annually. Hence, the carbon removal industry has to be able to remove at least half or three-fourth of these emissions. This is a massive task and cannot be achieved without a commitment from policy makers and leaders. Till NETs are fully developed and deployed aggressively, sequestering C in biomass and soil through agriculture and forestry along with BE & CCS remain only trusted sinks of C with us. Also by putting available research work in practice the amount and the residence time of C sequestered through these approaches can be increased substantially. Biomass supply chain

is going to be the most important factor in development of BE & CCS because use of unsustainable biomass will lead to a positive emission rather than neutral or negative emissions. Similarly, growing biomass without considering geographical and geological factors will lead to reduced soil fertility over time. BE & CCS without reforestation of degraded lands and afforestation of barren lands would not allow meeting the 1.5°C temperature goal of the Paris agreement. Hence, it is important to remain aware about limits and uncertainties of technology while choosing NETs for any scenario. Further, development of NET infrastructure will be energy intensive and has to be accompanied with increase in carbon neutral renewable energy to actually ensure negative emissions.

Reference

Minx, J.C., W.F. Lamb, M.W. Callaghan, S. Fuss, J. Hilaire, F. Creutzig, T. Amann, T. Beringer, W. de Oliveira Garcia, J. Hartmann, T. Khanna, D. Lenzi, G. Luderer, G.F. Nemet, J. Rogelj, P. Smith, J.L.V. Vicente, J. Wilcox and M.M.Z. Dominguez. 2018. Negative emissions—Part 1: Research landscape and synthesis. *Environmental Research Letters* 3.063001, https://doi.org/10.1088/1748-9326/aabf9b

Can chromium toxicity be mediated by application of chloride and sulphate ions?

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Abstract

Heavy metal toxicity in different ecosystems is increasing with time and is reducing the system efficiency and ecological services. Among the heavy metals, chromium (Cr) is one of the toxic metals and reaches human body via food chain contamination and adversely affects the metabolic activities that could lead to death. The effluent used for irrigation is one source of Cr in the food chain, but the toxicity expression can be influenced considerably by other ions present. In a screen house experiment, interactive effects of chloride and sulfate ions in a Vertisol on uptake of Cr by spinach crop were investigated. Three levels each of Cr (0, 50, 100 mg kg^{-1}*), chloride (*Cl^-*) (0, 25, 50 mM kg*$^{-1}$*) and sulphate (*SO_4^{2-}*) (0, 4, 8 mM kg*$^{-1}$*) ions were tested in combinations. Increasing* Cl^- *ions in soil reduced the Cr concentration in both root and shoot. Similarly, increasing sulphate ions from 4 to 8 mM kg*$^{-1}$ *also reduced the concentration and uptake of Cr. Application of sulfate ions countered the negative effect of* Cl^- *ions and Cr. Thus, addition of S fertilizers could minimize the Cr toxicity in high Cr contaminated soils.*

Introduction

Increasing population pressure on natural resources is decreasing the resource availability and quality. There is a need to use natural resources in rational manner and recycle the generated waste. Soil is a very complex system with many physical, chemical and biological reactions that affect nutrient availability and crop growth and recycling of various nutrients. Soil, water and air constitute the most important natural resources. And it is essential to use these resources wisely for sustainable development and feeding the growing world population (Dotaniya *et al*., 2014). In the past decade, a significant decline in soil quality has occurred worldwide due to adverse effects of different human activities and contaminations of chemicals used in agriculture and industry.

The leather industry is one of the major export industries in India, earning about 7000 crore rupees annually, mainly from the exports of leather and leather products from Vellore in Tamil Nadu and Kanpur in Uttar Pradesh (Shanker *et al.,* 2005). However, it is also one of the major sources of pollution. The effluent and sludge are discharged from the tanneries into rivers and use of water from these onto land has led to extensive degradation of productive lands (Dotaniya *et al.,* 2016). The tannery wastes (effluents and sludge) contain high concentrations of salts (sodium, chloride and sulfates, etc.) and chromium (Cr). The indiscriminate disposal of these wastes has resulted severe pollution of soil and water in Vellore and Kanpur, where most of the tanneries exist. Pollution of soil and water has drastically reduced the crop yields (25 to 40%) over the years and total cropped area within last 20 years has fallen by about 10.5% in Vellore district alone. Chromium occurs most frequently in hexavalent (Cr VI) or trivalent (Cr III) forms in aqueous solutions (Dakiky *et al*., 2002; Dotaniya *et al.,* 2017). Both are potentially harmful but hexavalent chromium poses a greater risk due to its carcinogenic properties. Hexavalent chromium, which is primarily present in the form of chromate (CrO_4^{2-}) and dichromate ($Cr_2O_7^{2-}$), poses significantly higher levels of toxicity than the other valency states (Sharma and Forster, 1995; Sundaramoorthy *et al.,* 2010).

Interest in interaction among heavy metals and its effect on plant uptake is increasing throughout the world as humankind recognizes the fragility of earth's soil, water, and air resources and the need to protect them for sustained agricultural production. Huge amount of effluent containing various types of salt ions like chloride and sulphate is used for irrigation purpose in developing countries across the globe (Dotaniya *et al.,* 2019). These ions can affect the uptake pattern of Cr in crops. In this study, interactive effect of these anions on Cr uptake by spinach has been explored through a pot culture experiment.

The bulk soil collected from field and analyzed for the soil physico-chemical properties (Singh *et al.,* 2005) was used for this pot culture study. Each plastic pot was filled with 5 kg well mixed soil ensuring good aeration. Three levels of each, Cr, Cl^- and SO_4^{2-} were applied in combinations, with three replications. Chromium was applied at 0, 50, and 100 mg kg^{-1} through $K_2Cr_2O_7$, chloride at 0, 25, 50 *mM* kg^{-1} as KCl; and sulfate at 0, 4, 8 *mM* kg^{-1} as K_2SO_4. The spinach variety '*Palak All Green'* was used as a test crop (5 plants pot^{-1}). The recommended doses of fertilizers were applied uniformly in each pot. The fully matured aboveground biomass of the crop was harvested. The plant roots and shoot were separately collected and Cr concentration was analyzed with the help of ICP-OES. Different phytoremediation parameters were also calculated, i.e. Bioconcentration factor (BCF), Translocation factor (TF), Translocation efficiency (TE) and Crop removal.

The combined application of Cr and Cl^- at various levels (Table 1) had no significant ($p=0.05$) effect on shoot and root dry weight as compared to Cr application alone. In presence of Cl^-, the Cr concentration and uptake in spinach shoot decreased at lower Cr level (50 mg Cr kg^{-1} soil) and increased at a higher Cr level (100 mg Cr kg^{-1} soil). The Cr concentration in the root increased due to application Cr along with Cl. However, no significant change in Cr uptake by spinach root was observed due to Cl^- application in Cr spiked soils. Similarly, BCF also decreased in lower Cr levels and increased in higher Cr level in the presence of Cl^-. But there was no significant difference in TE and TF due to application of Cl^- in Cr treated soils.

The SO_4^{2-}application with Cr reduced the root and shoots dry weight, Cr concentration and uptake of Cr, BCF and crop removal (Table 2). The TF and TE on the other hand were significantly ($p=0.05$) increased. The Cr concentration significantly reduced due to application of S (4 and 8 *mM* kg^{-1}) at both 50 mg kg^{-1} and 100 mg kg^{-1} Cr. The BCF factor declined from 0.810 to 0.428 and 0.459 to 0.264 in 50 and 100 mg kg^{-1} Cr levels with the increase in the dose of S from 0 to 8 *m*M kg^{-1}, respectively. The TF and TE significantly improved with increasing S and Cr levels. The Cr removal by the spinach crop decreased in presence of S.

Table 1. *Interactive effects of application of Cr (mg kg^{-1}) and Cl^-(mM kg^{-1}) on spinach. (Means with the same letter are not significantly different column wise based on Tukey grouping at P = 0.05)*

Treatment		**Dry weight (g pot^{-1})**		**Cr concentration (µg g^{-1})**		**Cr uptake (mg pot^{-1})**			**BCF**	**TF**	**TE**	**Crop removal**
Cr	**Cl^-**	**Shoot**	**Root**	**Shoot**	**Root**	**Shoot**	**Root**	**Total**			**(%)**	**(%)**
50	0	11.42a	2.04a	16.72a	45.92a	0.191a	0.097a	0.288a	0.626a	0.393a	19.54a	0.58a
50	25	10.92a	2.62a	11.93b	48.79a	0.135ab	0.138a	0.273a	0.607a	0.261ab	13.00ab	0.55a
50	50	11.68a	1.66a	9.11b	48.37a	0.108b	0.085a	0.193a	0.575a	0.199b	09.89b	0.39a
100	0	11.30a	2.21a	11.57b	50.61a	0.131ab	0.110a	0.242b	0.311b	0.265ab	13.18ab	0.24a
100	25	10.72a	2.77a	12.82ab	51.97a	0.137ab	0.144a	0.280b	0.324b	0.280ab	13.92ab	0.28a
100	50	10.89a	1.98a	16.86a	59.32a	0.185a	0.124a	0.309b	0.381b	0.298ab	14.83ab	0.31a

BCF=bioconcentration factor; TF = translocation factor; TE= translocation efficiency

Table 2. *Interactive effects of application of Cr (mg kg^{-1}) and SO_4^{2-}(mMol kg^{-1}) on spinach. (Means with the same letter are not significantly different column wise based on Tukey grouping at P = 0.05)*

Treatment		**Dry weight (g pot^{-1})**		**Cr concentration (µg g^{-1})**		**Cr uptake (mg pot^{-1})**			**BCF**	**TF**	**TE**	**Crop removal**
Cr	**S**	**Shoot**	**Root**	**Shoot**	**Root**	**Shoot**	**Root**	**Total**			**(%)**	**(%)**
50	0	14.12a	2.79a	13.70a	67.34b	0.193ab	0.188a	0.381a	0.810a	0.204b	10.15b	0.76a
50	4	10.21b	1.60a	12.92a	44.10cd	0.135bc	0.071b	0.206b	0.570b	0.296ab	14.73ab	0.41a
50	8	9.68b	1.93a	11.14b	31.63e	0.106c	0.061b	0.167b	0.428c	0.353a	17.56a	0.33a
100	0	13.96a	2.67a	14.33a	77.49a	0.198a	0.208a	0.407a	0.459c	0.184b	9.17b	0.41a
100	4	9.74b	1.80a	12.16a	46.32c	0.118c	0.081b	0.199b	0.293d	0.262ab	13.06ab	0.20a
100	8	9.21b	2.50a	14.76a	38.09d	0.137abc	0.089b	0.225b	0.264d	0.396a	19.70a	0.23a

BCF=bioconcentration factor; TF = translocation factor; TE= translocation efficiency

Conclusions

Increasing the chloride application from 25 to 50 *mM* kg^{-1} reduced the Cr concentration and uptake in root and shoot of spinach. Similarly, increasing SO_4^{-2} application from 4 to 8 *mM* kg^{-1} also reduced the Cr uptake by root and shoot. Percent reduction in Cr concentration and uptake was more in root compared to shoot part. The study revealed that the addition of S (8 *mM* kg^{-1}) could minimize the Cr toxicity in high Cr (100 mg kg^{-1}) contaminated soils.

References

Dakiky, M., M. Khamis, A. Manassra, and M. Meŕeb. 2002. Selective adsorption of chromium (VI) in industrial wastewater using low-cost abundantly available adsorbents. *Advances in Environmental Research* 6(4): 533-540.

Dotaniya, M.L., S. Rajendiran, M.V. Coumar, V.D. Meena, J.K. Saha, S. Kundu, A. Kumar and A.K. Patra. 2017. Interactive effect of cadmium and zinc on chromium uptake in spinach grown on Vertisol of Central India. *International Journal of Environmental Science and Technology* 15(2): 441-448.

Dotaniya, M.L., S. Rajendiran, V.D. Meena, J.K. Saha, M.V. Coumar, S. Kundu and A.K. Patra. 2016. Influence of chromium contamination on carbon mineralization and enzymatic activities in Vertisol. *Agricultural Research* 6(1): 91-96.

Dotaniya, M.L., J.K. Thakur, V.D. Meena, D.K. Jajoria and G. Rathor. 2014. Chromium pollution: A threat to environment. *Agriculture Review* 35(2): 153-157.

Dotaniya, M.L., C.K. Dotaniya, P. Solanki, V.S. Meena, M.D. Meena and R.L. Choudhary. 2019. Microbial resources in management of C sequestration, greenhouse gases, an bioremediation processes. *In* Singh J.S. (ed.) New and future developments in microbial biotechnology and bioengineering. DOI: https://doi.org/10.1016/B978-0-12-818258-1.00005-4

Shanker, A.K., C. Cervantes, H. Loza-Tavera and S. Avudainayagam. 2005. Chromium toxicity in plants. *Environmental International* 31(5): 739-753.

Sharma, D.C. and C.F. Forster. 1995. Column studies into the adsorption of Chromium (VI) using Sphagnum moss peat. *Bioresource Technology* 52: 261-267.

Singh, D., P.K. Chhonkar and B.S. Dwivedi. 2005. Manual on Soil, Plant and Water Analysis. Westville, New Delhi.

Sundaramoorthy, P., A. Chidambaram, K.S. Ganesh, P. Unnikannan and L. Baskaran. 2010. Chromium stress in paddy: (i) nutrient status of paddy under chromium stress; (ii) phytoremediation of chromium by aquatic and terrestrial weeds. *Comptes Rendus Biologies* 333(8): 597-607.

Theme 4: Water Harvesting and Improving Water Productivity

Lead Lectures and Rapid Presentations

Groundwater governance and irrigated agriculture: Global review and lessons for South Asia

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Extended Summary

Groundwater use in irrigation as well as meeting rural and urban domestic water demand has experienced explosive growth in recent years in many dry regions of the world. Groundwater makes massive contribution to agrarian livelihoods and national economies of many arid and semi-arid countries, and has become a strategic resource in view of its high 'stabilization value', its capacity to support land-use intensification as well as high-value agriculture. As a result, effective governance of groundwater resource has emerged as a critical and urgent challenge. However, thanks to their complexity, variability and uncertainty, groundwater systems have proved far less amenable to effective governance than other natural resource systems.

This review paper provides (i) an overview of the global groundwater economy, assessing the opportunity it offers for irrigated agriculture and the risks it poses of depletion and degradation of aquifer systems; (ii) surveys various approaches of groundwater governance that have been tried in different parts of the world; and finally (iii) examines the wider applicability of some of these approaches to global groundwater 'hotspots' where the need for promoting responsible groundwater use and management is urgent and critical for productivity, equity and sustainability. Several case studies have been included to illustrate local drivers and institutional innovations.

The review suggests that the context is critical and there is no one *best* approach to groundwater governance; and that each country/region needs to evolve a resource governance regime appropriate to its own unique set of socio-ecological, economic and political contingencies. Integrated approach to groundwater governance is critical; however, the first step has to involve reforming perverse subsidies and policies that exacerbate resource depletion and deterioration. The paper concludes by outlining a 3-stage process for evolving a groundwater governance protocol.

More crop per drop in drylands: Technologies, policy imperatives and institutional arrangements

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Extended Summary

Drylands, which account for 44% of the world's cultivated area, have a very important role to play in the food security, livelihood and economy of developing world (UN, 2011). Dryland ecosystem, home to most of the world's poor, is characterized by extreme rainfall variability, frequent droughts, high temperatures, low soil fertility and water scarcity. The growth of human population along with improvement in living standards, changing dietary habits, and increased urbanization and industrialization are straining the water resources, particularly in water-limited climatic regions such as arid and arid regions. The biggest challenge to dryland agriculture is a declining natural resource base, which is further exacerbated by climate change. Building a resilient natural resource base, with water as the entry point, is the very foundation for ensuring a sustainable production and livelihood support system as well as meeting sustainable development goals.

With only about 8% of the global water resources available in dryland areas, coupled with low yield levels and high on-farm water losses, it poses great challenge as well as opportunity for improvements to manage water. Considering the growing pressure on finite water resources and given the economic and environmental limitations to increase the supply of water for agriculture due to intensifying competition from other sectors, and uncertainties associated with climate change, improving water productivity, popularly also called as 'More Crop per Drop' has been accorded highest development priority by the governments.

With over 60% of cropped area being dryland/rainfed in South Asia, the agricultural sector is heavily reliant on annual monsoon rainfall and has low adaptive capacity. India ranks first among the dryland/rainfed countries in the world in terms of area with about 54% of the net sown area being dryland/rainfed, with a vast potential to close rainfed productivity gap. Water deficit and its management is the most critical determinant of the success or failure of agricultural production in these drylands. The major element of risk in dryland agriculture comes from the uncertainty in rainfall. Water productivity (WP) in drylands is broadly expressed in terms of more crop per unit of rainfall and/or harvested water. Rainfall water productivity indicates the extent by which green and blue water losses are minimized in favour of productive transpiration flow through effective management (Rockstrom and Barron, 2007).

Rainwater management in dryland agriculture is an important strategy to increase water productivity with adoption of efficient soil and water management practices along with suitable soil and crop management practices (Molden, 2007). There are an array of agronomic, engineering, breeding, and physiological techniques for improving water productivity. The most appropriate option(s) will vary from site to site, and will depend on

social and economic conditions of the farmers/stakeholders. Combining water harvesting and conservation measures with engineering solutions, agronomic measures and soil fertility management in an integrated manner is the best suitable strategy for improving WP. There are field evidences that water harvesting and supplemental irrigation/ deficit irrigation have improved WP in the dryland farming systems (Oweis and Hachum, 2009). For harnessing full potential of supplemental irrigation, its integration with other management practices is necessary.

Lack of extension, incentivization and adequate safety nets have limited adoption of potential technologies. The adoption of techniques to improve WP requires enabling policies, investments in drylands and an institutional environment that aligns the incentives of producers, resource managers and society, and provides a mechanism for dealing with trade-offs. Therefore, the programmes and policies must consider rainwater harvesting and groundwater recharge measures as "means" and the production, productivity and livelihood support systems compatible to resource base, ecology and market as the "ends", for more crop per drop in drylands. Fragmented approach of programmes will have to be converged into an integrated approach. Optimal combination of formal (governmental organizations) and alternative institutions (involving local groups), especially at the micro level, should be promoted to improve delivery efficiency of the programs aimed at enhancing water productivity in drylands. Integrated watershed management (WSM), rooted in the principle of ecosystem-based approaches, adopted in India since late eighties, is a good framework for the conservation and management of rainwater and more crop per drop for drylands. WSM has become a component of the National Flagship program called the *Pradhan Mantri Krishi Sinchayee Yojana* (Prime Ministers Irrigation Scheme) in July 2015, and more crop per drop is one of the four components of PMKSY. It may be appropriate now to assess how PMKSY has helped in improving more crop per drop in dryland areas.

References

Molden, D. 2007. Water for Food, Water for Life: a Comprehensive Assessment of Water Management in Agriculture. Earthscan, London, and IWMI, Colombo.

Oweis, T. and A. Hachum. 2009. Supplemental irrigation for improved rainfed agriculture in WANA region. *In* Rainfed Agriculture: Unlocking the Potential (S.P. Wani *et al.,* eds.). CAB International.

Rockstrom, J. and J. Barron. 2007. Water productivity in rainfed systems: Overview of challenges and analysis of opportunities in water scarcity prone Savannahs. *Irrigation Science* 25: 299-311.

United Nations (UN). 2011. Global Drylands: A UN system-wide response. First published in October 2011 by the United Nations Environment Management Group. United Nations.

Water harvesting: A key strategy for climate change adaptation in rainfed agriculture

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Abstract

Rainfed agriculture contributes 40% of food grains and supports two thirds of livestock population in India. Bulk of the pulses, oilseeds, coarse cereals and cotton in the country are produced under rainfed conditions. These areas encounter frequent droughts and crop failures. Such problems are likely to be exacerbated with projected impacts of climate change. According to the IPPC sixth report, the distribution of monsoon rainfall will become more erratic in India, with extreme rainfall events increasing and the number of rainy days going down. This would result in more dry spells and increased soil erosion impacting rainfed farming significantly. Among several adaptation strategies, on-farm water harvesting is a key intervention that helps small-holder farmers cope with climate change. A number of in situ and ex situ water conservation technologies have been evolved for different agro climatic zones of the country. These include contour planting, conservation furrows, compartmental bunding, Broad Bed Furrows (BBF), mulching and conservation tillage. The farm level adoption of these technologies is still quite low due to low awareness among small farmers. Harvesting surplus runoff and recycling for supplemental/life saving irrigation is another practice, which has caught the imagination of the farmers in India. Several designs of water harvesting structures covering size, storage volume, lining materials, water lifting and conveyance methods, etc. have been standardized for different rainfall zones and soil types. Both federal and state Governments are encouraging adoption of water harvesting technologies through liberal funding and mainstreaming them in to the development programs. The paper summarizes the potential of water harvesting technologies for climate change adaptation in rainfed farming in India.

Introduction

Globally rainfed agriculture is practiced over 1.3 billion ha. In India, 80 million hectare (mha) area is under rainfed cultivation, representing 58% of the net sown area. This area contributes 40% to the national food grain production. Some 87% coarse cereals, 85% pulses, 72% oilseeds, 62% cotton and 44% rice are grown under rainfed conditions. The area also supports two thirds of livestock population. Dominated by small and marginal farmers, farming in rainfed regions is highly risk prone and is relatively less profitable. The most important constraint is the water availability for crop production, which mainly depends on monsoon rains. Land degradation and poor credit and market support are other constraints. With little marketable surplus, farmers cannot invest on land development and adoption of new technologies; consequently they remain in a vicious circle of 'low productivity - low marketable surplus - low profitability'. Rainfed areas are distributed in arid (15 mha), semi arid-dry (15 mha), semi arid-moist (42 mha) and dry sub humid (25 mha) climatic zones in

India. The average productivity has remained in the range of 0.8-1.0 t ha^{-1} for several years, as against the global productivity of 2-3 t ha^{-1}. Climate change has exacerbated the problems of rainfed agriculture through its impacts on soil carbon and water availability besides direct effects on crops.

Climate change and water availability

IPCC technical paper VI, based on observed and predicted changes in water availability due to global warming, clearly states that warming will have significant impact on hydrological cycle, increase in rainfall in some latitudes, more extreme events, melting of glaciers, increased runoff and deterioration of water quality globally - more so in tropical and subtropical regions where most of the poor live (Bates *et al.,* 2008). In India climate change is projected to have significant impacts on agriculture; more particularly on rainfed agriculture, mainly because of its high dependency on monsoons (Venkateswarlu and Shankar, 2009). All models project an increase in total rainfall in India but with more spatial and temporal variability. Number of rainy days is likely to decrease with increase in heavy rainfall/extreme events. A study by Goswami *et al.* (2007) indicated increase in frequency of heavy rainfall events in the last 50 years in India. With high intensity rainstorms, more runoff and soil erosion are predicted in the wet season. On an average, runoff induced soil erosion is likely to increase by 10-30% in medium term. More runoff means more soil loss and less opportunity for groundwater recharge. The current soil and water conservation technologies, designed based on historical rainfall pattern, need to be redesigned to cope with higher runoff. Climate change will have indirect effect on water availability by increasing evaporative demand due to increased temperatures. Crop water requirement will increase leading to more ground water exploitation. A study by CRIDA, Hyderabad on major rainfed crop growing districts in the country, indicated a 2.2% increase in crop water requirement by 2020 and 5.5% by 2050, across all crops and locations. Any climate change adaptation intervention has to aid in reducing overland flow in the wet season, harvest surplus runoff, provide supplemental irrigation and optimize crop water use by agronomic and soil management techniques. This would help in coping with drought in rainfed crops, stabilize the yields and minimize the risk for farmers.

Water harvesting for climate change adaptation

India receives one of the highest annual rainfall (1200 mm) and yet large parts of the country suffer from droughts year after year. States in northern and eastern part also face floods due to heavy rains. This is largely due to the skewed distribution of rainfall during June to September in less than 25 rainy days. The annual rainfall also exhibits extreme variation with Barmer in western Rajasthan receiving just 250 mm and parts of north east receiving as high as 3600 mm. Two thirds of the country's topography is vulnerable to soil erosion. When monsoon rains are delayed, or if there are intermittent breaks during rainy season, agricultural crops suffer water deficits and sometimes farmers lose the entire crop. Rainfed crops are more vulnerable as soils in most rainfed areas are degraded, with light texture, and low water holding capacity and organic carbon. India has made substantial progress in providing irrigation to nearly 65 mha of net cultivated area, and more projects are in progress but still up to 60 mha area will remain under rainfed cultivation permanently. Water harvesting, therefore, is key for sustaining rainfed agriculture in the country. Water harvesting was practiced since millennia in India. Rural communities have evolved indigenous methods of water harvesting to secure enough water for humans, livestock and crop production. Pandey *et al.* (2003) have contributed an excellent review on water harvesting methods practiced in India since 2500 BC till today and how people could cope with climate variability during the long period.

Principles of water conservation/water harvesting in rainfed farming

Water conservation is practiced at different levels *viz*. individual fields, landscape level or a large watershed. Individual farmers can adopt simple agronomic and land management practices at farm level to conserve moisture *in situ* and improve water availability to crops. These include tillage, mulching, soil amendments and land configurations. The main soil types in rainfed regions of India are Alfisols and Vertisols. Alfisols suffer from low moisture holding capacity, high erodibility and crusting, while Vertisols have poor infiltration and are prone to water logging. Therefore conservation practices have to be soil and rainfall specific. In low rainfall arid and dry semi-arid regions, the runoff is generally low and *in situ* conservation practices are more important than water harvesting. In wet semi-arid and sub-humid regions there is always surplus runoff, which should be harvested in dugout structures and stored for use during dry spells.

In situ conservation practices

A number of *in situ* moisture conservation practices have been developed in India under the All India Coordinated Research Project on Dryland Agriculture (AICRPDA). These are simple agronomic measures like tillage and mulching or modified land configurations, which can be done through bullock drawn tools and implements owned by farmers. These are soil and rainfall specific and are generally practiced every crop season. The yield advantage from these practices ranges between 10 to 25%, the benefits being more in a drought year. Many of these practices have formed part of the package of practices adopted by different state Governments. A detailed list of such practices, along with expected economic benefits, are described by Venkateswarlu *et al.* (2009), but some important ones are described in this section.

Tillage: *In situ* conservation practices are based on either tillage/soil management or land configurations. Deep tillage was found to help better rainwater infiltration, higher rooting depth and 15-20% more yields in both Alfisols and Vertisols under semi arid conditions (Patil *et al.,* 2016). In Alfisols, deep tillage opens the hard layer and promotes infiltration. Similar effect is found in Vertisols, where deep tillage stores more soil moisture in the profile due to higher infiltration. The positive impact was more pronounced in a drought year than a normal rain fall year. The impact of tillage practices on infiltration, bulk density and yield of post rainy season sorghum at Bijapur in Southern India, a typical Vertisol region, is presented in Table 1. However the concept of tillage has undergone a major change with emergence of conservation agriculture. Conserving soil carbon with minimum soil disturbance has now become a priority. In rainfed farming practicing areas in India, however zero tillage has not yet found favor with the farmers as there is not much crop residue to be left on the surface and clear protocols for zero tillage have not been standardized through location-specific research. Nonetheless, adoption of appropriate tillage helps in crop adaptation to climate change through moisture conservation and drought coping.

Table 1. *Effect of tillage on infiltration rate, bulk density, root growth and grain yield of winter sorghum in the Vertisols of Bijapur, Karnataka, India*

Tillage practices	Infiltration rate (mm h^{-1})	Bulk density (Mg m^{-3})	Root length (cm)	Grain yield (kg ha^{-1})		
				1994-95	1995-96	Pooled
Deep tillage	9.7+0.6	1.23+0.03	67	1,919	1835	1877
Medium tillage	8.0+0.5	1.27+0.02	57.6	1,509	1562	1635
Shallow tillage	6.1+0.7	1.31+0.05	41.7	1,223	1368	1296
LSD (P-=0.05)	-	-	-	164	186	103

Mulching: Mulching is covering soil surface with organic or plastic materials. Mulching prevents soil erosion, reduces evaporation and conserves moisture *in situ*. Extensive trials were carried out across India on the benefits of mulching, both in Vertisols and Alfisols, but the technology has not picked up mainly due to the shortage of organic material. Plastic mulching is adopted in high value crops and horticulture. For smallholders, who cannot invest on external inputs, frequent inter cultivation for creating a soil/dust mulch was found more appropriate. This practice breaks the capillary movement and reduces evaporation, which is key for crop adaptation to water stress in dry regions.

Contour cultivation: Sowing of crops across the slope and along contour controls runoff and soil loss and helps in infiltration of rain water in to soil profile. It is practiced in all types of soils, rainfall up to 1000 mm and slopes varying from 0.5 to 4%. This practice is more advantageous in fields with medium slope and permeable soils. Several trials conducted under AICRPDA network indicated up to 22% increase in grain yield in Vertisols and Alfisols. These benefits are more in a drought year when the crops can cope with intermittent dry spells.

Conservation furrows: It is a simple low cost water conservation practice for areas with moderate slopes. In this practice a series of furrows are opened on contour or across the slope at 1-3 m apart. The spacing between the furrows depends on the slope, rainfall and topography. Furrows are made either during planting or as inter culture operation, using country plough. These furrows harvest local runoff and improve soil moisture in the adjoining crop rows, particularly during dry spells. This practice increases crop yields by 10-25%. This is an ideal practice for Alfisols with problem of crusting, sealing and hard setting.

Ridges and furrows system: Furrows are opened at 50 to 60 cm apart across the slope after completion of primary tillage to make field in to ridges and furrows. This is ideal for medium to deep black soils. A bullock-drawn ridger plough is used by farmers for making these ridges. Cultivation of crops under ridge and furrow system conserves more rain water *in situ*. Trials conducted at Bellary, Bijapur, Solapur and Parbhani in Peninsular India under AICRPDA network conclusively brought out yield advantages up to 20% in crops like sorghum, sunflower, cowpea and winter sorghum (Patil *et al*., 2016). At Parbhani, yield advantages were also obtained in soybean at Babulgaon village under NICRA project. The benefits were more during a drought year than normal year. This system is also followed in high rainfall conditions of eastern Uttar Pradesh and Bihar with ‘rainfed rice+pigeon pea’ cropping system, where rice is grown in furrows and pigeon pea on ridges to provide both moisture conservation and drainage.

Broad bed and furrow (BBF) system: The BBF system consists of a relatively raised flat bed or ridge, approximately 90 cm wide, alternated by a shallow furrow of about 30 cm deep. It is laid out on a grade of 0.4-0.8% for optimum performance. The beds are to be made with uniform shape without sudden and sharp edges because of the need to plant the crops on the shoulder of the broad bed. BBF system is ideal for Vertisols where heavy rainfall causes water logging. The beds store rain water during dry spells and drain off excess water during heavy rainfall. In central Indian states of Madhya Pradesh and Maharashtra, BBF system offers significant yield benefits to soybean crop (Table 2). ICRISAT, Hyderabad developed Tropicultor, a bullock-drawn implement, to make the beds. With increasing incidence of unseasonal heavy rainfall events, the BBF system is widely adopted by farmers across the country for onion, soybean, pulses and many other field crops as a climate resilient technology.

Table 2. *Effect of land configuration on productivity of soybean and maize-based systems in the watersheds of Madhya Pradesh, India, 2001-05 (Singh et al., 2009)*

Watershed location	Crop	Grain yield (t ha^{-1})		
		Farmers' practice	BBF system	Yield increase (%)
Vidisha and Guna	Soybean	1.27	1.72	35
	Chickpea	0.80	1.01	21
Bhopal	Maize	2.81	3.65	30
	Wheat	3.30	3.25	16

Ex situ conservation/water harvesting practices

While *in situ* moisture conservation practices are appropriate at individual farm level, at community or landscape level, harvesting surplus runoff for surface storage in dugouts or for ground water recharge are more important interventions. Harvested water stored either way can be used for crop life-saving irrigation, which is a key strategy for climate change adaptation in drylands. The harvestable surplus runoff depends on several factors like rainfall, topography, slope and soil type. According to estimate by CRIDA, Hyderabad, maximum harvestable runoff is available in 1000-2500 mm rainfall zone (14.61 mha meter) followed by 750-1000 mm (4.03 mha meter). Arid and dry semi-arid areas offer relatively less potential runoff (Table 3), but this could change in future with high intensity rain events becoming common even in arid regions due to climate change. Maximum returns on investment are possible in 500-750 mm zone. The current runoff estimates are likely to undergo major changes in future due to changed rainfall pattern. Rao *et al.* (2010) made an assessment of water harvesting potential of rainfed regions in India, production system wise, based on rainfall and crop water balance. Many districts of central and eastern India growing rainfed rice and soybean have considerable surplus runoff, which can be harvested (Fig. 1).

__Table 3.__ Potential of rainwater storage for water harvesting in different rainfall zones of India

Rainfall zone (mm)	Area (m ha)	Harvestable runoff (m ha m)
<500	52.07	0.78
500-750	40-26	1.51
750-100	65.86	4.03
1000-2500	137.24	14.61
>2500	32.57	3.26

Source: CRIDA, Hyderabad

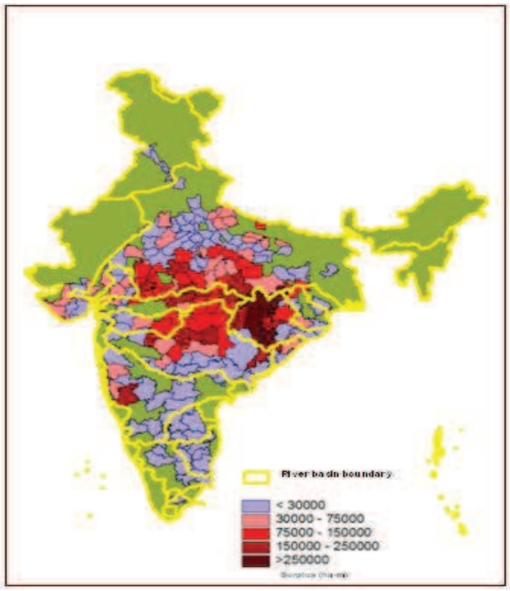

***Figure 1.** Water harvesting potential in rainfed production systems.*

The most common structures for storing surplus runoff in India are check dams or farm ponds. Check dams are constructed across the gullies where the runoff velocity is very high and a stable structure is needed to withstand the flow. Check dams store water and recharge ground water. These are very popular in the 'Watershed' programs in India. Masonry check dams are designed on the basis of rainfall-runoff relationships. Depending on the assumed depth and the corresponding area to be submerged, suitable height of the dam is designed to create adequate storage capacity (Fig. 2). Earthen check dams are common in India because of their low cost and farmers can construct with locally available material and labour.

***Figure 2.** Common water storage structures adopted by farmers in India viz., Check Dam (left) and Farm Pond (right).*

Farm pond is another structure very popular with Indian farmers for water harvesting at Individual farm and community level (Fig. 2). It is an age old practice in the country but extensive research carried out under AICRPDA has helped in creating many simple designs suitable for different farm categories and rainfall zones. High storage efficiency is achieved by locating the pond in a gully or depression with an inlet to capture runoff from upstream. In Vertisols, seepage losses are low and natural sealing takes place in few years due to high silt content. In Alfisols however lining is compulsory. Extensive research was done in India on the size, shape, location, depth, lining materials, and water lifting and conveyance methods for storing and using stored water for supplemental irrigation (Reddy *et al.*, 2012). The major challenge is, however, the high evaporative losses; sometimes as high as 40%. Anti-evaporative chemical sprays have been tried with limited success. In recent period, farmers are growing creepers on a wooden frame set up across the pond to prevent evaporative losses which is an indigenous practice but quite effective and provides supplemental income from vegetables.

Using farm pond water was found to be most cost effective if horticultural or commercial crops are grown. Water productivity is highest if sprinkler irrigation is followed. In remote tribal areas, devoid of electricity, solar energy can be used for water lifting from ponds. In high rainfall receiving eastern states of Orissa and Chattisgarh considerable quantity of runoff is available. In these states instead of ponds, on farm reservoirs and tanks are ideal for storage of water. In addition to supplemental irrigation, water productivity can be enhanced by fish culture in these water bodies where water is available for longer period (Mishra, 2011)

Traditional water harvesting systems in India

Indian farmers have evolved many traditional water harvesting systems over time that are still practiced today with some modifications. These systems are based on local knowledge and created with skills of the communities. They not only provide water for agriculture but also drinking water for livestock. These may vary from small dugouts in individual farms to large catchment level stop dams meant for a village or a micro watershed. The most well known are *Kunta* in Andhra Pradesh, *Tanks* in Peninsular India, *Havelis* in MP, Risers in eastern India, *Nadis* in south Rajasthan and *Khadins* in western Rajasthan (Table 4 and Fig. 3).

Table 4. *Traditional rainwater harvesting systems in India*

System	Technology	Region
Kunta	Small size community pond for providing supplemental irrigation to paddy, chillies and tobacco during long breaks in rainfall	Prakasam, Guntur and Nizamabad (Andhra Pradesh)
Percolation tank	Used for recharging the groundwater to bring stability to rainfed agriculture	Andhra Pradesh, Karnataka and Maharashtra
Haveli	Storing rainwater by raising field bunds, used in *kharif* fallow	Madhya Pradesh
Risers	Stone pitching of bench terrace risers to conserve rainwater	Hilly regions
Stone pitched barriers	Stone pitching along with stubbles of pigeon pea / sorghum / cotton across the slope for rainwater conservation	Vidarbha region
	Field bunds with waste weirs, stone checks and stone / boulder boundaries to conserve rainwater	Andhra Pradesh, Gujarat and Karnataka
Khadins	An earthen or masonry embarkment is made across the major slope to harvest the runoff water. Practiced where rocky catchments and valley planes occur in close proximity	Western Rajasthan

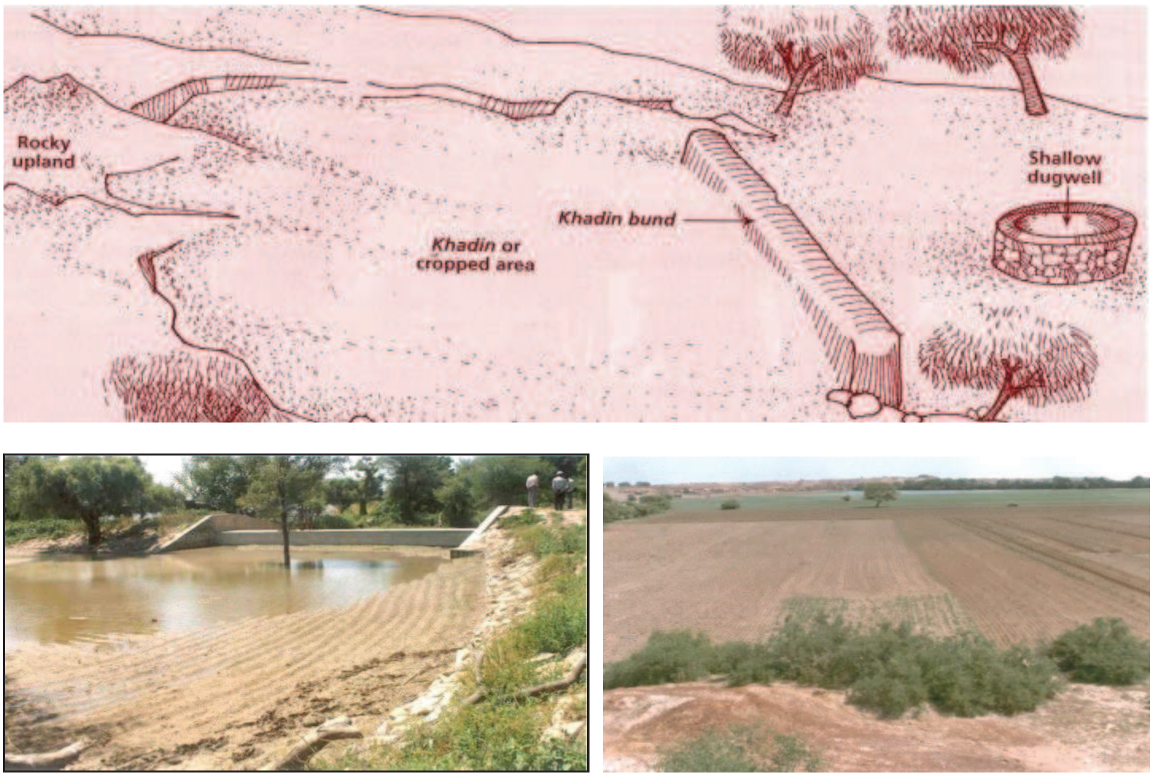

Figure 3. *Khadin system of water harvesting in western Rajasthan.*

All these systems harvest runoff during surplus rainfall and store it for 4 to 6 months for irrigation and drinking water. These structures are generally maintained by the communities but with introduction of tube well irrigation, these structures are being neglected and falling in to disuse in many parts. Since these are time tested adaptation practices for aberrant weather, there is an urgent need to revive and improve these traditional systems.

Up-scaling water harvesting technologies

Realizing the importance of water harvesting for bringing resilience to rainfed agriculture, the Government of India and States have attempted to mainstream the technology in agricultural development programs. Watershed development has been implemented in India for over 3 decades and valuable experience is gained on its drought proofing potential. More recently new programmers like farm ponds are designed which are targeted to individual farmers. The prime minister has given a call for *Har khet ko pani***,** meaning water to every farm, under which half million ponds were to be dug in the country in a five year period under the Prime Ministers *Krishi Sinchayi Yojana* (PMKSY). This is a decentralized form of providing water security to small and marginal farmers as opposed to huge investments on large scale irrigation projects. The Government of Andhra Pradesh is implementing a programme *Neeti Kuntalu* with a target to dig 1 lakh farm ponds in Rayalaseema region linked to micro irrigation mainly to provide life saving irrigation to *kharif* crops. The Government of Maharashtra has launched *Jalyukt Shivar,* another ambitious programme in 2015 for providing moisture security to every field. It aims to make about 2500 villages have water, in five years. The interventions include deepening and widening of streams, construction of need based stop dams, recharge of open wells and digging of farm ponds. Till 2018, the programme has covered 16521 villages. The unique feature of this programme is large scale public participation (Fig. 4). In 2015, Telangana Government launched *Mission Kakatiya***,** a huge tank desilting programme, to restore traditional water bodies that have attracted the attention of the world.

Jalayukata Shivar **Mission Kakatiya**

Figure 4. *Mainstreaming water harvesting programs through people's participation.*

Under this mission, 46531 minor irrigation tanks are being renovated to provide irrigation to 25 lakh ha. By 2018, 21713 tanks have been desilted. The unique advantage of this scheme is huge quantity of tank silt, which is available to farmers to incorporate in their farms to improve moisture holding capacity and drought proofing in *kharif* crops, besides providing employment. It is hailed as an unique climate change adaptation initiative for rainfed regions in India. Other States are also planning similar initiatives to utilize water harvesting technologies for climate change adaptation in India.

Conclusions and future research needs

Water harvesting undoubtedly is the most important climate change adaptation strategy for rainfed agriculture in India and several countries in Africa and Middle East. With projected increase in total rainfall and its intensity, more runoff and soil loss are expected in future in many dry areas. Harvesting, storing and reusing of water for life saving irrigation is the only way to adapt agriculture to changing climate. Other benefits of *in situ* and *ex situ* water conservation include control of soil erosion, conserving soil carbon and ground water recharge. There is an urgent need to estimate the surface runoff from small watershed level to large river basins in India, under regionally downscaled climate change scenarios, and revisit the design parameters for water conservation structures. Small holder farmers in India are to be enabled for greater adoption of these technologies through proactive extension services and by main streaming these in to flagship programs of the State Governments, as has been done by a few states in India. The indigenous knowledge of farmers in water harvesting needs to be documented, refined and shared among other developing countries in South Asia, west Africa and Middle East, which are facing similar water scarcity problems and are likely to be hit hard by climate change.

References

Bates, B.C., Z.W. Kundzewicz, S. Wu and J.P. Palutikof. 2008. Climate change and water; Technical paper of the Inter Governmental Panel on Climate Change, IPCC Secretariat, Geneva. 210 p.

Goswami, B.N., V. Venugopal, D. Sengupta, M.S. Madhusoodanan and Prince Xavier. 2007. Increasing trend of extreme rain events over India in a warmingenvironment. *Science* 314(5804): 1442-1445.

Mishra, A.R. 2011. Rainwater Conservation and Management In high rainfall regions for increasing land and water productivity. Pages 21-40 *in* SAARC Training Programme Manual, CRIDA, Hyderabad.

Pandey, D.N., Anil K. Gupta and David M. Anderson. 2003. Rainwater harvesting as an adaptation to climate change. *Current Science* 85(1): 46-59.

Patil, S.L., P.K. Mishra, M. Madhu, Mohd. Osman and M.N. Ramesha. 2016. Rainwater Management Strategies to Cope with Climate Variability. Pages 120-147 *in* Climate Resilient Agronomy (B. Venkateswarlu *et al*., eds.), Indian Society of Agronomy, New Delhi.

Rao, K.V., B. Venkateswarlu, K.P.R. Vittal and B.R. Sharma. 2010. Water harvesting potential assessment in rainfed regions of India. Pages 67-74 *in* Proc. National Workshop on Rainwater Harvesting and Reuse through Farm Ponds: Experiences, issues and strategies (K.V. Rao *et al*., eds.), CRIDA, Hyderabad.

Reddy, K.C.K., M. Kumar. K.V. Rao, V. Maruthi, B.M.K. Reddy, B. Umesh, R. Ganesh Babu, K. Srinivasa Reddy, Vijayalakshmi and B. Venkateswarlu. 2012. Farm Ponds: A Climate Resilient Technology for Rainfed Agriculture, Technical Bulletin No 3/2012, CRIDA, Hyderabad. 67 p.

Singh, P., P. Pathak, S.P. Wani and K.L. Sharawat. 2009. Integrated watershed management for increasing crop productivity and water use efficiency in semi-arid tropical India. *Journal of Crop Improvement* 23(4): 402-429.

Venkateswarlu, B. and Arun K. Shankar. 2009. Climate change and agriculture: Adaptation and mitigation strategies. *Indain Journal of Agronomy* 54(2): 226-230.

Venkateswarlu, B., B.K. Mishra, G.R. Chary, G.R.M. Shankar and G. Subba Reddy. 2009. Rainfed Farming: A Compendium of Improved Technologies, CRIDA, Hyderabad, 132 p.

Improving water productivity through rainwater harvesting

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Extended Summary

India accounts for about 2.4% of the world's geographical area and 4% of world's renewable water resources to support about 18% of the world's human population and 15% of livestock. Agriculture is an important sector of the Indian economy, accounting for 14% of the nation's GDP, about 11% of its exports, about half of the population still relies on agriculture as its principal source of income; agriculture is a source of raw material for a large number of industries. The net sown area has remained about 140 mha since 40 years but the number of farmers has increased from 70 to 140 million. About 10 million farmers are being added every five years. Hence, the country has the twin challenges of meeting its water needs along with sustaining pace of development.

In India, rainfed areas accounts for 56% of total cultivated area (78 mha) and contribute only 47% to national food basket. Even though rainfed areas are having low and unstable productivity, mainly because of vagaries of monsoon and rainfall variability, it will remain the main stay for the livelihood support of millions of small and marginal farmers across the country. About 68% of the sown area is subjected to drought in varying degrees (35% of the area receives rainfall of 750-1125 mm and is drought prone, 33% of the area receives rainfall of <750 mm and is chronically drought prone); 21% of the sown area receives rainfall of <750 mm that is located in peninsular India and Rajasthan. Drought prone area lies in arid region (19.6%), semi-arid (37%) and sub-humid (21%) areas that occupy 77.6% of its total land area of 329 mha. Per capita availability of water is steadily declining, from 5177 m^3 in 1951 to 1820 m^3 in 2001, and to 1588 m^3 per year in 2010 due to increase in population, rapid industrialization, urbanization, increasing cropping intensity and declining groundwater table; and it is expected to decline to 1341 and 1140 m^3 by 2025 and 2050, respectively. The problems are likely to aggravate in future if suitable measures are not adopted. Therefore, the challenge before Indian agriculture is to transform rainfed farming into more productive, stable and sustainable systems and the potential rainfed areas like eastern India need to be tapped through scientific methods of sustainable management of natural resources, particularly water and soil, supported by demand-driven, appropriate, and forward looking policies.

Rainwater harvesting and its management is the most critical component of rainfed farming. The successful production of rainfed crops largely depends on how efficiently soil moisture is conserved *in situ* or the surplus runoff is harvested, stored and recycled for supplemental irrigation. Different states have initiated special programs on rainwater harvesting in order to ensure the sustainability and to improve the livelihoods of people. Despite these experiences, the adoption of micro-scale water resource development at farm level has been very low, particularly for drought proofing through life saving irrigation of *kharif* crops. A number of

technological and socio-economic constraints are cited for this poor adoption and up-scaling. The rainfall extremes and high intensity rain events witnessed in recent years are likely to cause large spatial and temporal variations in the amount of surplus runoff available for harvesting. In some areas, there could be increased runoff and more potential for harvesting, while in other areas it might decrease. Further with climate change posing a major challenge for rainfed agriculture and the constraints in further expansion of irrigated area in the country, rainwater harvesting and efficient water use are inevitable options to sustain rainfed agriculture in future (Ambast *et al.*, 1998).

It is recommended to accelerate the pace of renovation of old and silted community ponds for water conservation as well as ground water recharge. Monitoring of the effectiveness of water harvesting structures constructed under various watershed development programs will be helpful to strengthen rainwater conservation in the country. It is also recommended that optimum land and water allocation of limited water resource to crops, efficient on-farm water management, conjunctive use of water from different sources, improved agronomic practices, crop diversification with low water requiring crops like pulses and oilseeds along with *in-situ* soil moisture conservation etc. are required to attain higher water productivity. Though the water resource development and its efficient application are a capital intensive activities, they only would be able to ensure the desired annual growth rate in the agricultural and allied sectors, thus help in paving the way for achieving the aim of doubling the farm returns.

Reference

Ambast, S.K., H.S. Sen and N.K. Tyagi. 1998. Rainwater management for multiple cropping in Sundarbans delta (WB). Bulletin No 2/98, Regional Research Station, Central Soil Salinity Research Institute, Regional Research Station, Canning Town, India.

Improving agricultural water productivity in the Indira Gandhi *Nahar Pariyojana* (IGNP)

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Extended Summary

By 2050 we will have 9.5 billion people to feed. Under business as usual scenario, this will require large additional amounts of land and water to be put under agricultural production. But majority of the water resources are already committed worldwide for different uses with 70-90% of freshwater withdrawals already going towards producing food and feed. Expansion of irrigated agriculture will involve allocation of additional blue water resources and expansion of rainfed agriculture will require additional green water resources - neither of which is readily available. In such a dilemma, it makes sense to improve agricultural water productivity which involves growing *more crop per drop* and overcoming the need for allocation of additional land and water resources. Going into the future, we have to produce more food with less water and generate bigger livelihoods with lower (or the same) volumes of water.

ICARDA and CAZRI have recently concluded a 6-year research study on investigation of avenues to improve agricultural water productivity in the IGNP canal command area. The study was conducted in stages I and II of the canal command area; stage I has predominantly cereal-based production systems under surface irrigation and stage II has pressurized irrigation-based cash crop production.

The study measured present levels of biophysical and economic land and water productivity for individual crops and cropping systems. Using two years of crop production, management practice and soil-water balance data, CropSyst model was calibrated and validated for each crop for both stages of command area. There was good to excellent agreement between observed and predicted data on yield, biomass, LAI, soil moisture, initiation of different crop growth stages and nitrogen uptake. Calibrated models were then applied for simulating different nitrogen and irrigation application scenarios using a 35-year weather dataset.

Targeted separate recommendations are presented for each crop on how decision makers can improve agricultural water productivity in the command area. Stage I can improve the interaction between applied water and inorganic fertilizers to improve yields and crop water productivity (Fig. 1). Whereas, stage II can move from lower value, water-thirsty crops to crops which generate higher incomes with same or lesser amounts of water (Table 1).

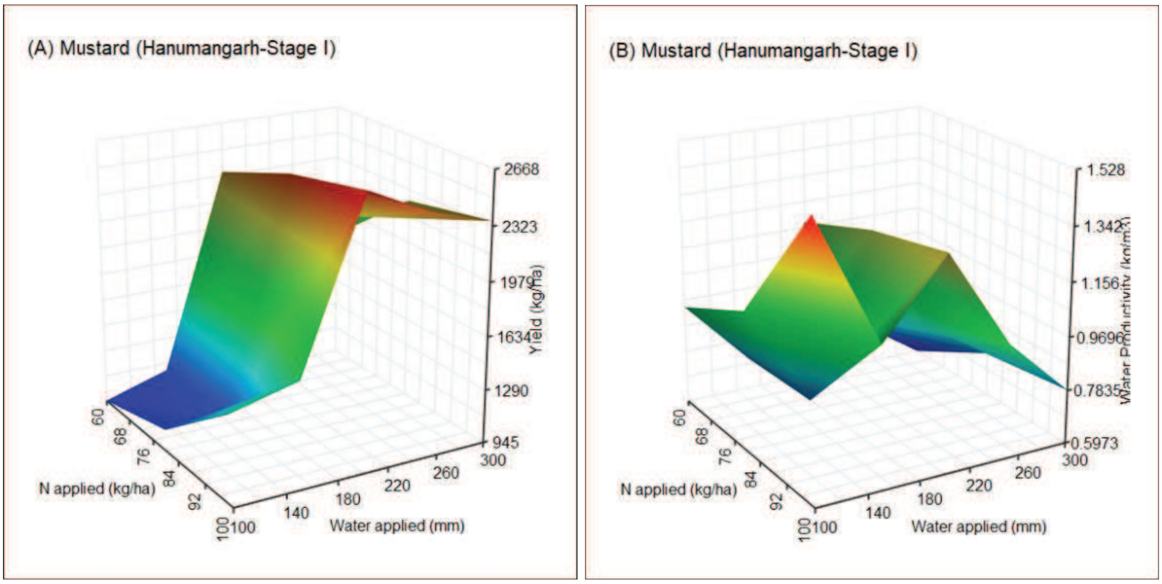

Figure 1. *Simulation results of 35-year scenario of mustard production at Hanumangarh site. (A) shows relationship between N-application, water application and yield, and (B) shows relationship between N-application, water application and water productivity. Highest yield is achieved at 100 kg N ha^{-1} and 200 mm water application (2,668 kg ha^{-1}), but highest WP is achieved at 100 kg N ha^{-1} and 100 mm water application (1.528 kg m^{-3}). An increase in water application beyond 100 mm increases crop yield to a small extent but reduces WP in trying to achieve the crop yield increase.*

Table 1. *Economic water productivity of different cropping systems followed at Hanumangarh (2012-13)*

Cropping system	Yield (kg ha^{-1} mm)		Return (₹ ha mm^{-1})	
	Biological yield	Seed yield	Gross return	Net return
	Water productivity (in terms of water applied)			
Cotton - Wheat	13.4	4.8	134.4	79.6
Cotton - Mustard	12.3	3.6	137.9	78.3
Clusterbean - Wheat	16.3	5.9	327.1	273.2
Clusterbean - mustard	15.5	4.6	383.6	323.1
Cotton - Barley*	15.1	5.3	155.3	91.4
Cotton - Chickpea*	12.2	3.7	151.8	91.5
	Water productivity (in terms of water used)			
Cotton - Wheat	17.7	6.3	177.4	105.1
Cotton - Mustard	15.4	4.5	171.7	97.5
Clusterbean - Wheat	21.2	7.7	425.4	355.3
Clusterbean - Mustard	18.6	5.5	458.1	385.9
Cotton - Barley*	18.3	6.4	187.6	110.4
Cotton - Chickpea*	15.2	4.6	189.3	114.1

* Cotton-barley and cotton-chickpea cropping system were negligible as they have less than 1% area in the study site.

Scaling pulses productivity - Exploiting the strength of supplementary irrigation in Indian context

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Abstract

Tremendous efforts made by all the stakeholders in India have resulted in a Pulse Revolution in the country as evident from higher production consecutively for the last two years. However, despite our best efforts in improving the tolerance of high-yielding and short duration varieties to biotic and abiotic stresses, we have not achieved our desired productivity goals. Aiming at the Sustainable Development Goals (SDG) for stability in food supply and balanced nutrition, adequate thrusts is needed for scaling pulses productivity beyond one tonne per hectare. Water is a major limiting facror in rainfed agro-ecology that has to be more judiciously used, especially in presence of diverse constraints. An efficient on-farm management of precious water is its use for supplementary irrigation, wherever possible, adopting microirrigation (drip and sprinkler irrigation). The latter safeguards its judicious use, besides providing opportunity for precision application of fertilizers and other agrochemicals, and conjunctive use of brakish water. As 52% farm fields are still dependant on rainfall, with uncertain production, there is a need to get improved stability through the use of supplemental irrigation in the rainfed areas. This paper highlights the importance of life saving/supplementary irrigation in augmenting the pulses production by relieving the moisture stress at critical stage of the crop growth.

Introduction

India is the world's largest producer of pulses. It had a production of 25.23 m tons of pulses from an area of around 31 mha with a productivity of 811 kg ha^{-1} during 2017-18 (DES 2018). Mostly grown as rainfed crops (87% of the sown area), these soil-building crops are boon to us in many ways. Improvement of rainfed farming, promotion of integrated farming systems, high value farming, secondary and precision agriculture are key to sustained increases in agriculture production in the country. Pulses can fit into these systems as they can be favourably grown across the seasons, locations/states/zones and diverse agroecological situations and farming systems. Over a dozen of pulse crops are grown in India. While pigeon pea, cowpea, mung bean and urd bean are grown in rainy season (*Kharif*), chickpea, lentil, field pea and rajmash are grown in winter season (*Rabi*). Mung bean and urd bean are also suitable for spring (*Zaid*) and summer seasons in a few regions of the country. Since these pulses are generally grown under rainfed agroecology and poor management conditions, they face various kinds of abiotic and biotic stresses, resulting in low productivity. Despite these constraints, introduction of new varieties and improved water and other input management have lately resulted in considerable gain in production and productivity of pulses (Praharaj *et al.*, 2017, 2018).

Pulses provide sizeable vegetable proteins to ever-growing population in the country. The split grains, called *dal*, are excellent source of high quality protein, essential amino acids and fatty acids, fibres, minerals and vitamins. Because of their symbiotic N fixation (SNF), a majority of their N need is met from this process and a sizeable leaf fall and nitrogen rich stumps and roots scale up soil N status, contributing to improved soil fertility and sustainability of the cropping systems. The residual N and soil organic matter (SOM) benefits subsequent crop(s) in the rotation (Sharma *et al.,* 1986). The needs of external inputs is rather meagre; their water requirement is about one-fifth of the cereals (Doorenbos and Pruitt, 1977); 200 to 300 mm for pulses against more than 500 mm for different cereal and oilseed crops and more than 900 mm for rice. Therefore, pulses can play a major role in nutritional security, soil amelioration and sustainable crop production.

Chickpea and pigeon pea are the two major pulses grown in India during winter and rainy seasons, respectively. Chickpea is grown during *rabi* season in an area of about 10.76 mha in India producing around 11.16 m tonnes with an average yield of 1037 kg ha^{-1}. Madhya Pradesh, Rajasthan, Maharashtra, Uttar Pradesh, Andhra Pradesh, Karnataka, Chhattisgarh, Bihar and Jharkhand together contribute around 95% of the total production (AICRPC, 2018). In recent years its area has expanded in the dry region of central and peninsular India because of the development of short duration, wilt resistant and HYV, and matching package of production technologies. The productivy of chickpea in several areas is constrained because of moisture deficit at critical stages of the crop growth (Praharaj *et al.,* 2016b). Pigeon pea is primarily grown as a rainfed crop during rainy months under diverse cropping systems including inter/mixed cropping. While early and long duration genotypes are prevalent in North Zone, medium duration cultivars are grown in rainfed Central and South Zone. The crop is grown in an area of 5.13 mha with a production of 4.23 mha and a productivity of 824 kg ha^{-1} (2016-17). The productivity is low, mainly because of abiotic stresses at both vegetative and reproductive stages (Praharaj *et al.,* 2017). Besides chickpea and pigeon pea, mung bean and urd bean - the fast growing and remunerative pulses with low water requirement - could also be useful in bridging the production gaps in pulses.

Many of our studies have showed that significant improvement in grain yield and water use efficiency (WUE) of these pulses could be made if they were grown with a few supplementary irrigations at the most critical stages of crop growth. A brief account of the benefit in these pulses from supplementary irrigation in India is given below.

Water management in winter pulses

Surface irrigation influenced the input use efficiency (IUE) and crop productivity in *desi* chickpea. A pre-plant irrigation (for achieving optimal plant stand) followed by an irrigation at pre-podding stage increased grain yield by 77% over no irrigation (Masood Ali, 2009). Chickpea productivity could be considerably increased by applying irrigation once (at 50% flowering/pod development stage), or two times (once at branching and then at pod development stage), depending on the rainfall received during the growth period. Higher grain yield and WUE could be obtained with 3.0 cm of irrigation water on flood irrigated flat beds (FIFB) and with only 1.5 cm in furrow irrigated raised beds (FIRB); FIRB planting increased yield over flat planting by around 18.8% and conserved more water that enhanced WUE in chickpea (Masood Ali, 2009). A two year study at ICAR-Indian Institute of Pulses Research (IIPR), Kanpur on Optimum Irrigation Scheduling (OIS) with irrigation applied at two critical stages (branching and pod development) of *desi* chickpea showed significantly higher grain yield (16.1%), biomass yield (9%), harvest index (5.7%), net return (22.4%), BCR (22.8%) and productivity per day (16.4%) over that applied at branching stage only (Praharaj *et al.,* 2016b). There was increase in water saving (29.4%), WUE (30.7%) and WP (20.8%) when OIS was done using sprinkler than flood irrigation, although yields were identical (2.65 t ha^{-1}). Appropriate rainfall forecasting is important for a quick decision on OIS.

In chickpea and long duration pigeon pea (that grows from rainy to winter seasons), two irrigations (one each at branching and pod formation) were optimum in central India (Mishra *et al.,* 2012 a, b). In the NWPZ and NEPZ, response to irrigation is generally low due to adequate winter rains and high relative humidity. However, under inadequate rains, two irrigations (one each at branching and flowering) gave optimum yield (Masood Ali, 2009). In *Rabi* pigeon pea, three irrigations (25, 75 and 100 DAS) could maximize its productivity in the absence of winter rains and the most important critical stage was when crop was 25-days old.

In field pea (*Pisum sativum* L.), 50% flowering stage was found most critical for irrigation (Panwar and Malik, 1977) although there might be additional irrigation requirement before and later than this stage. Irrigation at both branching and flowering stages was also beneficial for dwarf peas. More studies on field peas revealed that three irrigations (one each at 45 DAS, 50% flowering and pod development) resulted in good yield in the absence of winter rains.

In lentil (*Lens culinaris* Medik.), one irrigation at the early pod filling stage (at 55-60 DAS) was most effective. Raised bed planting could save 20-25% irrigation water (by volume) besides increasing grain yield (Masood Ali, 2009). So also was the effect of stubble length of preceding rice in mitigating soil moisture stress and grain yield of lentil in a 'rice-lentil' relay cropping system. Long stubble height (20 cm) increased both lentil grain yield and water productivity by 275 kg ha^{-1} and 0.1 kg m^{-3}, respectively compared to short (10 cm) ones (Bandyopadhyay *et al.,* 2016), perhaps by retaining more moisture.

Basing the amount of irrigation water to be used on evaporation demand of the crop (CPE) is useful in saving water. A IW/CPE of 0.8 was adequate for realizing optimum yield in field peas; 0.4 IW/CPE gave the highest yield in *Rabi* pigeon pea (Masood Ali, 2009). Frequent irrigation at higher IW/CPE ratio (>0.6) was not useful for chickpea (Yadav, 1975); irrigation between 0.4 to 0.6 ratio of IW/CPE was beneficial (Jethmalani, 1975). Furrow placement of a water absorbing polymer *Jal Shakti* @ 2 kg ha^{-1} was economical and improved productivity of chickpea by 12% (Singh, 1988).

Micro-irrigation techniques enable efficient management of both water and nutrient by delivering them precisely near the root zone of the crop plant with improved efficiency in water conveyance, WU and WP. The water is supplied through a low-pressure pipe network (comprising mains, sub mains, laterals and emitting/dripper devices), daily or on alternate day, at field capacity. Even saline water up to 8-10 dS m^{-1} electrical conductivity can be used. Fertilizer can be combined with drip-water. In the event of acute moisture stress, one or two irrigations, directly applied to root zone by this system, as a supplementary irrigation, can elevate crop performance. Chandegara and Yadavendra (1998) found that three sprinkler irrigations of 60 mm each at sowing, branching and pod formation stages were sufficient for chickpea with water saving of 44%.

Water management in spring and summer pulses

Fast growing, short duration pulses like mung bean and urd bean have potential to meet the shortfall in total pulses production in the country provided they are grown with appropriate technology such as right cultivars, compatible pre- & post-emergence herbicides/pesticides, precision crop management, appropriate irrigation scheduling and suitable land configuration (raised bed/ridge planting especially during *kharif*), replenishment of major mineral nutrients (P and K) commonly deficient micronutrients (Zn, S and Mo) and use of suitable machines for planting (IIPR No Till Drill), and harvest and post-harvest operations.

Many field experiments in North Indian Plain Zones have revealed that when summer mung bean is planted during mid-March, after potato/garlic or winter vegetables, it requires only 1-2 irrigations (due to higher residual soil moisture) in comparison to normal 3-4 irrigations for late (April) planted crop, after harvest of wheat, because of low residual soil moisture.

A micro-irrigation management study in summer mung bean showed a significant improvement in seed yield (31%), with water saving (11% less WU and 43.2% enhanced WUE), when laser guided precision tillage was carried out (Praharaj *et al.,* 2015). Sprinkler irrigation at podding and seed setting stage enhanced the irrigation efficiency in short duration (2 months) mung bean crop (with 20% less water use and 24% higher WUE) over flood irrigation (Praharaj *et al.,* 2016 a). Sprinkler irrigation in mung bean increased yield by 39.7% over surface irrigation and resulted in water saving of 49.8% (Velayutham and Chandrasekaran 2002).

Spring planted mung bean required less irrigation over the summer planted one. Large plot demonstrations of overhead sprinkler irrigation, done in the late afternoon, with improved agro-techniques (paired rows, narrow row spacing), convincingly showed the benefit of micro-irrigations in the summer/spring mung bean, giving significantly higher water economy (35-50%). Wider spacing of 30 cm commonly adopted by farmers for mung bean, gave 16-20% less yield than in 22.5 cm row spacing (Praharaj *et al.,* 2016b).

Water management in *Kharif* pulses

Excess soil moisture or water logging during monsoon season creates unfavourable conditions for the growth for kharif pulses (Praharaj, 2013), including reduced aeration, hampered nodulation, reduced nutrient uptake, and favourable environment for blight and seedling rot, resulting in reduced crop stand and yield. Thus, suitable land configuration such as ridge and raised bed planting has a role in maintenance of optimum plant population and crop productivity in contrast to conventional flat planting/broadcasting (Praharaj and Kumar, 2012; Singh *et al.*, 2015). On the other hand, moisture stress in the post-monsoon period adversely affects the development of reproductive organs leading to depressed yields. Therefore, management of surplus water during rainy months and supplemental irrigation to compensate soil-moisture deficit during post-rainy months are imperative for productivity enhancement in *Kharif* pulses.

Conclusion

Water being the critical input for productivity enhancement, there is a need for its optimum and judicious use (through supplementary irrigation) for realizing higher input use efficiency through various technological options available. As for optimum water use in pulses, only one or two irrigations at the critical stages of growth will suffice, there is a need for harnessing synergy of holistic water management, not just water *per se.* Against a possible natural resource degradation likely to be accentuated by increasing vagaries of climate, introduction and popularization of *grain legumes* as a water-efficient crop enterprise could emerge as a *transition towards sustainability* in intensive agricultural production systems in India (Venkatesh, *et al*., 2013). Modern technologies such as improved land configuration, supplemental irrigation through efficient irrigation methods like sprinkler and drip, adoption of agro-ecologically compatible intercropping/mixed cropping and improved crop husbandry are avenues for boosting production in pulses (Praharaj *et al.,* 2014*)*. Dissemination of proven technology along with provision for making availability of quality critical inputs, including water on time, at affordable prices to farmers will definitely help in achieving desired goal of higher crop productivity. To reduce water demand further, improved varieties with drought and heat tolerance would provide a long-term solution against adverse effects of recurrent droughts/high temperatures being witnessed in one or the other part of the country every year. Similarly, research needs to be intensified to develop high-yielding, short-duration strains which escape terminal drought as it could facilitate farmers to include them in a given cropping systems.

References

AICRPC. 2018. All India Coordinated Research Project on Chickpea, Annual Report 2018. 37 p.

Bandyopadhyaya, P.K., K.C. Singh, K. Mondal, R. Nath, P.K. Ghosh, N. Kumar, P.S. Basu and S.S. Singh. 2016. Effect of stubble length of rice in mitigating soil moisture stress and on yield of lentil (*Lens culinaris* Medik) in rice-lentil relay crop. *Agriculture Water Management* 173: 91-102.

Chandegara, V.K. and J.P. Yadavendra. 1998. Efficacy of sprinkler irrigation in chickpea. *Gujarat Agricultural University Research Journal* 24(1): 1-3.

DES, 2018. Area, production and productivity in pulses (2013-14). Directorate of Economics and Statistics, Government of India, New Delhi (cited from http://eands.dacnet.nic.in/ dated 13.11.2018).

Doorenbos, J. and W.O. Pruitt. 1977. Crop water requirements. *Irrigation and Drainage* Paper 24, FAO, Rome.

Jethmalani, S.C. 1975. All India Coordinated Research Scheme on Water Management and Salinity. JNKVV, Agriculture College, Indore, Madhya Pradesh, India.

Masood Ali. 2009. 25 years of pulses research at IIPR. ICAR- Indian Institute of Pulses Research, Kanpur (U.P.), India. 211 p.

Mishra, J.P., C.S. Praharaj and K.K. Singh 2012a. Enhancing water use efficiency and production potential of chickpea and field pea through seed bed configurations and irrigation regimes in North Indian Plains. *Journal of Food Legumes* 25: 310-313.

Mishra, J.P., C.S. Praharaj, K.K. Singh and N. Kumar. 2012b. Impact of conservation practices on crop water use and productivity in chickpea under middle Indo-Gangetic plains. *Journal of Food Legumes* 25: 41-44.

Panwar, K.S. and J.S. Malik. 1977. Critical stages of irrigation in field pea. *Indian Journal of Agronomy* 22: 255-256.

Praharaj, C.S. 2013. Managing precious water through need based micro-irrigation in a long duration pigeonpea under Indian Plains. Page 4 *in* Policies for Water and Food Security: Proceeding ofInternational Conference. 24-26 June 2013, Cairo, Egypt.

Praharaj, C.S. and N. Kumar. 2012. Efficient management of water and nutrients through drip fertigation in long duration pigeon pea under Indian Plains. Pages 819-20 *in* Agronomy, Environment and Food Security for 21st Century: Proceeding of 3rd International Agronomy Congress (Vol. 3). 26-30 November 2012, IARI, New Delhi.

Praharaj, C.S., Rajesh Kumar, M. Akram, U.C. Jha, Ummed Singh, Narendra Kumar, S.S. Singh and S.K. Singh. 2015. Dissemination of pulses production technologies for enhancing profitability of farmers in Uttar Pradesh. *Journal of Food Legumes* 28(2): 157-161.

Praharaj, C.S., Ummed Singh and Kalikrishna Hazra. 2014. Technological interventions for strategic management of water for conserving natural resources. *In* Conservation Agriculture - Soil Health and Wallet Wealth : Proceeding of 6th World Congress. 22-26 June 2014, Winnipeg, Manitoba, Canada.

Praharaj, C.S., Ummed Singh, S.S. Singh and N. Kumar. 2018. Tactical water management in field crops: the key to resource conservation. *Current Science* 115(7): 1262-1269**.**

Praharaj, C.S., Ummed Singh, S.S. Singh and N. Kumar. 2017. Micro-irrigation in rainfed pigeonpea-Upscaling productivity under Eastern Gangetic Plains with suitable land configuration, population management and supplementary fertigation at critical stages. *Current Science* 112(1): 95-107.

Praharaj, C.S., Ummed Singh, S.S. Singh, N. Kumar and Ram Lal Jat. 2016 a. Crop growth, productivity, water use and economics in mungbean and urdbean as influenced by precision tillage and sprinkler irrigation scheduling. *Journal of Food Legumes* 29(2): 113-119.

Praharaj, C.S., Ummed Singh, S.S. Singh, N.P. Singh and Y.S. Shivay. 2016b. Supplementary and life-saving irrigation for enhancing pulses production, productivity and water use efficiency in India. *Indian Journal of Agronomy* 61(4 ISI): S249-S261.

Sharma, C.P., B.R. Gupta and P.D. Bajpai. 1986. Residual effect of leguminous crops on some chemical and microbiological properties of soil. *Journal of the Indian Society of Soil Science* 34: 206-208.

Singh, B.N. 1988. Effect of irrigations and Jal Shakti on grain yield of chickpea. Annual Report. Directorate of Pulses Research, Kanpur, India. 27 p.

Singh, Ummed, C.S. Praharaj, S.S. Singh and N. Kumar. 2015. Influence of crop establishment practices and genotypes in pigeon pea-wheat system under IGP of India. *Journal of Food Legumes* 28(4): 315-319.

Velayutham, A. and B. Chandrasekaran. 2002. Pages 164-167 *in* Recent Advances in Irrigation management: *Proceedings of the Training Programme.* Tamil Nadu Agricultural University, Coimbatore.

Venkatesh, M.S., K.K. Hazra, P.K. Ghosh, C.S. Praharaj and N. Kumar. 2013. Long-term effect of pulses and nutrient management on soil carbon sequestration in Indo-Gangetic plains of India. *Canadian Journal of Soil Science* 93: 127-136.

Yadav, J.S.P. 1975. Annual Progress Report. All India Co-ordinated Scheme for Research on Water Management and Salinity, CSSRI, Karnal.

Single supplemental irrigation can double lentil (*Lens culinaris* Medik.) yield in mid hills of Nepal

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Abstract

Lentil production, in recent years, has been severely affected in mid hills of Nepal due to almost no rainfall during growing season, combined with terminal drought. An experiment was conducted during 2015 to 2017 to evaluate the effect of supplemental irrigation at various growth stage, singly and all combinations, on the performance of lentil in mid hills of Nepal. The soil was silty loam, low in organic matter with moderately acidic pH. Lentil variety 'Maheswor Bharati' was used with seed rate of 40 kg ha^{-1}. Amount of water used for per irrigation was 20.8 L m^{-2} in 2015/16 and 33.3 L m^{-2} in 2016/17 and 2017/18. Grain yield and yield parameters except 100 seed weight were significantly affected by water management treatments. Supplemental irrigation increased grain yield by 101 to 264% as compared to control (mean grain yield of 476 kg ha^{-1}). Grain yield was highest when supplemental irrigation was given at all the three stages i.e., vegetative, flowering and podding (1733 kg ha^{-1}), followed by irrigation at vegetative and flowering stages (1571 kg ha^{-1}). Good vegetative growth, greater number of filled pod per plant and longer crop duration contributed to greater yields in irrigated plots. Supplemental irrigation at pod filling stage showed comparatively less advantage over irrigation at other stages. There is a scope for doubling the grain yield with a single supplemental irrigation compared to water stress condition in mid hills of Nepal.

Introduction

Grain legumes play an important role in providing dietary protein, crop diversification, restoration of soil fertility and resilience of subsistence farming systems of Nepal. Lentil (*Lens culinaris* Medikus subsp. *culinaris*) is a major grain legume in the country, accounting for about 63% of area (206,969 ha) and 67% production (254,308 t) of all grain legumes (MESD, 2018). The national average yield is 1.16 t ha^{-1}. It is sown after rice harvest on tilled land (post-rice) or broadcasted in paddy field 1-2 weeks prior to rice harvest, as a relay cropping, entirely depending on residual soil moisture from the preceding rice crop. Sowing is done during October/November (autumn/post-monsoon) and crop matures during March-April (spring/pre-monsoon). Monsoonal rainfall contributes around 80% of the total annual rainfall (1800 mm), while rainfall during winter, pre- and post-monsoon seasons contributes only 3.5%, 12.5% and 4.0%, respectively, to the total (DHM, 2015). Winter (December-February) in Nepal is the driest season, with high winter precipitation in far western region and low in central *terai* and eastern regions. Climate change effects have been felt in Nepal in the form of increase in temperatures, frequent drought, changing rainfall pattern and frequent disasters that ultimately affect crop production (Malla, 2008).

In lentil, the water use (evapo-transpiration) has been reported to range from 115 to 274 mm, depending upon soil types, growing season, water supply, genotypes etc. (Shrestha, 2005), and frequency of irrigation depends on soil type, soil moisture, sowing time and crop duration. Also, genotypes vary in response to different moisture conditions (Erskine *et al.,* 1989; Hamdi *et al.* 1992; Silim *et al*., 1993; Zhang *et al.,* 2000). The macrosperm (large-seeded) lentil performing better under wet conditions as compared to microsperma (small-seeded), which perform better under dry environments (Erskine, 1996). Soil moisture deficit at early germination and reproductive stages and high temperatures during pod filling stage and nutrient deficiency are the major abiotic constraints limiting lentil production in Nepal (Shrestha *et al.,* 2012).

Water deficit because of change in rainfall patterns and occurrence of frequent drought during reproductive and grain filling stages causes significant reduction in yield of grain legumes (Farooq *et al.,* 2017). The impact of drought is much more pronounced in rainfed farming (Thakur and Karki, 2018). Studies on climatic variation have indicated the impact of climate change: increased temperature, irregular rainfall patterns (increase rainfall intensity, less number of rainy days), severe drought, flood etc. in Nepal (Malla, 2008; DHM, 2015; Thakur and Karki, 2018). Average temperatures recorded in the country are found to be increasing at the rate of 0.06°C per annum (Malla, 2008).

All Nepal rainfall trends show decreasing rainfall in all seasons (annual decrease 1.3 mm yr^{-1}) with the highest decrease (-0.3 mm yr^{-1}) in the post-monsoon season (DHM, 2017). Similarly, there is decline in rainfall from November to April, adversely affecting winter and spring crops (Thakur and Karki, 2018). There is a decrease in frost days and a shift of winter cold by a month later than regular in Kathmandu Valley (Malla, 2008). Lentil growth and yield are primarily determined by rainfall. Winter season is the driest and further decline in rainfall from November and April, due to climate change, exposes lentil crop to drought, resulting in low yield. In this context, supplemental or limited irrigation in lentil can improve or stabilize productivity.

Supplemental irrigation is limited amount of water added to crops when rainfall fails to provide enough moisture for normal plant growth for improving and stabilizing productivity (Oweis *et al.,* 2004). A number of researchers have conducted studies on supplemental irrigation in lentil at different growth stages, and have found positive crop response to irrigation. In Nepal, very limited work has been carried out on water management in crops, particularly in grain legumes. Therefore, the present study was conducted to determine the effect of supplemental irrigation, at various stages of crop growth, on the performance of lentil crop under rainfed mid hill conditions of Khumaltar in Nepal.

Materials and methods

The field experiment was conducted during three consecutive crop seasons at Khumaltar (85.20°E, 27.40°N, 1360 msl) in the Kathmandu valley, representing warm temperate mid-hill region of Nepal. The soil in Khumaltar is a deep, silty loam, developed on depositional alluvial terraces, medium in nitrogen (0.10 g ha^{-1}), high in available soil phosphorus (81.92

mg kg^{-1}), medium in available potassium (160.0 mg kg^{-1}), low in organic matter (2.15%), with moderately acidic reaction (pH 5.43) (Amgain, 2018).

Annual mean rainfall of the experimental site was 980, 1127 and 1178 mm, respectively, in the first (2015/16), second (2016/17) and third (2017/18) year of the study. Annual mean maximum, and minimum temperatures and total precipitation patterns for the study site during 2015/16 to 2017/18 were similar to long-term averages (2001/02 to 2016/17), but an abrupt rise in mean maximum temperature in April and erratic rainfall pattern were observed during the experimental period (Fig. 1).

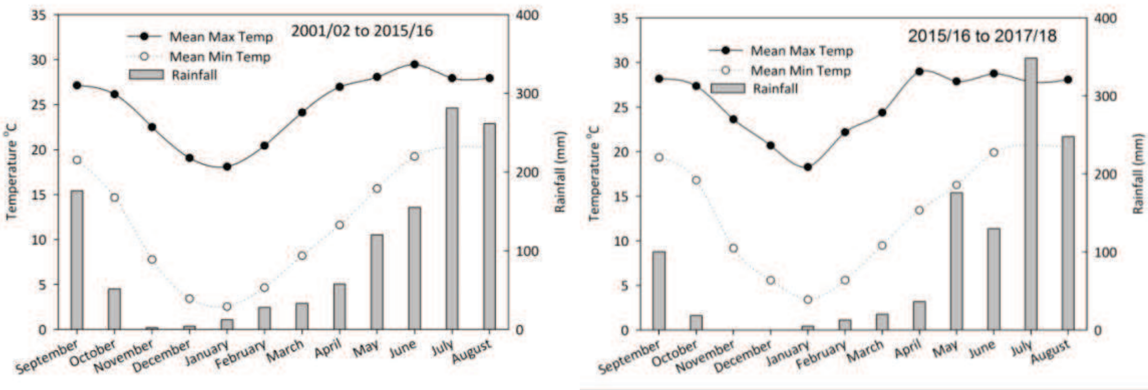

Figure 1. *Annual mean maximum and minimum temperatures and monthly total rainfall during the study period (2015/16 to 2017/18) and long term (2001/02 to 2015/16) average data during lentil growing season at Khumaltar, Nepal.*

The 2016/17 year had higher mean minimum temperatures during October to May, and drier months from October to February i.e., 52 to 79% less rainfall. The 2017/18 season was the driest as compared to the long term mean rainfall during the same months (98 mm) (Fig. 2).

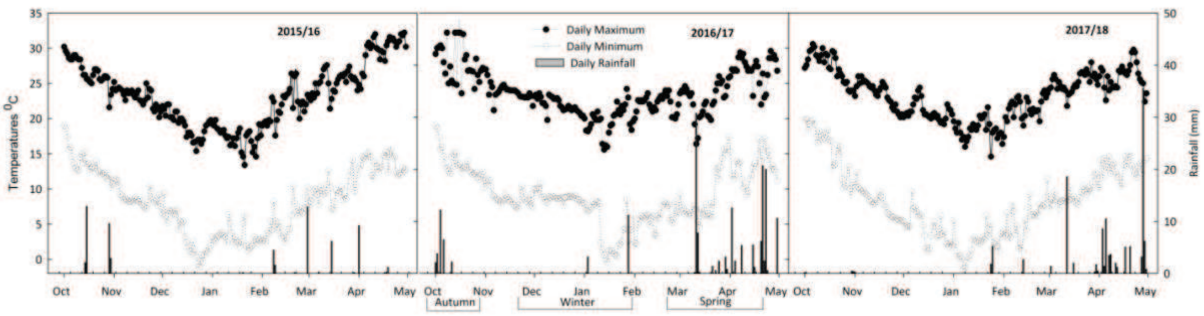

Figure 2. *Weather data during three lentil growing seasons at Khumaltar, Nepal*

Seven irrigation management treatments, 1) control (moisture stress), 2) supplemental irrigation (SI) at vegetative stage, 3) SI at flowering stage, 4) SI at pod filling stage, 5) SI at vegetative and flowering stages, 6) SI at vegetative and pod filling stages, and 7) SI at vegetative, flowering and pod filling stages, were evaluated in the experiment that lasted from 2015/2016 (first year) to 2017/2018 (3rd year). Experimental field was ploughed and leveled after the harvest of the previous crop (soybean), and trial was laid out in a randomized complete block design with four replications. Plot size for each treatment was 4 m x 3 m (12 rows of 4 meter length). Lentil variety 'Maheswor Bharati' was sown during 2nd to 3rd week of October (Table 1), with a seed rate of 40 kg ha^{-1}, in rows 20 cm apart.

Approximately 200 seed m^{-2} were planted. Chemical fertilizers @ 20 kg N, 40 kg P_2O_5 and 20 kg K_2O ha^{-1} were applied as basal at the time of land preparation. Pre-emergence herbicide Pendimethalin @ 2.5 L ha^{-1} was applied prior to seedling emergence, and later weeds were removed manually whenever needed. The amount of water used for each SI was 350 L $plot^{-1}$ in 1st year and 400 L $plot^{-1}$ in 2nd and 3rd year. Measured amount of water was applied uniformly in the plots manually. Check plots were covered with plastic shade to avoid rainwater, whenever there was cloudy weather or rain forecast. Details of time of planting, SI and harvesting are given in Table 1.

Table 1. *Details on planting, crop growth stages for giving supplemental irrigation (SI), amount of irrigation water (Litre/12 m^2 plot), date of physiological maturity and harvest area*

Parameters	**2015/16**	**2016/17**	**2017/18**
Planting date	16 October 2015	26 October 2016	13 October 2017
Crop growth stages:			
Vegetative	60 (13 Dec 2015)	51 (16 Dec 2016)	72 (24 Dec 2017)
Flowering	90 (14 Jan 2016)	96 (30 Jan 2017)	102 (23 Jan 2018)
Pod filling	142 (6 Mar 2016)	127 (2 Mar 2017)	136 (23 Feb 2018)
Irrigation water	**350** L	400 L	400 L
Date of 90% maturity	20 Mar-6 Apr 2016	26 Mar-2 Apr 2017	18-29 Mar 2018
Net area harvested (m^2)	7.5 (3 m x 2.5 m)	8 (4 m x 2 m)	7.5 (3 m x 2.5 m)

Early plant stand counts were taken from 1 m x 1 m quadrant at two places in a plot in 1st year and middle eight rows in 2nd year, while final plant counts were made from the middle eight rows in a plot for all three years. At physiological maturity, 10 plants from the middle rows were taken to measure plant height (from ground level to the base of apical bud), number of primary branches (branches subtending from the main stem), number of filled and unfilled pods, and seeds per pod. Data on days from sowing to 50% flowering, days from sowing to 90% maturity, grain yield and straw dry matter were taken from net harvest area.

Crop was harvested manually and sun dried, and hand threshed to separate seed and straw (leaves, stems, and pod walls). Grains were weighted when adequately dried. Straw biomass from net harvest plot was weighed and a pre-weighed straw subsample for each plot was oven-dried at 70°C for 48 h to estimate the straw dry matter yield on an oven-dry basis. Two hundred seeds were counted, and weighed to measure seed size (expressed as 100-seed weight). Harvest index (HI) was calculated as the proportion of seed weight to total biomass. Data were analysed using GenStat Discovery and SPSS 10 package. The relationships between yield and yield components were determined using the Pearson's simple correlation test. Least significant differences (LSD, P=0.05) were calculated to evaluate the significance of difference between means.

Results

Days from sowing to 90% maturity days, plant growth, number of pods per plant, grain yield and straw biomass were significantly affected by SI at different crop growth stages (Tables 2, 3). However, final plant stand, number of main branches per plant (except year 1), seed size and seeds per pod (data not shown) were unaffected by the treatments. Final plant stand varied significantly among years, with the lowest in the 3rd year. SI at different crop growth stages lengthened crop duration by 3-10 days and increased plant height by 1-15 cm as compared to the stressed treatment (check). In 2nd year of experiment, crop grew 4-5 cm taller and matured 7-10 days earlier than in 1st and 3rd year of experiment.

Table 2. *Final plant stand and days to maturity of lentil as affected by year and supplemental irrigation (SI) at Khumaltar, Nepal*

#	Water management	Final stand (m^2)				Days to 90% maturity			
		1st year	2nd year	3rd year	Mean	1st year	2nd year	3rd year	Mean
1	Control (stress)	142	106	57	102	160	151	157	156
2	SI at vegetative stage	121	111	74	102	163	156	160	160
3	SI at flowering stage	108	122	68	99	163	156	160	160
4	SI at pod filling stage	98	107	59	88	167	157	167	164
5	SI at vegetative & flowering	106	118	61	95	165	154	161	160
6	SI at flowering & pod filling	109	126	65	100	169	157	163	163
7	SI at vegetative, flowering & pod filling	97	114	78	96	170	157	163	163
	Mean	*112*	*115*	*66*	*97*	*165*	*155*	*162*	*161*
	P value	0.141	0.555	0.162	0.563	<.001	<.001	<.001	<.001
	LSD (<.05)	-	-	-	-	4	2	3	0.9
	P value: Year (Y)				<.001				<.001
	LSD (<0.05)				10				0.6
	P value WM*Y				0.13				0.056
	CV (%)	21	14	18	20	2	1	1.3	1

The number of main branches per plant differed from year to year, from a maximum of 6 in 2nd year to the lowest of 2 in 3rd year (Table 3). SI at different crop growth stages significantly increased number of pods per plant (54-201% in year 1, 17-90% in year 2 and 55-132% in 3rd year) as compared to control. Lowest number was recorded in 3rd year while the highest in 1st year.

Similarly, grain yields were higher (53-222%, 100-176% and 372-677%, respectively in year 1, 2 and 3) with SI as compared to control (Fig. 3). In the year 1 and 2, the highest grain yield was recorded when SI was applied at vegetative and flowering or at vegetative, flowering and podding stages while in the year 3, the highest grain yield was obtained with SI at vegetative, flowering and podding stages. Similarly, SI increased straw biomass (11-128% in 1st year, 67-133% in 2nd year and 21-98% in 3rd year) as compared to check. In the 2nd year, about 15-20% pod drop was observed in control plots.

Yield and yield components, except final plant stand (p=0.563), unfilled pods per plant (p=0.812), seed size (p=0.291), were highly significantly affected by water management treatments and year to year variation were also significant in all parameters under study (Tables 2, 3, 4 and Fig. 3). Check plots gave lowest mean grain yield of less than 0.5 t ha^{-1}, reduced plant height and the lowest number of pods per plant. The highest grain yield of 1.6 t

ha^{-1} was recorded when SI was given at vegetative and flowering or at vegetative, flowering and podding stages. In 3^{rd} year, although plants grew taller, overall crop produced less number of pods, lighter seeds, less seeds per pod, low harvest index and low grain yield.

Table 3. *Mean number of primary branches and plant height of lentil under supplemental irrigation at Khumaltar, Nepal*

#	Treatments/Year	Branches/plant				Plant height (cm)			
		1^{st} year	2^{nd} year	3^{rd} year	Mean	1^{st} year	2^{nd} year	3^{rd} year	Mean
1	Control (stress)	3	5	2	4	21	26	23	23
2	SI at vegetative stage	4	6	3	4	23	31	25	26
3	SI at flowering stage	4	6	2	4	25	28	26	26
4	SI at pod filling stage	3	5	3	3	27	28	24	26
5	SI at vegetative & flowering	4	6	2	4	29	32	26	29
6	SI at flowering & pod filling	4	5	3	4	29	28	23	26
7	SI at vegetative, flowering & pod filling	3	6	2	4	30	29	31	30
	Mean	4	6	2	4	26	29	25	27
	P value	0.013	0.167	0.551	0.016	0.001	0.002	<.001	<.001
	LSD (<.05)	1	-	-	0.51	4	3	2	2
	P value: Year (Y)				<.001				<.001
	LSD (<0.05)				0.3				1
	P value WM*Y				0.102				0.002
	CV (%)	16	15	11	16	11	6	6	8

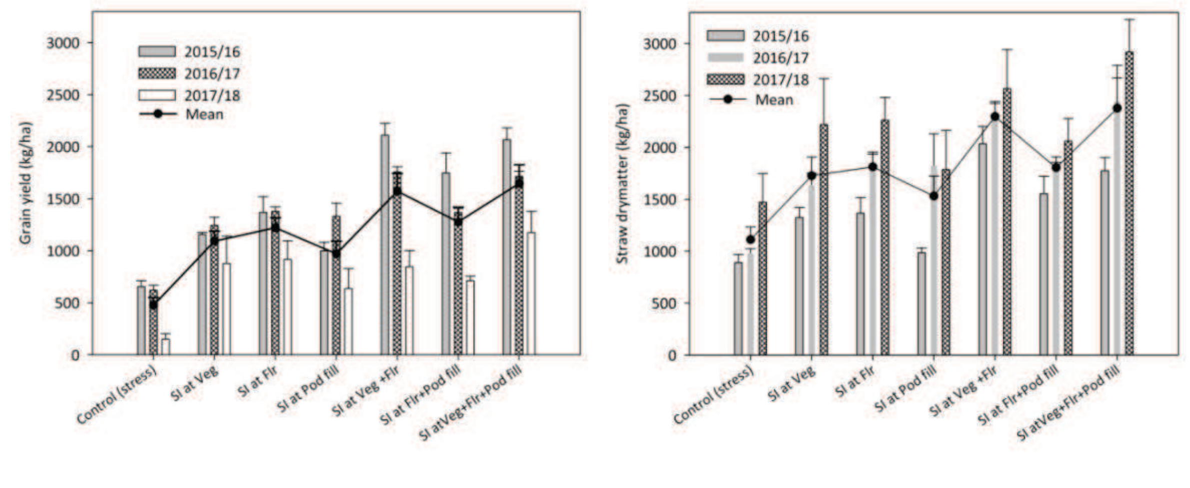

Figure 3. *Mean grain yield and straw dry matter production at different water management treatments at Khumaltar, Nepal. (Bars indicate standard errors of the mean of four replicates).*

Overall, supplemental irrigation showed positive correlation with number of pods per plant (r^2=0.33), grain yield (r^2=0.46) and straw dry matter (r^2=0.25). Grain yield significantly correlated with plant height (r^2=0.21), primary branches (r^2=0.17), seeds per pod (r^2=0.19) and pods per plant (r^2=0.41).

Table 4. Combined analysis of yield and yield components of lentil in Khumaltar, Nepal (2015/16 to 2017/18)

#	Water management (WM)/Year	Seeds per pod	Pods per plant	Unfilled pods per plant	100-seed weight (g)	HI
1	Control (stress)	1.6	35	5	2.1	0.28
2	SI at vegetative stage	1.7	56	5	2.2	0.37
3	SI at flowering stage	1.8	63	5	2.2	0.38
4	SI at pod filling stage	1.8	49	5	2.2	0.36
5	SI at vegetative & flowering	1.8	63	5	2.1	0.38
6	SI at flowering & pod filling	1.7	54	5	2.2	0.38
7	SI at vegetative, flowering & pod filling	1.7	74	4	2.1	0.39
	Mean	*1.7*	*56*	*5*	*2.2*	*0.36*
1	Year 1	1.9	73	3	2.2	0.47
2	Year 2	1.8	58	6	2.3	0.40
3	Year 3	1.5	37	6	2.0	0.22
	P value WM	0.024	<.001	0.812	0.291	<.001
	LSD (<0.05)	0.15	15		-	0.038
	P value Year (Y)	<.001	<.001	<.001	<.001	<.001
	LSD (<0.05)	0.1	10	0.88	0.09	0.025
	P value WM*Y	0.038	0.04	0.011	0.377	0.113
	CV (%)	10	33	35	7	13

Discussion

The study revealed SI increased grain yield and straw dry matter of lentil by 173% and 73%, respectively, as compared to control (moisture stressed), with significant variation among experimental years, which might have been due to variation in seasonal rainfall. Grain yield reduction was much higher than straw dry matter under water stress condition due to poor partitioning of dry matter into the reproductive parts (ICARDA, 1990). Highest yield increment was found when SI was given at all the three stages of crop growth i.e., at vegetative, flowering and podding (247% increase than control), followed by SI at earlier two stages (230% increase than control). Similar work done in light textured soil of central *terai* of Nepal showed increased grain yield by 12% (SI at vegetative) to 49% (SI at vegetative and flowering) as compared to rainfed condition (NGLRP, 2011; GLRP, 2013a; GLRP, 2013b). Under Mediterranean environment of Tel Hadya, in northern Syria, SI increased grain and biomass yields by >75% and 50%, respectively as compared to rainfed conditions (Oweis *et al.,* 2004). Hamdi *et al.* (1992) and Zhang *et al.* (2000) reported 20% and 70% increase in grain yield with SI at critical stages of growth.

Several studies on effect of different soil moisture regimes on lentil yield conducted elsewhere reported increased lentil grain yield by 9−465% with irrigation (Greco and Cavagnaro, 1991; Hamdi *et al.,* 1992; Nema *et al.,* 1984; Saraf and Baitha, 1985; Sharma and Prasad, 1984; Yusuf *et al.,* 1979; Singh *et al.,* 1988; Shrestha *et al.,* 2006a & b). In our study, SI increased numbers of pods per plant by 73%, plant height by 21%, seed number per pod by 10%, and harvest index by 37% as compared to control. Pot experiments by Shrestha *et al.* (2006a&b) on water deficits at flowering or podding stage showed reduced leaf area (48-81%), flower production (22-55%), number of pods and seeds (27-70%), while increased seed abortion (17-46%).

SI in our study prolonged crop duration thus contributing to higher grain yield than stressed condition. Many researchers have reported increased number of branches and pods per plant (Greco and Cavagnaro, 1991; Lal *et al.*, 1988; Murari and Pandey, 1985; Rathore *et al.*, 1992), taller plants (Lal *et al.,* 1988; Murari and Pandey, 1985; Nema *et al.,* 1984), high harvest index (Sharma and Prasad, 1984), extended maturity by 5-6 days (Lal *et al.,* 1988), all of which contributed to higher seed yield in irrigated plants. Irrigation seemed to increase seed size (Lal *et al.,* 1995; Nema *et al.,* 1984) or no effect on seed size (Greco and Cavagnaro, 1991**;** Murari and Pandey, 1985; Shrestha *et al.,* 2006b). Tiwari and Vyas (1994) indicated positive correlation of soil moisture and field emergence. Seedling, branching, flowering and pod filling are the sensitive stages to water stress in lentil, depending upon variety, soil type, soil moisture status and environmental condition (Yusuf *et al.,* 1979; Zhang *et al*., 2000).

Conclusion

Lentil is the most important grain legume of Nepal in terms of area covered, production, dietary protein and as export commodity. But, it has remained a marginal rainfed crop in terms of resource allocation for external inputs and crop management. SI is important in improving crop establishment and avoiding drought, particularly in rainfed dry growing season. SI at vegetative, flowering, podding or combination of any two or three stages significantly improved lentil yield. Greater numbers of pods/plant, taller plants, less numbers of empty pods and prolonged crop duration contributed to greater yield in irrigated plots. SI at pod filling had comparatively less advantage over that at vegetative and flowering stages under mid hill rainfed environments of Nepal. Farmers here do not irrigate lentil crops because of the general perception that irrigation would kill their crop. This is partly true as traditional cultivation practice is to broadcast seed in standing rice crop or land cultivated just once, in both cases land leveling and crop establishment are the issues. In the context of climate change, crop production from rainfed environment can be highly influenced by erratic rainfall, rising temperatures, extreme drought, etc. Therefore, optimization of irrigation water is crucial and SI can be the best option for farmers to increase and stabilize lentil production. SI can be expanded to rainfed mid hill environment (in maize or soybean - lentil rotation) of Nepal. Proper feasibility studies are, however, needed for effective implementation and encouraging adoption of SI technique.

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References

Amgain, R. 2018. Effect of nutrient sources on soybean yield and soil properties under mid hill condition of Nepal. Page 20 *in* partial Fulfillment of the requirements for the degree of Master of Science in Agriculture (Soil Science). Thesis submitted to the Agriculture and Forestry University, Faculty of Agriculture, Rampur, Nepal.

DHM. 2015. Draft Report Study of Climate and Climatic Variation over Nepal. Government of Nepal, Ministry of Science, Technology and Environment, Department of Hydrology and Meteorology, Nepal. Hydrological and Meteorological Research Centre and Consultancy Pvt. Ltd. (http://www.dhm.gov.np/climate/).

DHM. 2017. Observed Climate Trend Analysis in the Districts and Physiographic Regions of Nepal (1971-2014), Department of Hydrology and Meteorology, Kathmandu, Nepal.

Erskine, W. 1996. Seed-size effects on lentil (*Lens culinaris*) yield potential and adaptation to temperature and rainfall in West Asia. *Journal of Agricultural Science* 126: 335-341.

Erskine, W., F.J. Muehlbauer and R.W. Short. 1989. Food Legume Improvement Program: Annual Report for 1989. International Centre for Agricultural Research in the Dry Areas, ICARDA-163 En, Aleppo, Syria.

Farooq, M., N. Gogoi, S. Barthakur, B. Baroowa, N. Bharadwaj, S.S. Alghamdi and K.H.M. Siddique. 2017. Drought stress in grain legumes during reproduction and grain filling - A review. *Journal of Agronomy and Crop Science* 203: 81-102.

GLRP. 2013a. Response of supplemental irrigation and foliar spray of nutrients in lentil var. Maheswor Bharati under Rampur conditions. Pages 77-79 *in* Annual Report 2068/69 (2011/12). Nepal Agricultural Research Council, Grain Legume Research Program, Rampur, Nepal.

GLRP. 2013b. Response of supplemental irrigation and foliar spray of nutrients in lentil var. Maheswor Bharati under Rampur conditions. Pages 100-101 *in* Annual Report 2069/70 (2012/13). Nepal Agricultural Research Council, Grain Legume Research Program, NARC Publication Serial No. 0049-2013/14.

Greco, S.A. and J.B. Cavagnaro. 1991. Influence of drought at different growth stages on yield of lentils. *LENS Newsletter* 18: 27-30.

Hamdi, A., W. Erskine and P. Gates. 1992. Adaptation of lentil seed yield to varying moisture supply. *Crop Science* 32: 987-990.

ICARDA. 1990. Food Legume Improvement Progarm: Annual Report 1990. International Centre for Agricultural Research in the Dry Areas, Aleppo, Syria

Lal, B., M.P.C. Gupta and R.K. Pandey. 1988. Response of lentil to different irrigation schedules. *LENS Newsletter* 15: 20-23.

Malla, G. 2008. Climate change and its impact on Nepalese agriculture: A review. *Journal of Agriculture and Environment* 9: 62-71.

MESD. 2018. Pulses. Page 71 *in* Statistical Information on Nepalese Agriculture 2073/74 (2016/17). Government of Nepal Ministry of Agriculture, Land Management and Cooperatives, Monitoring, Evaluation and Statistics Division Agriculture Statistics Section, Singhdurbar, Kathmandu, Nepal.

Murari, K. and S.L. Pandey. 1985. Influence of soil moisture regimes, straw mulching, and kaolin spray on yield-attributing characters, and correlation between yield and yield attributes in lentils. *LENS Newsletter* 12: 18-20.

Nema, V.P., S.P. Singh and P.P. Singh. 1984. Response of lentil to irrigation and fertility levels. *LENS Newsletter* 11: 21-24.

NGLRP. 2011. Annual Technical Report 2066/67 (2009/10), National Grain Legumes Research Program, Nepal Agricultural Research Council, Nepal.

Oweis, T., A. Hachum and M. Pala. 2004. Lentil production under supplemental irrigation in a Mediterranean environment. *Agricultural Water Management* 68: 251-265.

Rathore, R.S., R. Khandwe, N. Khandwe and P.P. Singh. 1992. Effect of irrigation schedules, phosphorus levels and phosphate-solubilizing organisams on lentil yield. *LENS Newsletter* 19: 17-19.

Saraf, C.S. and S.P. Baitha. 1985. Water use patterns and water requirement of lentil planted on different dates. *LENS Newsletter* 12: 12-15.

Sharma, S.N. and R.P. Prasad. 1984. Effect of soil moisture regimes on the yield and water use of lentil (*Lens culinaris* Medic). *Irrigation Science* 5: 285-293.

Shrestha, R. 2005. Adaptation of Lentil (*Lens culinaris* Medikus subsp. *culinaris*) to Rainfed Environments - Response to Water Deficits. Page 56 in Ph.D. thesis, The University of Western Australia.

Shrestha, R., N.C. Turner, K.H.M. Siddique and D.W. Turner. 2006a. Physiological and seed yield responses to water deficits among lentil genotypes from diverse origins. *Australian Journal of Agricultural Research* 57: 903-915.

Shrestha, R., N.C. Turner, K.H.M. Siddique, D.W. Turner and J. Speijers. 2006b. A water deficit during pod development in lentils reduces flower and pod numbers but not seed size. *Australian Journal of Agricultural Research* 57: 427-438.

Shrestha, R., R.K. Neupane and N.P. Adhikari. 2012. Status and Future Prospects of Pulses in Nepal. Page 115 *in*Current Status and Future Prospect of Pulse Production in SAARC Countries. SAARC Agriculture Centre (SAC), Momin Offset Press, Dhaka, Bangladesh, ISBN 978-984-33-5402-0.

Silim, S.N., M.C. Saxena and W. Erskine. 1993. Adaptation of lentil to the Mediterranean environment. 2. Response to moisture supply. *Experimental Agriculture* 29: 21-28.

Singh, K., M.D. Vyas, P.P. Singh, D.C. Thakre and D.P. Nema. 1988. Effect of irrigation and fertility levels on lentil. *LENS Newsletter* 15(2): 7-9.

Thakur, S.B. and G. Karki. 2018. Climate change impacts on agriculture and livestock in Nepal. *The Journal of Agriculture and Environment* 19: 108-117.

Tiwari, R.J. and M.D. Vyas. 1994. Effect of soil moisture content on the field emergence and yield of lentil. *LENS Newsletter* 21(1): 20-21.

Yusuf, M, N.P. Singh and N.G. Dastane. 1979. Effect of frequency and timings of irrigation on grain yield and water use efficiency of lentil. *Annals of Arid Zone* 18: 127-134.

Zhang H., M. Pala, T. Oweis and H. Harris. 2000. Water use and water-use efficiency of chickpea and lentil in a Mediterranean environment. *Australian Journal of Agricultural Research* 51: 295-304.

Theme 5: Conservation and use of Agrobiodiversity in Drylands, Developing Adapted Cultivars

Lead Lectures and Rapid Presentations

Field crops breeding for resistance to biotic and abiotic stresses at ICARDA: Achievements and prospects

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Extended Summary

Crop production is highly affected by biotic and abiotic stresses at global level in general and in the Central and West Asia and North Africa (CWANA) and Sub Saharan Africa (SSA) regions in particular. Associated to climate change, heat and drought stresses are increasingly important resulting in reduction of photosynthesis, pollen viability, grain number and weight, and hence lowering yield and quality of major cereals and legumes crops.

The crop breeding program at ICARDA uses conventional and molecular approaches, such as the Focused Identification of Germplasm Strategy (FIGS), mega environments, shuttle breeding, doubled haploids, marker-assisted selection or genomic selection, speed breeding and key location phenotyping, to identify sources of resistance, develop elite genotypes with high yield potential and resistance to the major biotic and abiotic stresses.

In recent years, under the CGIAR research program, wheat precision field-based phenotyping platforms have been established where germplasm can be tested against different stresses. In Sudan a heat platform, in Izmir, Turkey a biosafety facility to test foreign isolates of yellow, stem and leaf rust, and in Sidi el Aidi, Morocco a heat and drought platform are being established. Marker Trait Associations (MTA) has been identified for different crops and they are being used in the breeding process.

ICARDA distributes yearly more than 1000 of so developed elite genotypes to its partners through international nurseries. In the last 5 years alone, more than 100 cultivars of ICARDA origin - many of them heat and drought tolerant, have been released by National Agricultural Research System (NARS) in the CWANA and SSA regions.

Translational genomics for improving dryland crops

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Extended Summary

Although crop improvement programs have made excellent progress in enhancing crop productivity and production, there is still a huge scope to fill the yield gap for majority of crops in dryland areas. Genomics-assisted breeding can help enhancing crop productivity as well as nutrition in these crops. However, until recently, majority of the dryland crops have remained untouched with genomics revolution. Two key reasons for this situation include engagement of only few institutes and availability of limited resources at international level for research and development in these crops.

With an objective to address these issues, the Center of Excellence in Genomics and Systems Biology (CEGSB) at International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) floated several multi-institutional consortia. As a result of collaborative efforts from such strong partnership, a large number of genomic resources including genome assemblies for 9 crops have been developed and several improved lines have been developed through molecular breeding. In summary, translational genomics approach has transformed the so-called 'orphan crops' to 'genomic resources-rich crops' and contributed to develop several improved lines in some dryland crops.

Genome sequencing

We have deployed next-generation sequencing (NGS) technologies in developing high quality reference genomes for the so-called orphan crops in dryland regions (Table 1). Pigeon pea was the first orphan legume crop, and probably the first non-industrial crop, for which NGS was adopted for developing its draft genome sequences (Varshney *et al.,* 2012; Saxena and Varshney, 2017). Subsequently genome sequence assemblies were developed for chickpea (Varshney *et al.,* 2013; Thudi and Varshney, 2017), diploid progenitor genomes of cultivated groundnut (Chen *et al.,* 2016; Bertioli *et al.,* 2016) and pearl millet (Varshney *et al.,* 2017a). Genome sequence for sorghum was made available by the US led team in collaboration with ICRISAT (Peterson *et al.,* 2009).

In addition to sequencing the genomes of ICRISAT mandate crops, the CEGSB scientists also collaborated with several partners to sequence genomes of other plant species such as adzuki bean (*Vigna angularis*) (Yang *et al.,* 2015; Kang *et al.,* 2015), mung bean (*Vigna radiata*) (Kang *et al.,* 2014), sesame *(Sesamum indicum)* (Wang *et al*., 2014) and longan (*Dimocarpus longan*) (Lin *et al.,* 2017). In summary, we have led/contributed in sequencing of genomes of 9 dryland crops so far.

Germplasm characterization

In order to harness genetic diversity from germplasm collection in these important crops, various re-sequencing efforts were carried out. For instance, in the case of chickpea, ICRISAT-led team has undertaken the sequencing of thousands of chickpea genomes as part of 'The 3,000 Chickpea Genome Sequencing Initiative' - an international effort to sequence and phenotype the chickpea global composite collection. Similar efforts were carried out in pigeon pea (Varshney *et al.,* 2017b), groundnut (Pandey *et al.,* 2017; Clevenger *et al.,* 2017), sorghum and pearl millet (Varshney *et al.,* 2017a). Genome-wide association studies using re-sequencing and genotyping data together with multi-location phenotyping data have provided marker-trait association in several cases.

Table 1. *Advances in the genomics, trait mapping and molecular breeding in the ICRISAT mandate crops during last 11 years*

Features	Chickpea		Pigeon pea		Groundnut		Sorghum		Pearl millet	
	2007	2019	2007	2019	2007	2019	2007	2019	2007	2019
Genomic resources										
Genome assembly	No	***	No	***	No	**	No	**	No	***
Transcriptome assembly	No	***	No	***	No	***	No	**	No	**
Genetic maps	*	***	No	***	*	***	**	***	*	***
Marker genotyping platforms										
SSR markers	**	***	*	***	*	***	***	****	*	***
SNP markers	No	***	No	***	No	**	**	****	No	****
DArT markers	No	***	No	***	No	***	No	***	No	*
KASP assays	No	***	No	***	No	**	No	No	No	No
GoldenGate	No	**	No	**	No	**	No	No	No	No
SNP arrays	No	***	No	***	No	***	No	No	No	No
Trait mapping										
Biotic stress	*	***	No	***	*	**	**	***	*	**
Abiotic stress	*	***	No	**	No	*	*	***	*	**
Other traits	*	***	No	**	*	***	*	**	*	***
Diagnostic markers	No	***	No	***	No	***	No	**	No	**
Molecular breeding products										
Superior line	No	***	No	No	No	***	*	**	*	**

*limited, ** optimum, *** abundant, **** highly abundant, No- non availability

Trait mapping

By using genomic resources, genotyping platforms and working in collaboration with breeders, physiologists, pathologists, entomologists, microbiologists, and genetic resource and pre-breeding specialists from ICRISAT and other collaborating institutes, 20 to 50 traits have been mapped in the ICRISAT mandate crops. It is important to mention here that mapped traits do not essentially mean that diagnostic markers are available for all these traits. In fact, in terms of availability of diagnostic markers, they are available for limited number of traits so far. Efforts need to be accelerated to map desired traits in cost-effective and faster manner.

Product development

Molecular markers associated with different breeding traits were deployed in several breeding programs both in ICRISAT as well as collaborating national programs in India and Africa. As a result of extensive collaboration with breeders, several superior lines have been developed for a number of traits in different crops. CEGSB has now initiated some efforts in the area of deployment of genomic selection in crop improvement programs.

Summary and outlook

As evident from above, because of strong partnership coupled with technological advances, the CEGSB/ICRISAT has made significant efforts in the area of development of genomic resources and generation of molecular breeding products in several dryland crops (Table 1). Furthermore, 380 scientists from national/international institutes/universities have been trained by organizing 11 training courses. With the availability of ample genomic resources, trained national partners and reduction in the cost of genotyping, we anticipate accelerated use of translational genomics approach in crop improvement programs to develop climate resilient varieties in dryland regions.

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References

Bertioli, D.J., *et al.* 2016. The genome sequences of *Arachis duranensis* and *Arachis ipaensis*, the diploid ancestors of cultivated peanut. *Nature Genetics* 48: 438-446.

Chen, X., *et al.* 2016. Draft genome of the peanut A-genome progenitor (*Arachis duranensis*) provides insights into geocarpy, oil biosynthesis, and allergens. *Proceedings of National Academy of Sciences (USA)* 113: 6785-6790.

Clevenger, J., *et al.* 2017. Genome-wide SNP genotyping resolves signatures of selection and tetrasomic recombination in peanut. *Molecular Plant* 10: 309-322.

Kang, Y.J., *et al*. 2015. Draft genome sequence of adzuki bean, *Vigna angularis*. *Scientific Reports* 5: 8069.

Kang, Y.J., *et al.* 2014. Genome sequence of mung bean and insights into evolution within *Vigna* species. *Nature Communications* 5: 5443.

Lin, Y., *et al.* 2017. Genome-wide sequencing of longan (*Dimocarpus longan Lour*.) provides insights into molecular basis of its polyphenol-rich characteristics. *Giga Science* 6: 1-14.

Pandey, M.K., *et al.* 2017. Development and evaluation of a high density genotyping 'Axiom_*Arachis*' array with 58K SNPs for accelerating genetics and breeding in groundnut. *Scientific Reports* 7: 40577.

Paterson, A.H., *et al.* 2009. The *Sorghum bicolor* genome and the diversification of grasses. *Nature* 457(7229): 551.

Saxena, R.K. and R.K. Varshney. 2017. Whole-genome sequencing of pigeon pea: Requirement, background history, current status and future prospects for crop improvement. Pages 81-91 *in* The Pigeonpea Genome. Springer, Cham, Switzerland.

Thudi, M. and R.K. Varshney. 2017. Requirement of whole-genome sequencing and background history of the national and international genome initiatives. Pages 107-115 *in* The Chickpea Genome. Springer, Cham, Switzerland.

Varshney, R.K., *et al.* 2017a. Pearl millet genome sequence provides a resource to improve agronomic traits in arid environments. *Nature Biotechnology* 35: 969-976.

Varshney, R.K., *et al.* 2017b. Whole-genome resequencing of 292 pigeon pea accessions identifies genomic regions associated with domestication and agronomic traits. *Nature Genetics* 49: 1082-1088.

Varshney, R.K., *et al.* 2013. Draft genome sequence of chickpea (*Cicer arietinum*) provides a resource for trait improvement. *Nature Biotechnology* 31: 240-246.

Varshney, R.K., *et al.* 2012. Draft genome sequence of pigeon pea (*Cajanus cajan*), an orphan legume crop of resource-poor farmers. *Nature Biotechnology* 30: 83-89.

Yang, K., *et al.* 2015. Genome sequencing of adzuki bean (*Vigna angularis*) provides insight into high starch and low fat accumulation and domestication. *Proceedings of National Academy of Sciences (USA)* 112: 3213-13218.

Agriculture innovation - Climate ready crops

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Extended Summary

Plant breeders have been continuously innovating to breed better varieties and hybrids. This has allowed agricultural productivity to continue to rise despite the changing climate. Given that climate change is going to be a continuing phenomenon, plant breeding innovation become that much more critical for continuing to meet our food, feed and fiber requirement while sustaining our environment. Numerous tools are available for meeting our needs. We need a facilitating operational environment in terms of intellectual policy and regulatory procedures. All tools, whether in public or private domain, must be available and used for us to stay ahead of the anticipated change and demand.

Conservation and use of plant genetic resources: Developing adapted cultivars

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Extended Summary

Plant Genetic Resources (PGR) are one of the components of agricultural biodiversity. PGR can be defined as 'any living plant material of actual or potential value' and are the key resources of crop improvement programs. However, PGR are increasingly being threatened by anthropogenic activities, biotic and abiotic stresses, climatic change and natural calamities. Therefore, safeguarding PGR and their sustainable use to improve and sustain food production should be first priority of any research group, institution or state. According to the fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC), over the century (1906-2005) the average global temperature rose by 0.74°C and further projections indicate that the global warming will accelerate in the future. The evidence indicates that non-tropical dry areas will likely face warming of higher magnitude. The major output of the global warming is the change in precipitation pattern and increased uncertainty of rainfall. This is impacting agriculture very adversely, particularly dryland and rain-fed farming systems. To certain extent, breeding crop varieties with characteristics of drought and heat tolerance, thermo-insensitivity, early maturity, and better water use efficiency can solve the problem. Here, genetic diversity present in particular genepool will decide the productivity of the particular crop. Therefore, *ex situ* genebank collections are going to play a very crucial role in present and future breeding programs.

The main objective of genebanks is to collect, protect and facilitate utilization of genetic diversity of crop plants. The diversity conserved in the form of *ex situ* collection is in static stage of evolution where all natural evolutionary processes stop, but these collections play a very dynamic role in shaping crop cultivars genome to adapt to changing climatic conditions like global average temperature rise, erratic and low precipitation, evolution of new insects and pathogens, etc. Therefore, *ex situ* collections are considered as the key to the present and future crop improvement programs for development of new varieties adapted to new climatic conditions. Collections, particularly of those crop species that are adapted to the dryland and high temperature growing conditions, are the key to sustain and secure world's future food production. The local landraces or farmers' varieties, many of which are extinct from the farmers' field due to influence of green revolution, have now got the place in breeders' field as well as are being re-established in their natural habitats through on-farm conservation activities being led by several mega programs.

The National Genebank at ICAR-NBPGR is one of the leading genebanks in the world. It conserves around 4.4 lacs accessions of several cultivated taxa, including their wild relatives and wild forms, and is playing very active role in national and international crop improvement programs. Out of the total genebank collections, around 1.34 lacs collections belong to such crops (Table 1) that have the inherent adaptation to dryland growing conditions and occupy the major portion of world's arable land.

Since the systematic breeding programs has started, along with farmers' invaluable role in selection of useful diversity, *ex situ* or *in situ* collections have played a significant role in development of crop varieties with desired trait like higher yield, tolerance/resistance to biotic and abiotic stresses, and better nutritional qualities. This has resulted in the increase of global average yield from around 13.53 q ha_{-1} to 40.73 q ha_{-1} in cereals and 6. q ha_{-1} to 10.08 q ha_{-1} in pulses between the period of 1961 and 2017.

Table 1. *List of ex situ collections of some important crops suitable for dry-land agriculture conserved in the National Genebank at ICAR-NBPGR*

Crop	Indigenous collections	Exotic collections
Pearl millet (*Pennisetum glaucum* (L.) R.Br.)	8,000	830
Sorghum (*Sorghum bicolor* (L.) Moench)	11,211	9,067
Maize (*Zea mays* L.)	8,612	141
Barley (*Hordeum vulgare* L.)	6,371	1,267
Wheat (*Triticum aestivum* L.)	17,726	9,885
Moth bean (*Vigna aconitifolia* (Jacq.) Marechal)	1,459	31
Pigeon pea (*Cajanus cajan* (L.) Millsp.)	10,997	308
Cowpea (*Vigna unguiculata* (L.) Walp.)	2,566	1,066
Lentil (*Lens culinaris* Medikus)	1,818	501
Mung bean (*Vigna radiata* (L.) R. Wilczek)	7,453	3,588
Urd bean (*Vigna mungo* (L.) Hepper)	2,683	8
Faba bean (*Vicia faba* L.)	498	351
Grass pea (*Lathyrus sativus* L.)	2,505	64
Indian Mustard (*Brassica juncea* (L.) Czern.)	5,385	118
Sesame (*Sesamum indicum* L.)	6,921	2411
Safflower (*Carthamus tinctorius* L.)	4,241	2,517
Sunflower (*Helianthus annuus* L.)	293	928
Castor bean (*Ricinus communis* L.)	2,490	162
Total	101,229	33,243

Ex situ collections of crop wild relatives and their utilization

Crop wild relatives (CWRs) are genetically close related taxa to cultivated crops and are potential genetic resources for crop improvement. Not only cultivated genepool, but non-conventional sources of variation like CWRs, wild species, weedy forms vis-a-vis climate change have gained momentum in their utilization in most of the crop improvement programs. Since their existence in wild or in their natural habitats is threatened by climate change they are being collected and conserved (Table 2). As CWRs continue co-evolving in their natural habitats along with changing climatic conditions in diverse agro-ecologies and new races of insect pest and pathogens, they are considered as the goldmine of novel and useful genes/traits. Currently they are being utilized in various ways like germplasm enhancement, introgression breeding, trait specific genes identification, allele mining and genome sequencing.

Table 2. *List of ex situ collections of CWRs related to dryland crops conserved at National Genebank at ICAR-NBPGR*

CWRs	No. of accessions	CWRs	No. of accessions
Millets and cereals		*Hordeum bogdanii*	1
Pennisetum orientale	1,427	*H. brevisubulatum*	3
P. hohenackeri	1	*H. hexasticum*	3
P. pedicellatum	145	*H. himalayense*	21
P. purpureum	54	*H. spontaneum*	1
P. squamulata	9	**Pulses**	
P. typhoides	382	*Cajanus albicans*	2
Zea mexicana	21	*C. cajanifolius*	2
Triticum aestivum subsp. *vavilovii*	3	*C. scarabaeoides*	13
T. carthlicum	1	*C. volubilis*	1
T. compatctum	39	*Cicer microphyllum*	35
T. dicoccum	255	*C. bijjugum*	21
T. ispahanicum	3	*C. cuneatum*	3
T. monococcum	32	*C. echinospermum*	8
T. sphaerococcum	75	*C. judaicum*	27
T. timopheevii	13	*C. pinnatifidum*	13
T. turgidum	34	*C. reticulatum*	10
*T. turgidum*sub sp. *dicoccoides*	16	*C. yamashitae*	1
*T. turgidum*sub sp. *dicoccum*	6	*Lathyrus aphaca*	2
*T. turgidum*sub sp. *durum*	44	*L. odoratus*	7
*T. turgidum*sub sp. *polonicum*	2	*Vigna dalzelliana*	28
T. uratu	73	*V. angularis*var. *nipponensis*	9
T. ventricosa	24	*V. hainiana*	6
T. vulgare	11	*V. khandalensis*	1
T. zhukovskyi	1	*V. minima*	1
Aegilops bicornis	9	*V. mungo*var. *sylvestris*	16
A. biuncialis	5	*V. nepalensis*	3
A. caudata var. typica	9	*V. pilosa*	4
A. columnaris	14	*V. radiata*var. *sublobata*	245
A. comosa	9	*V. stipulacea*	6
A. crassa	12	*V. trilobata*	159
A. cylindrica	49	*V. trinervia*	2
A. geniculata	5	*V. trinervia*var. *bourneae*	15
A. juvenalis	9	*V. vexillata*	108
A. kotschyi	20	**Oilseeds**	
A. longissima	18	*Brassica tournfortii*	22
A. lorentii	21	*B. oleracea var. gimmifera*	1
A. markgrafil	4	*Sesamum malabaricum*	68
A. neglecta	4	*S. marlothii*	1
A. ovata	18	*S. mulayanum*	190
A. peregrina	10	*S. prostratum*	6
A. sharonensis	7	*S. radiatum*	18
A. speltiodes	83	*Helianthus resinosus*	1
A. squarrosa	113	*Pulicaria wightiana*	1
A. triaristata	40	*C. lanatus*	1
A. triuncialis	79	*Carthmus tenuis*	1
A. umbellulata	11	**Total**	**4,307**

Most of the cultivated crops' genepools have undergone drastic genetic erosion due to domestication processes and, therefore, these crops lack sufficient genetic variability to improve upon and face new challenges. On the other side, CWRs are rich source of diverse and useful variability, few examples of which are given below.

CWRs of barley (*Hordeum vulgare*) have been extensively used for germplasm enhancement of cultivated barley. Utilization of barley wild species *H. spontaneum* has proven very fruitful for developing drought and salt tolerance in cultivated barley. *H. bulbosum* has been mainly used for conferring disease and pest resistance, and to some extent for abiotic stress tolerance. *H. marinum* has been recognised for its salt tolerance and the trait has been attempted to be transfered in cultivated wheat (*Triticum aestivum*) by developing amphidiploids.

Cultivated species of wheat (*T. aestivum*), which has around six CWRs in its primary genepool and twelve in secondary genepool, has got significant contribution from these genepools in its improvement for various traits. *T. monococum* has been utilized for heat tolerance and salt tolerance. Some other examples of use of CWRs in wheat improvement program are: *Aegilops tauschi* and *A. geniculatus* for drought tolerance; *Agropyron cristatum* for drought and cold tolerance.

Pigeon pea CWRs have found significant use in varietal development programs. They have been used in genetic base broadening and trait improvement. *Cajanus sericeus, C. albicans* and *C. reticulates* have been usedfor drought tolerance; and *C. acutifolius, C. platycarpus, C. scarabaeoides, C. sericeus, C. albicans* for salinity tolerance.

CWRs of other pulse crops are also gradually getting attention and are increasingly being utilized. For instance in chickpea, emphasis is being given for utilizing chickpea wild relatives for improving traits like drought tolerance using *Cicer anatolicum, C. microphyllum, C. songaricum, C. reticulatum* and *C. pinnatifidum*. Similarly, lentil (*Lens culinaris*), an important Indian pulse crop, has been improved for various traits utilizing wild species genetic resources. The *Vigna* group of crops, which are mostly grown in Asian and African countries, have great amount genetic diversity in its wild relatives. Several CWRs of the genus has been identified as potential donor species for various traits. For example, cultivated Vignas have been improved for several important traits like drought tolerance (*Vigna aconitifolia* and *V. radiata* var. *sublobata*), heat tolerance (*V. aconitifolia* and *V. riukenensis*), yellow mosaic disease resistance (*V. radiata* var. *sublobata* and *V. umbellata*), photo-thermo insensitivity (*V. umbellata* and *V. glabrescens*), etc.

Safflower (*Carthamus tinctorius*) was once grown only for colouring purpose, but the crop also got popularity for the quality of its seedoil. Safflower CWRs are known to carry several important traits and are being used for the cultivated genepool of the crop. For example *C. oxyacantha* has been reported to be tolerant source for drought tolerance and safflower-fly. *C. flavescens* and *C. lanatus* are reported to also carry genes for resistance against safflower-fly.

Wild relatives of sunflower are found in a wide range of diverse habitats. For example *Helianthus anomalus, H. deserticola, H. neglectus* and *H. niveus* ssp. *niveus* inhabit dry and sandy soils; *H. angustifolius, H. agrestis, H. californicus, H. giganteus, H. nuttallii* ssp. *nuttallii, H. paradoxus* and *H. tuberosus* very moist soils; *H. decapetalus* in deep woods; and

H. pauciflorus ssp. *subrhomboideus, H. maximiliani* and *H. grosseserratus* in prairies. These CWRs of *Helianthus* can have a great impact on improving cultivars. There are other potential CWRs of sunflower identified for different traits like dwarf nature (*H. arizonensis*), round the year flowering (*H. niveus* ssp. *niveus*), and the short day-length requirement (*H. paradoxus*).

Perspectives

ICAR-NBPGR has envisioned, on long-term basis, complete characterization and field evaluation to identify germplasm accessions with superior agronomic and adaptation traits. This would facilitate identification of core, mini-core, trait-specific reference sets as well as genomic resources for use by researchers and breeders. The identified trait-specific accessions and genomic resources would specifically be used by the plant breeders for increasing water and nutrient use efficiency, carbon fixation efficiency, nutritional value, biotic and abiotic stress tolerance etc. The subject of utilization of PGR stands at a crucial juncture and for strategic decisions on the way forward. Traditional methods of PGR management are being challenged by changing needs, priorities, climate, technologies, and policies. Envisaging the overwhelming pressure on the natural existence and evolution of PGR does not require prophecy. However, looking through more than four decades, the promise of modern technologies in combating genetic erosion and enhancing utilization of PGR in the future is tremendous. It is in this context that adopting every upcoming technology is the only way forward. Adoption of all the forthcoming technologies to maximize accuracy, coverage and efficiency of germplasm collection; economize and rationalize germplasm conservation; identify trait-specific germplasm and promote utilization; add value to germplasm based on genomic and geographical information and develop a decision support system to manage PGR is the need of the hour. Also, harmonizing with multitude of stakeholders including private seed sector, farming communities, NGOs and international agricultural research centres is essential to enhance conservation and utilization.

Improvement strategies for developing climate smart crop cultivars for drylands

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Crop yields must grow significantly more in the next decade than they did in the previous half-century to avoid a net expansion of harvested cropland worldwide. To achieve this, plant breeding should use the power of selection to develop phenotypically and genetically diverse populations, resilient to the changing climate, showing input-use efficiency and suitable for sustainable intensification of agriculture, from which high-yielding, nutritious cultivars for various uses will be release for growing elsewhere, particularly in the developing world.

Crossbreeding gives the seeds with desired traits that increase farming profitability, resilience and sustainability in drylands. Genetics allows crop improvement to continue evolving into knowledge-based undertakings. Increasing edible yields remain the main goal of genetic betterment of crops. It may be achieved in the drylands by either improving releasing cultivars with low susceptibility or enhanced adaptation to stress-prone environments, affected by, *inter alia*, adverse climate (drought, heat, and salinity), poor soils, pathogens and pests. A genetic enhancement approach for developing climate-smart cultivars should define a target population of environments, understand crop limitations to yield potential or means for reducing yield gaps, define selectable traits for use in strategic crossing seeking an ideotype, searching for those traits in available genetic resources through core or mini-core subsets of genebank accessions or using the Focused Identification of Germplasm Strategy (FIGS), applying molecular-aided gene discovery through association genetics and in selection, and pursuing physiological trait-based breeding. New plant breeding methods are assisting on releasing genetically enhanced seed-embedded technology to cope with the changing climate in arid and semi-arid agro-ecozones.

A stepwise approach for sustainable genetic gains in plant breeding should first define breeding objectives with end-users and thereafter identify useful character(s) in breeding population(s) or genebank(s). The next step will be managing genetic variation of useful trait(s) based on genetics and “omics” knowledge to put desired genes into a usable form(s) [lines, clones, or populations] for further use in crossbreeding - Genetic engineering for transgenic breeding or genome editing may be pursued if target trait(s) are unavailable in genebank or breeding population(s). The use of DNA markers will assist monitoring chromosomal changes from, and as selection aid. It will be still necessary to undertake multi-site testing across target population of environments and over years, which feeds into cultivar release pipelines (that may involve participatory research). The main outputs for such a breeding enterprise will be genetically-enhanced seed-embedded technology and genetic gains therein to be shared with farmers, consumers and other end-users.

Breeding durum wheat in the heat along the Senegal River provides an example of genetic research and enhancement to identify germplasm for further use in cultivar development aiming African drylands, mine alleles capable to mitigate the adverse effects of global warming, and deploy these alleles for enhancing adaptation to heat into high yielding cultivars.

The experiment used a 384-accession core subset of durum wheat defined by ICARDA. Genotyping of this core subset was completed with platform Axiom 35K SNP array. The multi-site testing was undertaken along a North-South heat gradient in West Africa: Kaedi (Mauritania), Fanaye (Senegal) and Melk Zehr (Morocco). All experiments were designed as small plots with limited replications within location, and statistical significance was guaranteed by the implementation of spatial (augmented) designs. Principal component analysis (PCA) of data from multi-environment trials was used to reveal relationships between environments for growing durum wheat. Genotypic data along phenotyping was used for association genetics (GWAS), which led to identifying the genomic regions and the specific single nucleotide polymorphism (SNP) associated with measured traits across sites.

Genotypes (G), environments and their interaction (GE) were significant across testing environments. Heritability (H_2) was medium to high for grain yield and 1000 kernel weight. It seems that the larger the size, the greater the yield under heat stress, particularly in Fanaye due to extended grain filling or water available. Association genetics - based on linkage disequilibrium mapping - led to finding significant quantitative trait loci (QTL) across sites for various agronomic traits in a subset of promising during wheat germplasm and allow describing allelic variations in 9-top yielding durum wheat genotypes, which allows targeting crossing between the top yielding lines to maximize the number of positive alleles.

Four years of field testing led to selecting durum wheat germplasm that withstand high temperatures and with grain yields harvests between 3 and 6 t ha_{-1} after 92 days from planting. These heat tolerant lines have been submitted to the variety catalog of Mauritania and Senegal.

Core and mini-core subsets, core selectors and FIGS allow sampling, while their whole phenotyping and genotyping lead to finding genome-environment associations in landraces or crop wild relatives that predict adaptive traits, and “turbo-charging” genebanks using genomic prediction. Moreover, pursuing DNA re-sequencing of various landraces or cultivars and pangenomics facilitate the large-scale discovery of novel alleles using bioinformatics along with genetics. Furthermore, genomic prediction to estimate breeding values (GEBV) for selection decreases time, increases intensity, and enhances efficiency for low heritability traits. Likewise, moving from phenotyping to phenomics, high throughput field omics and e-typing in managed environments will ensure accurate and fast genetic gains when pursuing knowledge-intensive, genomic-led, speed plant breeding. For example, greenhouse or growth chamber-based methods enable 4-6 crop generations within a year that facilitates GEBV.

Plant genetic resources, nevertheless, remain the raw materials for mining allelic variations associated with target traits. Crop improvement will continue to rely on combining diversity in crop populations via genetic recombination. Unlocking functional diversity using omics, precise high throughput phenotyping and e-typing for key agronomic traits such as crop phenology, plant architecture, edible yield, resilience to changing climate, host plant resistance and input-use efficiency, plus speed breeding may further assist germplasm use in the genetic enhancement of crops for the drylands in this 21st century.

Climate resilient maize for drought- and heat-prone environments

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Extended Summary

Maize is cultivated on more than 180 mha globally, contributing ~50% (1,170 m tons) to the global grain production. About 60-70% of the cultivated area under maize is located in the developing world, with a predominant proportion in the low- and lower-middle income countries. Maize is predominantly cultivated under rainfed conditions by the smallholders in the tropics of sub-Saharan Africa, Asia and Latin America. The crop contributes over 20% of total calories in human diets in 21 low-income countries, and over 30% in 12 countries that are home to a total of more than 310 million people who survive on less than US$ 2 per day (Shiferaw *et al.*, 2011). However, grain yields of maize in the tropical rainfed environments in sub-Saharan Africa (SSA), Asia and Latin America are quite low, with high year-to-year variability, due to the adverse effects of drought, heat, waterlogging, sub-optimal soil nitrogen, and soil acidity/aluminum toxicity, besides the incidence of devastating diseases, insect pests and parasitic weeds.

The Global Maize Program of CIMMYT, with its more than 60 years of breeding history, brings the benefits of a vast tropical/subtropical germplasm, cutting-edge breeding technologies, extensive partnerships with public and private sector institutions worldwide, and one of the most successful and well-coordinated germplasm phenotyping/testing networks in the (sub) tropics of SSA, Asia and Latin America (Fig. 1). Integration of high-throughput and novel phenotyping tools, doubled haploid (DH) technology (Prasanna *et al.*, 2012), molecular markers for key traits, and rapid-cycle genomic selection for improving complex quantitative traits (Nair *et al.*, 2018) are core components of CIMMYT's maize breeding strategy to accelerate genetic gains and for enhancing the competitiveness of improved CGIAR Research Program MAIZE-derived varieties in the target regions. This forms the base for a strong pipeline of impactful maize inbred lines and varieties, that offer not just higher yield but also resilience to important abiotic and biotic stresses, nutritional quality, and end-use traits.

Based on technological breakthroughs in the early 1990s and a strong breeding program on drought tolerance initiated by CIMMYT and subsequently by IITA, more than 300 drought-tolerant (DT) maize varieties have been developed and released across SSA, and more recently also in India, over the two decades. Intensive efforts on strengthening maize seed systems in SSA, including public-private partnerships and capacity development of NARS and seed company partners, catalyzed delivery of DT maize varieties across 13 countries in SSA, and helped to circumvent market failures. In 2018, more than 100 seed companies in SSA produced an estimated 75,000 tons of certified seed of MAIZE-derived improved DT maize varieties.

Figure 1. *Managed stress phenotyping in Kiboko, Kenya, showing distinct phenotypes of drought-susceptible and drought-tolerant maize hybrids (Source: Yoseph Beyene, CIMMYT).*

In South Asia, through the USAID-funded Heat Tolerant Maize for Asia (HTMA) project, a large heat-stress phenotyping network, comprising 23 sites in the four countries (India, Nepal, Bangladesh and Pakistan), has been established (Fig. 2). Several drought tolerant and heat-tolerant CIMMYT-derived elite maize varieties have been released during 2016-2018 by public and private sector partners in South Asia, and several more are in pipeline. It is possible to further increase genetic gains in maize grain yield in stress-prone environments of the tropics through a clear product development and deployment strategy (Cairns and Prasanna, 2018).

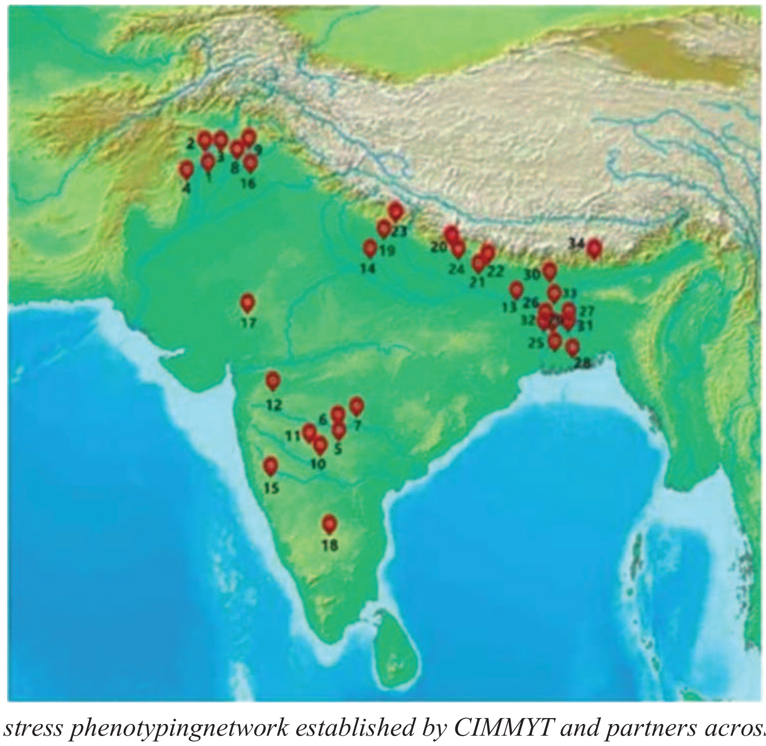

Figure 2. *Heat stress phenotypingnetwork established by CIMMYT and partners across South Asia for developing elite heat-tolerant maize varieties (Source: M.T. Vinayan, CIMMYT)*

Targeted deployment of improved climate-resilient varieties by GIS-based prediction of areas of climate vulnerability, improving varietal turnover (with newer and better genetics), appropriate agronomic management practices for realizing the genetic potential of improved varieties, and creating better linkages for the smallholder maize farmers to output markets are critical for strengthening maize value chains in the developing world. Delivering low-cost improved maize seed to smallholder farmers with limited purchasing capacity and market access requires stronger public-private partnerships, and enhanced support to the committed local seed companies, especially in terms of information on access to new products, adequate and reliable supplies of early-generation (breeder and foundation) seed, and training on hybrid seed production, quality assurance/quality control (QA/QC), seed business management, market segmentation and territory planning. Appropriate government policies and adoption of progressive seed laws and regulations, are critical for improving smallholder farmers' access to improved climate-resilient seed, and for overcoming key bottlenecks affecting the seed value chains, particularly in the areas of policy, credit availability, seed production, germplasm and marketing (Cairns and Prasanna, 2018).

While we tend to focus mostly on abiotic stresses in the context of increasing climatic variability, it is equally important to consider the changing spectrum of pathogens and insect-pests, as well as sudden incidence of devastating diseases and insect-pests. Since 2012, CIMMYT has been successfully coordinating a multi-disciplinary and multi-institutional initiative against a devastating disease, the maize lethal necrosis (MLN), in eastern Africa, through fast-tracked breeding and deployment of MLN-resistant varieties, capacity strengthening of national plant protection organizations (NPPOs) in MLN diagnostics and management, and interface with commercial maize seed sector in production and exchange of MLN-free seed. This has led to containment of the disease within eastern Africa and preventing its spread to the maize growing countries in southern and West Africa.

Fall Armyworm (*Spodoptera frugiperda*; FAW), a highly aggressive and invasive insect-pest with devastating effect, has been officially reported in the beginning of 2016 in Nigeria, and since then, rapidly spread to more than 40 countries across Africa. In July 2018, the southern state of Karnataka in India was the first to officially report the incidence of FAW; the pest was reported to have further spread to at least six different States in India within a span of 4-5 months. FAW has a strong appetite for maize; therefore, the implications of the incidence of this pest in maize-growing countries in Africa and India are indeed a major concern. CIMMYT and IITA, under the CGIAR Research Program MAIZE established a FAW R4D International Consortium in which more than 40 international/regional organizations are now partners, for a collective and synergistic R4D action. The Consortium brings together diverse institutions in public and private sectors to explore ways to synergistically work on short-, medium- and long-term solutions to tackle the challenge of FAW in Africa, and in other parts of the world where the pest is prevalent, through a science-based integrated pest management (IPM) strategy (Prasanna *et al.*, 2018).

In summary, intensive multi-institutional efforts are required to identify and utilize climate-resilient tropical/subtropical maize germplasm in product development pipelines. There is an increasing body of evidence confirming the benefits of climate-resilient maize varieties to increase yields, reduce yield variability and, ultimately, increase food security. To increase genetic gains through maize breeding in the stress-prone tropics, and for enhancing the pace, precision and efficiency of breeding progress, judicious and effective integration of modern tools/strategies, especially high-density genotyping, high throughput and precision phenotyping, DH technology, molecular marker-assisted and genomic selection-based breeding, and knowledge-led decision-support systems, is vital.

References

Cairns, J.E. and B.M. Prasanna. 2018. Developing and deploying climate-resilient maize varieties in the developing world. *Current Opinion in Plant Biology* 45: http://dx.doi.org/10.1016/j.pbi.2018.05.004.

Nair, S.K, B. Raman and B.M. Prasanna. 2018. Genomic and enabling technologies for enhancing genetic gain in tropical maize. Pages 15-27 *in* Book of Extended Summaries, 13th Asian Maize Conference and Expert Consultation on Maize for Food, Feed, Nutrition and Environmental Security (B.M. Prasanna *et al*., eds), Ludhiana, India, October 8-10, 2018. Mexico D.F.: CIMMYT.

Prasanna, B.M. 2016. Developing and deploying abiotic stress tolerant maize varieties in the tropics: challenges and opportunities. Pages 61-67 *in* Molecular Breeding for Sustainable Crop Improvement, Volume 2 (Vijay Rani Rajpal, S.R. Rao and S.N. Raina, eds.), Springer, New Delhi.

Prasanna, B.M., V. Chaikam and G. Mahuku. 2012. Doubled haploid technology in maize breeding: Theory and practice. Mexico D.F.: CIMMYT.

Prasanna, B.M., J.E. Huesing, R. Eddy and V.M. Peschke (eds.). 2018. Fall Armyworm in Africa: A Guide for Integrated Pest Management, First Edition. Mexico, CDMX: CIMMYT.

Shiferaw, B., B.M. Prasanna, J. Hellin and M. Banziger. 2011. Crops that feed the world. 6. Past successes and future challenges to the role played by maize in global food security. *Food Security* 3: 307-327.

Indian pearl millet breeding for resilience to changing climate

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Extended Summary

Pearl millet is an important crop for arid and semi-arid regions of the world including India. It is a climate resilient, low input requiring C_4 crop producing nutritious grain, feed and fodder. Pearl millet is the staple food of a large number of the poor and small land holder farmers in the developing world. It excels all other cereals due to its unique features of resilience to adverse climatic conditions, with high photosynthetic efficiency and high dry matter production capacity; it is grown under the agro climatic conditions where other crops like sorghum and maize fail to produce economic yields.

In India, pearl millet is the fourth most widely cultivated food crop after rice, wheat and maize. It is grown on 7.5 mha with an average production of 9.73 m tonne and productivity of 1305 kg ha^{-1} during 2016-17 (Directorate of Millet Development, 2018). Pearl millet is mainly grown in states of Rajasthan, Maharashtra, Gujarat, Uttar Pradesh and Haryana accounting for more than 90% of pearl millet acreage in the country. It is commonly grown in rainy (*kharif*) season (June/July-September/October). It is also cultivated during summer season (February-May) in parts of Gujarat, Rajasthan and Uttar Pradesh; and during the post-rainy (*rabi*) season (November-February) at a small scale in Maharashtra and Gujarat. It is recently notified as nutricereal by Govternment of India due to its rich nutrient composition.

Research on pearl millet improvement in India is carried through the All India Coordinated Research Project on Pearl Millet (AICRP-PM) administered by Indian Council of Agricultural Research (ICAR). The AICRP-PM has a network of 14 AICRP centers in Rajasthan, Gujarat, Maharashtra, Uttar Pradesh, Karnataka, Andhra Pradesh, Madhya Pradesh, Punjab, Haryana and Tamil Nadu. The AICRP-PM centers located in 12 State Agricultural Universities (SAU's) and University of Mysore pursue mandated activities and strategic research on pearl millet in the area of germplasm utilization, improvement, production, protection, value addition etc. As the growing conditions for pearl millet vary from near-optimum with high external inputs to highly drought-prone environments, prioritization of research in cognizance of production constraints and differential requirement of various crop growing regions led to the deleniation of three zones viz., A_1, A and B, based on annual rainfall received and the prevailing temperature conditions. Zone A_1 is comprised of parts of Rajasthan, Gujarat and Haryana receiving less than 400 mm annual rainfall.

Indian pearl millet breeding programme evolved over a period of 54 years after the inception of the AICRP on pearl millet during 1965. Since pearl millet is a highly cross-pollinated crop and displays a high degree of heterosis for grain and stover yields, attempts were made in the 1950s to exploit heterosis in hybrids utilizing the protogynous nature of flowering to produce chance hybrids. Exploitation of heterosis became a reality with the discovery of cytoplasmic-nuclear male sterility and release of male-sterile lines: Tift 23A and Tift 18A in early 1960s

by Tifton Georgia, USA; and their availability to Indian breeding programmes at Punjab Agricultural University (PAU), Ludhiana and Indian Agricultural Research Institute (IARI), Delhi. The male-sterile line Tift 23A was extensively utilized because of its semi-dwarf stature, profuse tillering, uniform flowering and good combining ability. Intensive cultivation of hybrids based on a single male-sterile line Tift 23A, however, led to a downy mildew epidemic in the mid 1970s. Hence, seed multiplication of hybrids based on Tift 23A was discontinued. Two new hybrids BJ 104 and BK 560 produced on CMS line 5141A bred at IARI, New Delhi became popular. These hybrids were widely cultivated from 1977 to 1984 but a high incidence of downy mildew on 5141A and the resultant susceptibility of both hybrids caused 5141A to be phased out as a seed parent in 1985.

Initially the emphasis was on yield and no data was recorded on disease reaction of the parents and hybrid. In the later years, emphasis was laid on data of the downy mildew incidence along with grain and fodder yields. Hybrid parental lines are developed with considerable amount of diversity and hence germplasm from different geographic regions has been strategically used in male sterile and restorer line breeding. The same is confirmed through heterotic pool development in pearl millet. In the development of A lines, African germplasm has been used, whereas locally adapted material was used in R line breeding programmes in most of the public and private sector breeding programmes. Germplasm from different regions has also been utilized in developing composites and open pollinated varieties through recurrent selection.

Trait based breeding was used in breeding parental lines. In the seed parental lines, high grain yield potential in *per se* performance and in the hybrid performance were considered i.e. combining ability. Other traits of importance were lodging resistance, compact panicles, good exertion and seed set. In the restorer parental lines, pollen production, some resistance to ergot and smut, lodging resistance, tillering and tallness were the preferred traits. In both the parents, screening for downy mildew resistance is an integral part. With increasing incidence of blast, focus on incorporation of blast resistance in the parental and hybrid breeding is underway.

Pearl millet being a nutricereal, but the limitation of storability of its flour for longer periods and development of rancidity has moved the research focus to developing genotypes with low rancidity and improved shelf life. With priority being given to enhanced nutritional quality, breeding for increased grain micronutrients like iron and zinc was initiated in national and international programmes resulting in development of biofortified varieties and hybrids. Minimum benchmark levels of iron and zinc along with prescribed levels of resistance to downy mildew, blast, rust, smut and ergot were included in promotion criteria of the pearl millet entries in the coordinated trials to provide resilience to the future pearl millet programme in the changing climate.

Till date a total of 167 hybrids and 61 varieties have been identified and released for cultivation in different pearl millet growing agro-ecological zones of the country.

Reference

Directorate of Millet Development. 2018. Ministry of Agriculture & Farmers Welfare, Government of India. (millets.dacfw.nic.in/ContactUs.html)

Diversity, conservation and uses of pasture grasses of hot arid region of India

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Extended Summary

Indian hot arid zone occupies about 31.7 mha of which 62% lies in western Rajasthan. In this region, perennial grasses play significant role to ensure fodder availability to the livestock. These grasses are mostly rhizomatous and remain dormant during adverse climatic conditions. Buffel grass (*Cenchrus ciliaris*), birdwood grass (*Cenchrus setigerus*), sewan (*Lasiurus sindicus*), burero (*Cymbopogon jwaruncusa*), karad (*Dichanthium annulatum*), blue panic (*Panicum antidotale*) and murath (*Panicum turgidum*) are important grasses of the region. Aassociated community species are *Cenchrus biflorus*, *Tragus roxburghii* and *Aristida funiculata*. Among low perennials, two species, *Dactyloctenium scindicum* and *Ochthochloa compressa,* occur in diverse habitats and are avidly grazed by livestock. Genetic variability exists among different grasses with respect to their distribution, adaptation, perennial growth, biomass production and quality. A rich diversity also exists in the halophytes, i.e. *Sporobolus* (*S. coromandelianus*, *S. helvolus*, *S. indicus*, *S ioclados*, *S. maderaspatanus*), *Aleuropus*, *Urochondra* and *Chloris*, in the region that is important for saline/alkaline conditions.

About 106 species of grasses are found in western Rajasthan. The Thar desert constitutes seven potential grassland types on different habitats with one or more key grass species viz. (i) *Sehima nervosum* - on the hills and piedmont regions, (ii) *Dichanthium annulatum* - on older alluvial flats with sandy clay loam to clay soils, (iii) *Cenchrus* - on well drained alluvial soils, (iv) *Lasiurus sindicus*- on loose sandy soils, (v) *Desmostachya bipinnata*- on young alluvium, (vi) *Sporobolus-Dichanthium annulatum*- on low lying heavy soils, and (vii) *Panicum turgidum*- on sand dunes. Precipitation is the major driver for growth and biomass production, and partitioning of biomass in above and below ground plant parts in the arid ecosystems.

The germplasm of these grasses, explored and collected in different surveys in past, have been maintained, documented and conserved under field conditions at ICAR-CAZRI, Jodhpur. Various morphological, growth, yield and molecular characteristics were determined in the selected promising genotypes.

Sizeable variability was observed in the characteristics contributing to forage yield, forage quality and underground biomass in arid zone pasture grasses. The morphological variability was influenced by variation in habitat and genetic variations as is evidenced by variable forms in *C. ciliaris, C. setigerus* and *L. sindicus* (Yadav and Krishna, 1985; Rajora, 1998). *L. sindicus* survives under extreme arid conditions and grows in the areas receiving 100-300 mm annual precipitation and produces 5.0 - 7.5 t ha^{-1} air dried biomass. Crude protein in young leaves varies from 5.9 to 6.7% and remains high even at maturity stage as compared to other grasses making it more suitability for livestock production system. *C. setigerus*, tolerant to heat and drought, grows in areas receiving annual rainfall as low as 200 mm and produces 1.0 - 2.5 t ha^{-1} dry biomass. Crude protein varies from 5 to 12% of dry matter. *C. ciliaris* grows in the areas receiving rainfall from 150 to 1250 mm producing 2.0 - 4.5 t ha^{-1} dry biomass. Five promising genotypes of *C. ciliaris* tested for forage production revealed that dry biomass accumulation ranged from 9.85 to 25.67 q ha^{-1} with crude protein varying from 6 to 10%.

High coefficient of variation, moderate to high heritability, and high genetic advance were observed in *C. ciliaris*, *L. sindicus* and *D. annulatum* for tiller number, stem thickness and fodder yield. In *C. setigerus,* maximum variation in seed yield was due to spike density (Rajora *et al*., 2009). Rajora (1998) reported that the *C. ciliaris* genotypes differed significantly for days to flower initiation, days to 50% flowering, plant height, tillers $plant^{-1}$, leaves $culm^{-1}$, green fodder yield $plant^{-1}$ and dry matter yield $plant^{-1}$. The range for the mean of the genotypes was wider for green fodder yield, dry matter yield, plant height and tillers. Dry matter and green fodder yield showed higher values of genotypic and phenotypic coefficients of variation, while the values were moderate for tiller number and leaves $culm^{-1}$. Plant height, days to flower initiation and days to 50% flowering exhibited low values of genotypic and phenotypic coefficients of variation. In *C. ciliaris* the extent of variability was high for morphological, growth and seed contributing traits. Estimates of heritability and genetic advance were also high (Rajora *et al.,* 2008).

RAPD and ISSR markers independently and collectively detected diversity among *L. sindicus* populations collected from Barmer, Jaisalmer and Bikaner (Sharma *et al.,* 2017). Higher level of diversity within population is important for the survival of arid pasture grasses under fragile ecosystem and diversity among populations might have been important in niche specific adaptations. Genetic diversity is of considerable importance for sustainability of plant populations (Wang *et al.,* 2007).

Causes of diversity losses in pasture grasses of the region are overgrazing, frequent droughts, desertification and mechanization of agriculture and use of pasture land for non-agricultural purposes. Germplasm conservation is an important activity for maintaining live material over the years. Conservation of grass diversity rich areas is possible through *in situ* and *ex situ* conservation strategies, protection, controlled grazing and rehabilitation of degraded lands. The conserved germplasm can be used in further improvement programmes. Efforts are required to preserve the biodiversity of arid grasslands.

A sizeable genetic stock of forage grasses collected from different habitats is being maintained at ICAR-CAZRI, Jodhpur and has been evaluated for yield and its components. Varieties of *C. ciliaris* (CAZRI 75, CAZRI Anjan 358 and CAZRI 2178), *C. setigerus* (CAZRI 76) and *L. sindicus* (CAZRI Sewan 1) have been released by ICAR-CAZRI, Jodhpur from this germplasm.

Thus pasture grasses of arid zone have considerable variability for various growth and quality parameters both within as well as between species. This variability of arid zone grasslands and resources can be protected only by judicious use and conservation efforts at regional levels in farmer participatory mode.

References

Rajora, M.P. 1998. Variability and character association in buffel grass. *Annals of Arid Zone* 37(1): 99-101.

Rajora, M.P., S.K. Jindal and Manjit Singh. 2008. Seed yield components and stability analysis in buffel grass (*Cenchrus ciliaris*). *Indian Journal of Agricultural Sciences* 78(3): 225-229.

Rajora, M.P., Manjit Singh, S.K. Jindal and M. Patidar. 2009. Seed production and germination in birdwood grass (*Cenchrus setigerus*) under hot arid conditions. *Indian Journal of Agricultural Sciences* 79b(2): 148-151.

Sharma, R., M.P. Rajora, R. Dadheech, R.K. Bhatt and R.K. Kalia. 2017. Genetic diversity in sewan grass (*Lasiurus sindicus* Henr.) in the hot arid ecosystem of Thar Desert of Rajasthan, India. *Journal of Environmental Biology* 38: 419-426.

Wang, W., L. Chen, P. Yang, L. Hou, C. He, Z. Gu and Z. Liu. 2007. Assessing genetic diversity of populations of topmouth culter (*Culter alburnus*) in China using AFLP markers. *Biochemical Systematics and Ecology* 35: 662-669.

Yadav, M.S. and G.V.S.R. Krishna. 1985. Studies on variability, correlations and path analysis in *Lasiurus sindicus*. *Annals of Arid Zone* 25(2): 157-163.

Climate-resilient maize for stress-prone dryland system: Chasing the moving target

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Abstract

Rain-fed dryland systems, which represents significant part of maize mega-environments in Asian tropics, are largely dependent on prevailing weather conditions, and therefore extremely vulnerable to climate change effects. Most part of Asian tropics is recognized as hot spot for climate change effects, and associated negative effects due to climate variability, including weather extremes. Climate change is no longer a fiction, rather it is a fact, as it is well experienced in various form of weather extremes, with increased frequency in recent years. One of the biggest challenges with climate change is the uncertainty in weather pattern, especially year-to-year variability and extremes with space and time. Therefore the current agricultural research, including developing of crop variety need to pay major attention on resilience towards variable weather conditions rather than tolerance to individual stress in a specific situation or at particular crop stage. C4 crops are known for their wider adaptability and ability to cope-up with range of climatic conditions. However, recent trends in climatic conditions and associated variabilities seems to be challenging the threshold limit of wider adaptability of even C4 crop like maize. In collaboration with national maize programs and private sector partners, CIMMYT-Asia maize program have initiated several project largely focusing on saving achievable yields across environment by incorporating reasonable level of tolerance/resistance to key stresses without compromising on yields under optimal conditions (which is rare in target population environments). Integrating the power of genomics and precision phenotyping, and focusing on reducing genotype x environment interaction effects new generation of maize germplasm were developed with multiple stress tolerance that can grow well across variable weather conditions within season. The overarching goal of the stress-resilient maize improvement program is to save upside yield potential with downside risk reduction.

Introduction

Most of the maize in Asian tropics (about 70%) is grown in lowland tropics (<1000 masl), including both dry and wet-lowlands, followed by sub-tropical/mid-altitudes and tropical highland (Zaidi *et al*., 2014). Maize is largely (about 80%) grown as a rain-fed crop, which is prone to face vagaries of monsoon rains associated with an array of abiotic and biotic constraints. This is clearly reflected in the productivity of the rainfed system, which is usually less than half of the irrigated system (Zaidi *et al*., 2014). In general, there is considerable pressure on irrigation water, resulting in increased irrigation intervals thus subjecting the maize to stress and a consequent reduction in yield. Moisture availability is seldom adequate for rainfed maize. Erratic/un-even distribution pattern of monsoon rains occasionally causes drought or excessive moisture/waterlogging at different crop growth stage(s) within the same crop season, which is probably the main factor responsible for relatively low productivity of rainfed maize. Due to the uncertainty of assured returns, farmers are often hesitant to invest on recommended crop management practices that results in low soil fertility, and eventually poor yields. Also, in recent years Asian tropics have experienced frequent and widespread severe drought years, for example - seven drought years in South Asia since 2000, coupled with increased day/night temperatures during major maize growing season (monsoon season) covering about 80% of the total maize area, apart from scattered drought/heat almost every year in one or other country in South Asia (Zaidi *et al*., 2016).

Lowland tropics, especially wet-lowland, are most congenial for biotic stresses, including diseases and insect-pests of economic importance. *Turcicum* leaf blight (*Exserohilum turcicum)*, Maydis leaf blight (*Helminthosporium maydis)*, Rust (*Puccinia polysora)* and Downy mildew (*Pernosclerospora* spp*.)* are the most common foliar diseases in Asian maize. Though reasonable sources of resistance to these diseases exist in Asian maize germplasm, new introductions and the evolution of more virulent strains are posing a major challenge to the longevity of such resistance. Therefore, host-plant resistance breeding programs require close monitoring of virulence changes in the pathogen and identification of new resistance sources to new virulent strains. Banded leaf and sheath blight (BLSB) is emerging as a major threat in much part of Asian tropics, especially in the area where rice-maize rotation is followed. The main concern lies mainly in the lack of good sources of resistance to BLSB. Maize in Asian tropics is prone to several stalk rots, caused by range of causal organisms. *Diplodia* ear rots are the most common, but *Fusarium* and *Aspergillus* ear and kernel rots are also found, especially after a dry spell or insect attack, and often lead to dangerous levels of mycotoxin in grain. Stem borers, including *Ostrinia furnicalis, Sesamia inferens* and *Chilo partellus,* are widely distributed in Asia. Some partial resistance to these pests has been identified, that is largely dependent on inoculum load and intensity of infestation.

Climate-change effects - dealing with uncertainties

Rain-fed systems, which represent major part of maize mega-environments in Asian tropics, are more dependent on prevailing weather conditions, and therefore extremely vulnerable to climate change effects. Studies suggested that Asia would experience an increasing frequency of extreme weather conditions with high variability beyond the current capacity to cope up with (ADB, 2009; Cairns *et al*., 2012). Several climate modelling studies suggested sharper increases in both day and night temperatures in future, which could adversely impact maize production in the tropical regions (Lobell *et al.,* 2011; Cairns *et al.,* 2012). Such impacts are already being experienced in the region in a number of real and recognizable ways, such as shifting seasons and higher frequency of extreme weather events, such as drought, waterlogging and heat stress coupled with emergence of new/complex diseases. One of the major and well-realized effects of climate change has been the reduction in the number of rainy days (although there has been no significant change in total rainfall) in South (Kashyapi *et al*., 2012) and Southeast Asia (Manton *et al*., 2001). This has resulted in heavy rainfall events within a reduced number of days, thus extending the dry periods within same cropping season. The erratic distribution pattern in monsoon rains results in extremes of water regimes within the cropping season, thus causing contingent/intermittent waterlogging at some crop stage(s) and drought periods at other stages. Most part of Asian tropics is identified as hot spot for climate change effects, and associated negative effects due to climate variability, including weather extremes (ADB, 2009). Climate change effect is a hard-fact, well experienced in terms of weather extremes with increased frequency in recent years. One of the biggest challenges with climate change is the uncertainty in weather pattern, especially year-to-year variability and spatial and temporal extremes. During most critical two months period, rainy season maize crop may be exposed to variable moisture regimes in same area in different years (Fig. 1).

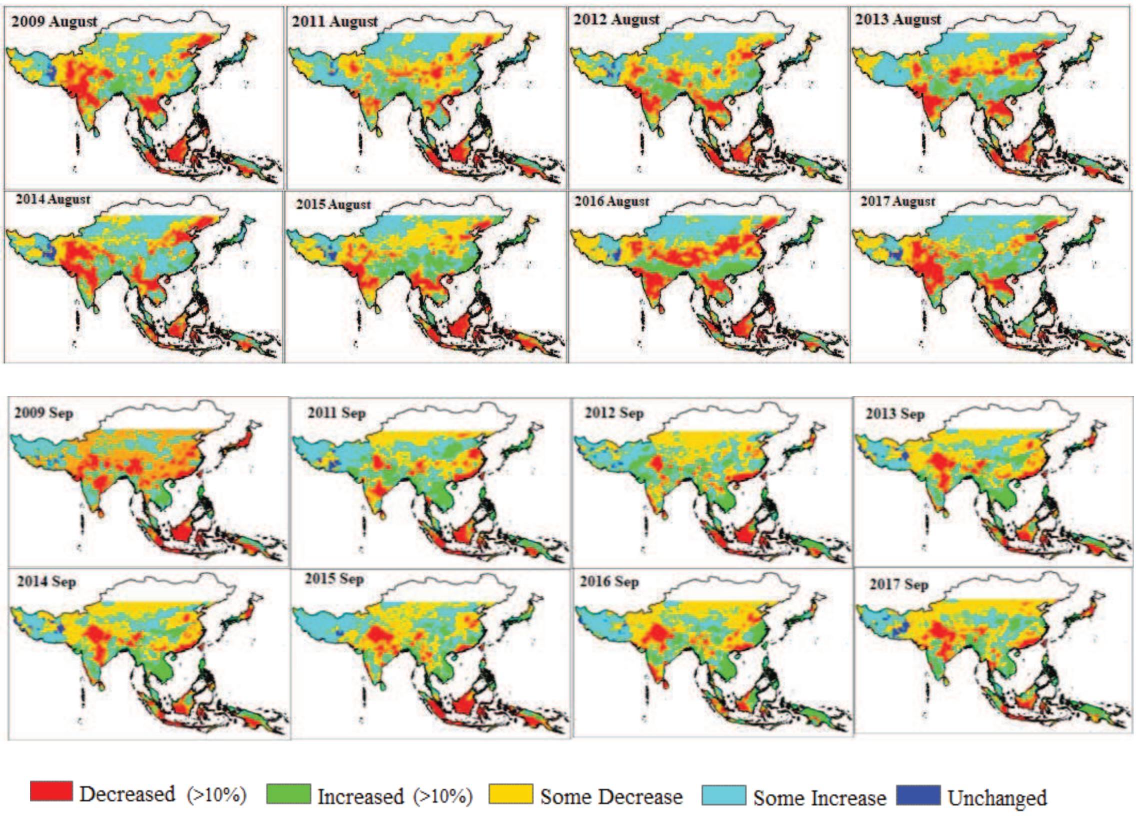

Figure 1. *Variation in monsoon rains in Asian tropics during 2009-2017 in relation to 2010 (close to normal year).*

Stress-resilient maize - an option for current and future climate

Challenged with growing problems of food security and climate change, Asian agriculture must become more productive, more resilient and more climate-friendly. Varieties with increased resilience to abiotic and biotic stresses will play an important role in autonomous adaptation to climate change (Fedoroff *et al*., 2010). Efforts to develop field crops with enhanced stress tolerance are vital. Millions of small holders in Asia grow maize under rain-fed conditions for their subsistence. The future of maize production, and consequently, the livelihoods of several million smallholder farmers in such climate vulnerable regions are based to a great extent on access to climate resilient cultivars.

C4 crops are known for their wider adaptability, however, recent trends in climatic conditions and associated variabilities seems to be challenging the threshold limit of even C4 crop, like maize. However, maize production can be increased by the availability of invaluable genetic diversity, which harbours favourable alleles for higher yield and biotic and abiotic stress tolerance (Prasanna *et al*., 2012). Maize varieties with increased resilience to abiotic and biotic stresses will play an important role in adaptation of climate change vulnerable farming communities in tropical Asia. Targeted crop improvement, aided by precision phenotyping, molecular markers and doubled haploid (DH) technology, offers a powerful strategy to develop climate change-adapted germplasm. However, given the time lag between the development of improved germplasm and the adoption of the same by the farmers in the targeted region(s), it is of utmost importance that necessary actions are initiated at the earliest in selected tropical Asian countries that are likely to be most affected by the changing climate (Cairns *et al.,* 2012).

In CIMMYT-Asia maize program, we focused on enhancing resilience in maize germplasm for an array of climatic conditions. The overarching goal of the stress-resilience maize program has been to improve upside yield potential with downside risk reduction. This is achieved by focusing on, and integration of, the following key components:

- Precision phenotyping for key traits at several representative sites as well as under managed-stress screens,
- Integration of novel breeding tools, including genome-wide association studies (GWAS), genomic selection (GS), and double haploid (DH) technology to fast-track stress-resilience breeding pipeline
- Research collaboration with committed NARS partners in the region for sustainable deployment and delivery of stress-resilient cultivars.

Phenotyping with precision

Irrespective of breeding approach, whether conventional or molecular breeding, high-quality phenotyping is the key of success for genetic improvement for targeted traits. In order to realize true success of breeding program (or power of novel molecular breeding approaches), it is essential to appreciate the principles of phenotyping and apply in practices (Zaidi *et al*. 2016b; Zaidi *et al*., 2016c; Zaman-Allah *et al*., 2016).

Managed stress screen*:* Precision phenotyping involves a detailed characterization of phenotype of test-entries under well-defined conditions (for example - managed drought stress). The intent is to precisely study the overall phenology of the test entries, which is the foundation for establishing genotype-phenotype associations in a molecular breeding approach. Quality of phenotypic data is defined by the precision in phenotyping environment. Understanding the target population of environment and simulating similar but more precise and uniform conditions (managed stress) is a pre-requisite for generating useful phenotypic data. Phenotyping sites need to be carefully developed on the basis of key information about the site, including:

- A minimum set of medium-term (past 10 years) weather data (daily maximum and minimum temperature, humidity, rainfall, and sunshine hours).
- Soil type - physical and chemical properties

- Cropping history of the site
- Field levelling, irrigation & drainage facility

The overall purpose of these managed stress trial is to simulate the targeted stress with desired level of stress intensity and uniformity at critical stages of crop growth, in a way that the available genotypic variability is clearly expressed and could be recorded.

Trait-based selection along with yield under stress: In general, the major trait of interest is always grain yield; however, under abiotic stresses heritability of grain yield is usually low, whereas heritability of some secondary traits remains reasonably high, and also the genetic correlation between those traits and grain yield increases significantly (Banziger *et al.,* 2000). Also, at times selection only on the basis of high grain yield under stress is misleading, for example - selecting a high yielding test entry with prolonged anthesis-silking interval (ASI; >5.0 days). Such an entry is able to produce high yield as it is fed by the synchronous availability of pollen from other test entries in the trial, a luxury that is not available in farmer field where a single hybrid is grown in large area.

In case of molecular breeding projects, detailed phenotyping is essentially required to support the huge volume of genotypic information generated, and unearth the power of that valuable information. It is essential to dissect complex traits, into components that can enhance understanding the cascade of event involved in conferring tolerance, and add value in genomic- region discovery efforts. However, for a secondary trait to be considered in phenotyping portfolio, it must comply with some basic requirements (Edmeades *et al*., 1998), such as:

- Significant genetic variability existing for the trait
- Significant genetic correlation with grain yield in the target environment, i.e. - relationship is causal, not casual,
- Heritability of the trait is higher than grain yield itself, i.e.- less affected by genotype x environment interaction
- Trait should not be associated with poor yields under optimal conditions, i.e. - it must confer tolerance rather than avoidance, and
- Rapid and reliable measurement, which is less expensive than measuring yield itself.

Recently, initiatives are being taken to establish field-based high throughput phenotyping platform (HTPP) to increase the throughput, more detailed measurements with better precision (Makanza *et al*., 2018). The target is to develop field-based HTTP using low cost and easy-to-handle tools, so that it becomes an integral and key component in the breeding pipeline of stress-resilient maize.

Developing stress-resilient maize

High yields under optimal conditions (yield potential) and reasonably good yields under stress conditions (adaptation to stress conditions) are not mutually exclusive. Therefore, we focus more on improved-stable yields across stressed and non-stressed environment (i.e. resilience, rather than just tolerance to a particular stress). This is achieved by defining the phenotyping and selection strategy across range of environments, and select the progenies that have high-stable performance across stressed and un-stressed environment. To increase the efficiency of breeding pipelines, CIMMYT-Asia maize program use a combination of approaches including index selection for stress-adaptive secondary traits along with grain yield, and modern molecular breeding approaches, e.g. genome-wide association studies (GWAS), rapid-cycle genomic selection (RC-GS) and double haploid (DH) technology. The strategy helped in developing new Asia-adapted maize germplasm pipeline with enhanced stress tolerance for individual or multiple stresses, without compromising optimal condition performance, are described as follows:

Constitution of base germplasm: The constitution of base germplasm is key factor in stress-resilience breeding program targeting product that performs across un-stressed and a set of stresses with varied intensity. In CIMMYT Asia and Africa maize program association, mapping panels were constituted involving 300-500 maize inbred lines representing genetic diversity of tropical maize. This includes, drought tolerant maize for Africa (DTMA) panel, CIMMYT Asia association mapping panel (CAAM) and heat tolerant association mapping (HTAM) panel. These panels were genotyped using various marker systems, including 1536 (Illumina-Golden Gate), 55K (Illumina-Infinium) and GBS (Genotyping by Sequencing - around 900K SNPs). Across-site phenotyping data was generated through genome-wide association analysis (GWAS) and major genomic regions associated with key biotic (Gowda *et al*., 2015; Zerka *et al*., 2018; Gowda *et al*., 2018) and abiotic stresses, including heat or drought (Babu *et al*., 2014; Cerrudo *et al*., 2018), waterlogging (Zaidi *et al.,* 2015) and root traits (Zaidi *et al*., 2016d) were identified. The study resulted in the following major outputs:

- Identification of major genomic regions associated with drought, water-logging or heat tolerance.
- Introgression of those regions in elite but stress susceptible Asia-adapted maize inbred lines with established commercial value through accelerated back cross approach using molecular markers and doubled haploid technology.

New generation of stress-resilient maize hybrids: While introgression of major genomic regions identified is being executed, the large-scale robust phenotyping data helped in identification of highly promising donor lines for various complex traits (abiotic & biotic stresses). These promising trait donor lines for one or multiple stresses were used in various ways in breeding stress-resilient maize hybrids.

***a) First generation hybrids*:** These maize hybrids were identified in two ways:

- Promising testcrosses from across site results of association mapping panel, as ready hybrid combination for individual stresses, and few hybrids, with stable performance across stresses and unstressed environments.
- Elite donor lines identified after across site phenotyping of association mapping panel testcrosses with known heterotic pattern were crossed using north-Carolina design-II.

The hybrids from above two sources were evaluated across range of stresses, including both biotic and abiotic stresses as well as under optimal growing conditions. The best hybrids with combination of traits (and respectable yields under optimal trial) were identified on the basis of across location trials results (Fig. 2). These hybrids were licensed to partners (on semi-exclusive basis) and taken forward for deployment and scale-out in collaboration with public sector and seed company partners in the region.

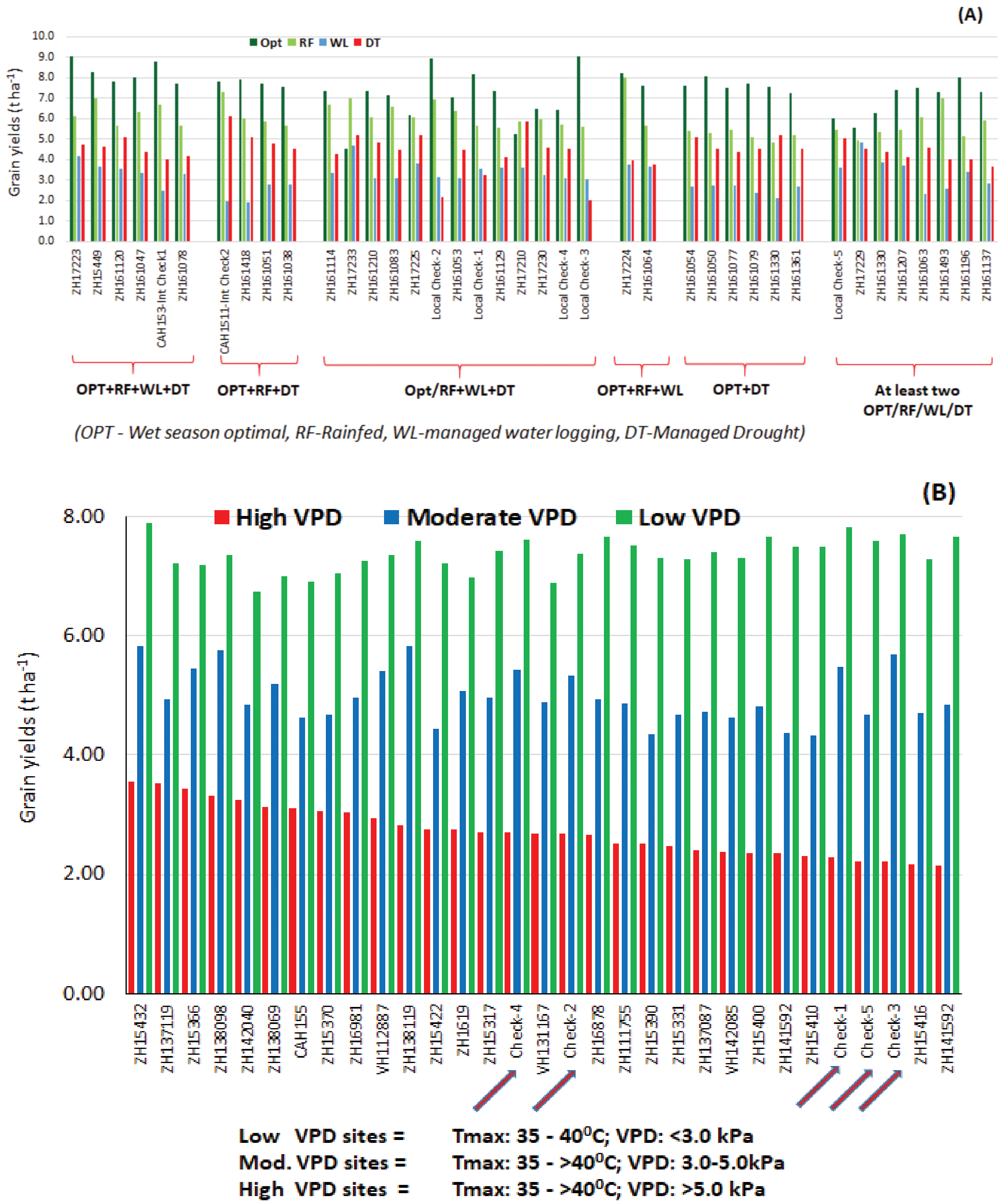

Figure 2. *Stress-resilient maize hybrids -choice for various stress-prone ecologies (A) during rainy season prone variable moisture regimes and (B) spring season prone to heat stress.*

b) Second generation hybrids: The inbred lines with promising performance in one or multiple stresses were used as trait donor in developing multi-parent synthetic populations (8-10 lines), which were used as base population (Cycle-0 or C0) in stress-resilient breeding program. These populations were advanced through rapid-cycle genomic selection approach, C1 was constituted by inter-mating top 10% $F_{2:3}$ progenies on the basis of their test-cross performance across several locations under stresses and un-stressed environments. Marker/haplotype/QTL effects were estimated by analysing genotype of $F_{2:3}$ families and phenotype datasets from $F_{2:3}$ test-crosses. The C1 was subjected to next two cycles (C2 and C3) through rapid-cycle genomic selection (RC-GS) using genomic estimated breeding values (GEBVs) for grain yield (GY) across stresses and un-stressed environments. The advanced cycles were subjected to double-haploid (DH) induction; these DH lines were used in developing new hybrid combinations for identification of new generation of stress-resilient hybrids for stress-prone target environment of South and Southeast Asia. These hybrids have gone through stage-1 testing across various stresses and optimal moisture condition, along with promising 1st generation hybrids and popular commercial hybrids as check entries in the trials. Selected hybrids are advanced to stage-II, and are being tested to at least two more stage, i.e. stage-III and MLT (multilocation testing in larger plots), before finalizing best-bet hybrids for licensing to partners for deployment and scaling-out.

Efforts have also started to follow genomic selection in the breeding pipeline which will help to dynamically create training populations and recalibrate GS models based on the breeding program, to effectively predict the breeding values bringing down the time and cost, leading to enhancing genetic gains.

References

ADB. 2009. Food security under threat from climate change. http://reliefweb.int/ report/.

Babu, R. 2014. Molecular marker-assisted breeding for tropical maize improvement. 12th Asian Maize Conference, 30 Oct - 1 November, 2014. Bangkok, Thailand.

Banziger, M., G.O. Edmeades, D. Beck and M. Bellon. 2000. Breeding for drought and low nitrogen tolerance: From theory to practice. Mexico, D.F.: CIMMYT

Cairns, J.E., K. Sonder, P.H. Zaidi, N. Verhulst, G. Mahuku, R. Babu, S.K. Nair, B. Das, B. Govaerts, M.T. Vinayan, Z. Rashid, J.J. Noor, P. Devi, F. San Vicente and B.M. Prasanna. 2012. Maize production in a changing climate: Impacts, adaptation and mitigation strategies. *Advances in Agronomy* 114: 1-58.

Cerrudo, D., C. Shiliang, Yuan Yibing, Carlos Martinez, Antonio Suarez Edgar, Raman Babu, Xuecai Zhang and Samuel Trachsel. 2018. Genomic selection outperforms marker assisted selection for grain yield and physiological traits in a maize doubled haploid population across water treatments. *Frontiers in Plant Science* 9: 1-12.

Edmeades, G.O., J. Bolanos, M. Banziger, J.M. Ribaut, J.W. White, M.P. Raunols and H.R. Lafitte. 1998. Improving crop yields under water-deficits in tropics. Pages 437-451 *in* V.L. Chopra, R.B. Singh and A. Varma (eds.). Crop Productivity and Sustainability -

Shaping the Future. Proceeding of the 2nd International Crop Science Congress, New Delhi.

Fedoroff, N.V., D.S. Battisti, R.N. Beachy, P.J.M. Cooper, D.A. Fischhoff, C.N. Hodges, V.C. Knauf, D. Lobell, B.J. Mazur, D. Molden, M.P. Reynolds, P.C. Ronald, M.W. Rosegrant, P.A. Sanchez, A. Vonshak and J.K. Zhu. 2010. Radically rethinking agriculture for the 21st Century. *Science* 327: 833-834.

Gowda, M. *et al*. 2015.Genome-wide association and genomic prediction of resistance to maize lethal necrosis disease in tropical maize germplasm. *Theoretical and Applied Genetics* 128: 1957-1968.

Hodson, D.P., E. Martinez-Romero, J.W. White, P.G. Jones and M. Bänziger. 2002. Asia Maize Research Atlas. Version 1.0. Published February 2002. http://www.cimmyt.org/ru/services/geographic-information-systems/resources/maize-research-atlas.

Kashyapi, A., Deepa A. Kulkarni, Anita S. Bahot and Archana P. Hage. 2012. Asian monsoon in a changing climate - Does it have impact on *kharif* season agriculture? International Conference on "Opportunities and Challenges in Monsoon Prediction in a Changing Climate", 21-25 February 2012, Pune, India.

Lobell, D.B. *et al.* 2011. Climate trends and global crop production since 1980. *Science* 333: 616-620.

Makanza, R., M. Zaman-Allah, J.E. Cairns, J. Eyre, J. Burgueño, Ángela Pacheco, C. Diepenbrock, C. Magorokosho, A. Tarekegne, M. Olsen and B.M. Prasanna. 2018. High throughput method for ear phenotyping and kernel weight estimation in maize using ear digital imaging. *Plant Methods* 14: 49 (https://doi.org/10.1186/s13007-018-0317-4).

Manton, M.J., P.M. Della-Marta, M.R. Haylock, *et al*., 2001. Trends in extreme daily rainfall and temperature in Southeast Asia and South Pacific: 1961-1998. *International Journal of Climatology* 21: 269-284.

Prasanna, B.M., J.L. Araus, J. Crossa, J.E. Cairns, N. Palacios, B. Das and C. Magorokosho. 2012. High through-put and precision phenotyping for cereal breeding programs. *In* Gupta, P.K. and R.K. Varshney (eds.). Cereal Genomics-II. Springer, Heidelberg.

Zaidi, P.H., Zerka Rashid, Madhumal Thayil Vinayan, Gustavo Dias Almeida, Ramesh Kumar Phagna and Raman Babu. 2015. QTL mapping of agronomic waterlogging tolerance using recombinant inbred lines derived from tropical maize (*Zea mays* L) germplasm. *PLOS ONE* DOI:10.1371/journal.pone.0124350.

Zaidi, P.H., K. Seetharam, G. Krishna, L. Krishnamurthy, S. Gajanan, R. Babu, *et al.* 2016d. Genomic regions associated with root traits under drought stress in tropical maize (*Zea mays* L.). *PLOS ONE* 11(10): e0164340. DOI:10.1371/journal.pone.0164340.

Zaidi, P.H., M. Zaman-Allah, S. Trachsel, K. Seetharam, J.E. Cairns and M.T. Vinayan. 2016b. Phenotyping for abiotic stress tolerance in maize - Heat stress. A field manual. CIMMYT: Hyderabad, India.

Zaidi, P.H., M.T. Vinayan and K. Seetharam. 2016c. Phenotyping for abiotic stress tolerance in maize: Waterlogging stress. A field manual. CIMMYT: Hyderabad, India.

Zaidi, P.H., M.T. Vinayan, K. Seetharam and B.M. Prasanna. 2016a. Stress-resilient maize for adaptation to climate-change effects in Asia. 7th International Crop Science Congress. 14-19 Aug, 2016, Beijing, China.

Zaidi, P.H., K. Seetharam, Zerka Rashid, L. Krishnamurthy and B.S. Vivek. 2014. Root functional traits are more important than structural traits for drought tolerance of maize (*Zea mays* L.). 12th Asian Maize Conference, 30 October - 1 November, 2014. Bangkok, Thailand.

Zaman-Allah, M., P.H. Zaidi, S. Trachsel, J.E. Cairns, M.T. Vinayan and K. Seetharam, 2016. Phenotyping for abiotic stress tolerance in maize - Drought stress. A field manual. CIMMYT, Mexico.

Zerka, Rashid, Pradeep Kumar Singh, Hindu Vemuri, P.H. Zaidi, Boddupalli Maruthi Prasanna and Sudha Krishnan Nair. 2018. Genome-wide association study in Asia-adapted tropical maize reveals novel and explored genomic regions for sorghum downy mildew resistance. *Scientific Reports* 8(366): 1-12.

Enhancing genetic gains and resilience to climatic stresses in pearl millet

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Extended Summary

Pearl millet grown on about 30 mha in semi-arid and arid ecologies of drylands in Asia and Africa is a valuable staple for humans and its stover is an important component of livestock feed in these marginal ecologies. IFPRI's foresight analysis is quite optimistic indicating increased demand for millets in India and Sub-Sahelian African (SSA) countries by 2040. In a scenario, when pearl millet cultivation is being further pushed to more marginal ecologies across these regions, there is strong need to understand the challenges this crop is facing and then to strategize the approach for enhancing both genetic gains in productivity and resilience to climatic and biotic stresses.

Pearl millet is challenged by downy mildew, low soil fertility and extreme drought conditions in both the continents, Africa and Asia; while millet head miner, striga weed in West and Central Asia (WCA) and blast in India are the major regional constraints to increase productivity. The production of pearl millet in SSA countries has increased in last 30 years due to increase in area but there has been almost no productivity increase. On the other hand, India witnessed pearl millet productivity increase at an annual rate of 3%, but rapidly decreasing area is a cause of concern.

Indian pearl millet breeding program took a paradigm shift in 1960-70s when hybrids started replacing open pollinated varieties (OPVs) leading to rapid increase in productivity, while WCA countries are still waiting for such a change to happen. Indian pearl millet program clearly defined its crop mega-environments, and with strong germplasm support from ICRISAT, followed 'environment-adaptation specific breeding strategy' in public and private sectors to develop cultivars having high yield potential for different agro-ecologies. Recent investigations showed that trait-specific breeding followed in Indian hybrid breeding program led to differentiation of breeding materials into clear cut heterotic pools, separately for seed and restorer parents. Now moving further, highly heterotic B- (seed parent) and R- (restorer parent) heterotic groups have been identified to further elevate genetic gains in pearl millet.

ICRISAT and national programs are continuously restructuring breeding priorities based on farmer- and consumer-driven feedback. Greater emphasis is being laid on high grain yield productivity coupled with disease resistance to enhance cultivar diversity for better endowed environments (with >400 mm rainfall per annum), while screening and breeding approaches are fine- tuned to develop cultivars for highly drought-prone environments (< 400 mm annual rainfall). ICRISAT, committed to continuously enhance genetic diversity in pearl millet cultivars, recently identified heterotic pools among wide range of African and Asian based pearl millet populations, which will go a long way in the development of high yielding cultivars. Recently, Leasyscan system has been standardized at ICRISAT to identify drought tolerant breeding lines/cultivars and validation process is underway to integrate these new screening systems with breeding programs. Breeding efforts are underway to introgress drought tolerant QTLs in promising genetic backgrounds through forward breeding approaches. ICRISAT in collaboration with advanced ARIs and other research partners has also identified flowering-period heat tolerant sources which have shown high seed set under air temperatures >42°C to enhance cultivar diversity in summer cultivated pearl millet crop in North-Western India, and in several African and Central Asian countries where ambient temperatures are quite high in different crop seasons. Targeted breeding followed by shuttle breeding in target ecology has led to generation of new breeding materials having higher levels of heat tolerance.

Efforts have been made continuously to map downy mildew and blast virulence pathogenicity, to identify disease resistance sources and utilize them in breeding programs to keep breeding programs ahead of pathogen. Multiple disease resistant composites have been developed against downy mildew and blast to provide new gene pools to derive disease resistant breeding lines, and efforts are underway to identify blast resistance in wild species.

While working with International Center for Biosaline Agriculture (ICBA,) salinity tolerant cultivars were identified and cultivars like "*Hashaki 1*" were released recently for cultivation in salinity affected tracts of central Asian countries. WCA programs are now re-orienting towards strengthening of disease screening systems, initiating hybrid breeding, encouraging stakeholders especially private sector to invest in quality seed production to enhance millet productivity in the region.

The recent availability of pearl millet genome sequence information is helping to map genes of traits of interest. Genomic selection (GS) model has been recently standardized with high predictive ability of breeding value of hybrid parents (with 0.48 to 0.51 for grain yield, and 0.8 to 0.9 for other important traits) and efforts are underway to further strengthen it to enhance the selection efficiency in future breeding programs. Efforts are in progress towards introducing Rapid Generation Advancement (RGA) coupled with forward breeding for multiple traits, strengthening of screening protocols (diseases, lodging, early generation testing network), digitalization of breeding programs, identification of new germplasm for biotic and abiotic stresses, and introducing hybrid technology for Africa to finally move towards new phase of higher genetic gains and climatic resilience in pearl millet.

Conservation and use of agrobiodiversity: Developing adapted cultivars in arid legumes

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Extended Summary

Arid legumes are summer annual crops that are mainly grown by marginal farmers under dry climates and poor soils with minimal inputs as a source of sustenance and livelihood. These crops are well suited to drier eco-systems encountering harsh and hostile growing environments. Arid legumes in India comprise four annual legumes viz., clusterbean or guar [*Cyamopsis tetragonalaba* (L.) Taubert], moth bean [*Vigna aconitifolia* (L.) Marechal], cowpea [*V. unguiculata* (L.) Walp.] and horsegram [*Macrotyloma uniflorum* (Lam.) Verdc].

Cowpea is an introduced crop in the country while moth bean and horsegram are believed to have originated in India and their wild forms are common. *Vigna trilobata*, a wild endemic species is considered as the progenitor of moth bean. Guar has an Asiatic origin and is domesticated in the region with *Cyamopsis senegalensis*, an African species, its probable progenitor. While not much importance has been given to these crops in commercial cultivation due to lower productivity, arid legumes have received attention at regional level, especially in location-specific traditional farming systems. Besides, highly nutritious grains, these crops also provide nutritious vegetable and fodder.

These crops are typically characterized by poor production potential linked with poor source-sink relationship, plant types suited to survival mechanism rather than productivity potential, longer maturity periods making them vulnerable to terminal stresses and suitable to specific climatic niches. Therefore, breeding efforts in recent years have targeted improved grain yield, curtailment of their growth period, disease resistance, drought tolerance and quality improvement. Plant genetic resources have played a vital role in improvement of all arid legumes and germplasm lines have been extensively used for release of most of improved varieties in these crops.

Genetic resources

Genetic resources in crop plants have evolved over thousands of years surviving all odds against nature and therefore provide a reservoir of useful genes for various survival traits. The wild and weedy relatives of crop plants grow in harsh environments and therefore provide an important source of adaptation-related traits and resistance to biotic and abiotic stresses.

Extensive collections have been made in arid legumes by ICAR-National Bureau of Plant Genetic Resources (NBPGR), New Delhi as well as State Agricultural Universities (SAUs) and ICAR Institutes and thousands of accessions are stored in the national repository. At present, NBPGR repository has a collection of 11765 accessions of arid legumes. These include 3649 accessions in cowpea (2556 indigenous, 1062 exotic, 30 wild), 2555 in horse gram (2536 indigenous, 11 exotic and 8 wild), 1511 in moth bean (1474 indigenous and 37 exotic) and 4050 in clusterbean (4012 indigenous and 38 exotic). Besides NBPGR, ICAR-Indian Institute of Pulses Research, Kanpur also conserves germplasm accessions of arid legumes in medium-term storage. While the germplasm utilization in major pulses is very minimal (<1%), most of the varieties in arid legumes (>65%) have been released after direct or indirect selection from germplasm resources.

Guar: Diversity in guar has been classified in grain types, vegetable types or dual purpose types. More than 5000 accessions have been collected by NBPGR, mainly from Rajasthan, Gujarat, Haryana, parts of Punjab, Uttar Pradesh and Delhi. Potential wild accessions such as C. *serrata* and *C. senegalensis* were also introduced from USA. More than 3700 accessions of guar have been subjected to *ex situ* conservation. Besides, 4878 accessions from local collections were conserved in medium-term storage. In total, >5500 accessions were evaluated for 21 characters and superior accessions have been identified. Several lines for high gum content (IC116577, 116601, 116609, 116627, 116676, 116682, 116752), earliness (IC 116804, 116868, 116869, 116930, etc) and disease resistance (GAUG9406, GG1, RGC 1027 for bacterial leaf blight; GAUG 9406, GAUG 9005, GAUG 9003, GC 1 for *Alternaria* blight and GAUG 9406, GG1 and HGS 844 for root rot) have been identified. Many of the germplasm lines have been released as cultivars in this crop.

Cowpea: More than 4300 germplasm accessions have been collected by NBPGR, SAUs and ICAR institutes. Over 2100 accessions have been evaluated, characterized and documented for 24 descriptors while 342 lines have been conserved *ex situ*. Promising accessions were identified for several traits viz., pod length (EC 392203, EC 390286, IC 390287 and IC 202821), bold seeds (EC 107171-2, IP-20304, IP 20359 and IP 20364), long straight pods (NIC-14039, 13894, 1374, 13761, IC 97853, 97848 and 97846), early maturity ((EC 973, 10206, 101929, 101975, 107183, 10775), high plant vigour and leafiness (EC 390226, 390239, 202776, 209164 and IC 202821). A few accessions were also found resistant to diseases viz., *Cercospora* (R.17-1-37 and Ala 969-82) and bean common mosaic virus (EC 297562). In a few accessions resistance against yellow mosaic disease and anthracnose were also reported. Varietal development in this crop has been mainly dependent on selection from indigenous and exotic germplasm and >67% of the released varieties have been developed from germplasm resources.

Horsegram: Some 2586 germplasm accessions have been conserved *ex situ* in the gene bank. Besides, >1500 germplasm accession have been collected and maintained at New Delhi, Akola and Thrissur. In addition, about 450 accessions are also being maintained at TNAU, Coimbatore and UAS, Dharwad. Almost all the varieties developed in horsegram have their origin in local germplasm in which extensive evaluation and selection work has been done. The germplasm accessions contain several sources for biotic and abiotic stress resistance.

Moth bean: Moth bean is an indigenous crop to India with maximum genetic diversity available. Till date, >2000 accessions have been collected and evaluated for various morho-physiological traits. More than 1100 accessions have been evaluated for earliness, branching and yield characters. A total of 1540 accessions have been conserved *ex situ*. Most of the varieties developed are direct selections from germplasm accessions.

Breeding and varietal development

Arid legumes are area-specific crops confined to specific regions of the country. Targeted breeding efforts were initiated during the last 3 decades for improving their grain yield, shortening crop duration, alteration in plant types, increasing disease and drought resistance and quality enhancement. This resulted in development and release of 72 varieties in arid legumes (26 in guar, 16 in cowpea, 12 in moth bean and 18 in horsegram), mostly from the indigenous and exotic germplasm (Table 1).

Table 1. *Promising varieties developed in arid legumes utilizing germplasm resources*

Crop	Varieties
Cowpea	Aseem, PTB 1, C 152, Shweta, Co-2, Co-4, Pusa Falguni, Pusa Sawni, Rituraj, S 288, S 488 (Exotic germplasm)
	Bundel Lobia 1, Co-1, Co-5, Charodi, Cowpea 78, Cowpea 88, FS 68, GC 1, Gomti, JC 2, BBC -1, Paitur-1, Pusa dofasli (Indigenous germplasm)
Moth bean	Type 3, T-9, Beleshwar-12, MG-1, Jadia, Jwala, IPCMO-880 and IPCMO 912
Horsegram	BR-5, BR-10, Madhu, HKP-2, HKP-4, HPK-5, HPK-6, PDM-1, VZM-1, K-82, Birsa Kulthi, S-27, S-28, S-39, S-1264, Maru Kulthi, KS-2, AK-21, AK-42, VL Ghat-1, Hebbal, Hurali-2, PHG-9, KBH-1, Co-1, 35-1-22, 35-5-123
Moth bean	Sona, Suvidha, IC-09229/P3, Naveen, PLG-85, RGC-471, Pusa Mausami, Pusa Sadabahar, Pusa Navbahar, IC 11388, PLG 850, Sharad Bahar

Future strategies

There has been an increased awareness about rejuvenating arid legumes cultivation and consumption globally in recent years, keeping in view their nutrition potential, suitability to harsh climates and role in sustainable farming. For promoting their cultivation, increasing yield potential by 2-3 folds from the current level, curtailing growing period by 10-20 days, and developing disease and drought resistant varieties need to be taken on top priority. Developing guar varieties maturing in 70-75 days, cowpea varieties in 60-70 days and horsegram varieties maturing in 75-80 days will help them in escaping terminal drought.

Germplasm has played an important role in development of these crops and therefore, collection, evaluation and characterization of trait-specific germplasm needs systematic investment in time and money so that potential germplasm can be deployed to best use in filling the gaps related to traits of interest. Wild and exotic germplasm needs to be collected and utilized carefully as this possesses numerous genes for yield and adaptation-related traits and non-conventional and aggressive breeding approach is required to make inter-specific hybridization successful. Developing remedial measures against anti-nutritional compounds in crops like horsegram may promote its use as food. Of late, molecular marker technology has given new dimensions to breeding disease and insect resistant varieties in other pulses like chickpea and this approach needs to be adopted in arid legumes as well to get expedited and directed results through hybridization.

Plant biotechnology has potential to turn grey areas into green - evergreen

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Abstract

Increasing population will cause increasing demand for food from agriculture sector. While it is well recognized that conventional plant breeding has kept pace with the increasing population so far, new approaches will be required to meet the future needs of agriculture, particularly with growing challenge from climate change. Biotechnology has shown encouraging results in helping produce high yielding cultivars with multiple resistance to abiotic and biotic stresses. Genetic transformation has also been used to improve nutritional quality of food crops. The new procedures of plant biotechnology (trangenics and gene editing) have, however, become a target of unjustified criticism and opposition from certain quarters which have no stakes in agriculture. It is necessary to convince the governments of all countries about the role plant biotechnology is destined to play in increasing productivity of agriculture in the coming years in the face of changing climate.

Introduction

It is an undisputable fact that feeding the ever-increasing world population, which is expected to reach 10 billion by the year 2050, will be a major challenge to meet in about three decades from now. Agriculture being the major source of food, both plant and animal productivity will have to be enhanced at much faster rate than at present. Cropped area, perhaps, cannot be increased by a significant margin as the demand for land to meet the needs of non-agricultural purposes will keep on rising and there will be increasing emphasis on preserving forests. Therefore crop management will have to be geared toward producing more food, fodder, fibre, fuel crops, fruits and vegetables, animals, poultry and fish from less cropped area.

To meet this requirement, geneticists and agricultural scientists from other disciplines will need to develop new technologies, and the farmers will be required to adopt them speedily. Experience has shown that the farmers are ready to adopt any new technology that gives them better returns. So, it will be the major responsibility of the scientists to create new technologies in terms of varieties and crop management practices. Generally speaking, crop management is also decided by the properties and requirements of varieties in response to the growing conditions such as soil type, quantity and quality of irrigation water, temperature variations, photoperiod in different seasons, enhanced cropping intensity, and disease and pest management.

While it is well recognized that conventional plant breeding has kept pace with the increasing population so far, new approaches will be required to meet the future needs of agriculture. Developing new varieties that could give reasonable yields in water-stressed conditions (less water or poor quality water) must be the primary goal of plant breeding in all crops across the board, in the coming decades. A 2014 study noted that GM (genetic modification) technology increased crop yields by 22% in about 22 previous years. Even at this rate, average crop productivity per unit area would be at least 33% higher in 2050 than today if GM varieties are adopted at the same pace as in the initial period of plant biotechnology (transgenics, and now gene editing) research. Hesitation or opposition to the adoption of GM varieties has started declining in the recent years. It is now confirmed that biosafety is not an issue with genetic modification. More and more countries are adopting GM varieties that have undisputable advantages such as drought tolerance, ability to grow under extreme temperatures (high, low, or both in the same cropping season), insect-pest and weedicide resistance, and nutritional enrichment.

Biotechnology research in crop plants has shown encouraging results. Increasing tolerance to water stress can increase yields and economic returns in all crops because short spells of water stress also occur in water-surplus areas or seasons. The most significant impact of drought resistant varieties will be under conditions of persistent water shortage that includes arid lands and deserts. Drought tolerance is crop insurance under all conditions. After all, many annual plants and perennial trees grow naturally even in deserts. Strong genes for drought tolerance harvested from xerophytic plant species (annual herbs as well as perennial trees) should be deployed in annual crop plants and fruit crops. This opens a new area of expanding crop cultivation in the regions that have remained barren till now. The third advantage of varieties with low water requirement will be the water economy in high water demanding crops like rice, sugarcane, wheat, vegetables, cotton etc. The water saved from such crops can be used in the neighbouring fields hitherto starved for water.

Genetics of drought tolerance

Drought tolerance is caused by genetic reasons of escape (earliness), avoidance (root growth, hydraulic conductance, water holding in tissues, and reduced water loss by stomatal closing, leaf rolling and folding, flashy stems and leaves, waxy coating etc.), and physiological mechanisms under genetic control (leaf turgor, osmotic potential, solute accumulation, delayed leaf senescence - stay green, ascorbic acid and proline content, and metabolic adjustment through gene products like osmotin and dehydrin).

The complex genetically controlled mechanisms appear to be operating under a network of regulatory genes. In spite of involvement of multiple genetic factors, monogenic segregation has been frequently observed in crosses between drought tolerant and susceptible genotypes. Drought tolerant genotypes have been frequently reported to be salt tolerant also. A drought tolerant accession of lentil, PDL-1, received from ICARDA, is also tolerant to salinity and gives monogenic segregation when crossed with a series of drought susceptible Indian varieties. A reliable screening procedure that ensures unmistaken identification of the rare drought tolerant segregants in a large population will greatly increase breeding efficiency. Marker aided selection (MAS), or even visual selection in hydroponics and sand beds, makes it possible to screen huge segregating populations for drought tolerance at seedling stage.

Genes for drought tolerance have been identified virtually in all biological systems from microbes to man (Table 1). As many as 18 genes have been found to be associated with drought tolerance in cowpea (Table 2). The genes in the closely related or distant plant species naturally growing in arid and desert conditions are expected to possess stronger genes for drought tolerance and yield better results.

Table 1. *Genes identified for drought tolerance in diverse organisms*

Gene	Source	Function
Tps 1	Yeast	Trehalose synthesis
P5cs	Yeast	Pyrroline-5-carboxylase synthetase involved in carboxylate proline synthesis (overexpressing p5cs [in tobacco] induced 10 to 18-fold more proline)
Sacb	*B. subtilis*	Levan sucrase (fructan) synthesis in tobacco
BetA	*E. coli*	Choline dehydrogenase
BetB	*E. coli*	Betaine aldehyde dehydrogenase. Glycine betaine synthesis in tobacco
Odc	Yeast & mouse	Ornithine decarboxylase
Adc	Oat	Arginine decarboxylase
Sod	Pea	Superoxide dismutase [tobacco]
Hva1	Barley	Three late embryogenesis abundant proteins [rice]
Bg1	Rice	Increases grain size and yield, associated with auxin regulation
Erecta	Arabidopsis	Added to rice & tomato genomes. Overexpression increases heat tolerance and biomass
Erecta	Common bean	Maps on chromosome 1. Drought tolerance
Hawrky76	Sunflower	Transcription factor for drought & submergence
SAMDC	Human	S-adenosyl-methionine decarboxylase10 (proline content)

Table 2. *Drought tolerance genes and enzymatic products in cowpea*

Gene	Accession	Gene function
VuNCED 1	AB030293	9-Cis-epoxycarotenoid dioxygenase catalyzes ABA synthesis
8CPRD 6	AB030294	9-Cis-epoxycarotenoid dioxygenase catalyzes ABA synthesis
VuABA 1	AB030295	Zeaxanthin epoxidase-enzyme for early step in ABA synthesis
CPRD 12	D88121	Cowpea response to dehydration stress
CPRD 46	D88122	Water stress-inducible gene for neoxanthin cleavage enzyme in ABA synthesis
CPRD 8	D83970	Cytosolic glutathione reductase enzyme for detoxification of AOS
CPRD 14	D83971	Cowpea response to dehydration stress
CPRD 22	D83972	Cowpea response to dehydration stress
dtGR	DQ267475	Cytosolic glutathione reductase enzyme for detoxification of AOS
VucAPX	U61379	Cytosolic ascorbate peroxidase enzyme for detoxification of AOS
VupAPX	AY466858	Peroxisomal ascorbate peroxidase enzyme for detoxification of AOS
VutAPX	AY484492	Thylakoidal ascorbate peroxidase enzyme for detoxification of AOS
VusAPX	AY484493	Stromatic ascorbate peroxidase enzyme for detoxification of AOS

It is not yet known how much the genes for tolerance against water stress in different organisms (plants, animals, microbes) are structurally and functionally similar or different. We do not even know what will happen when drought tolerance genes from different plants will be pyramided with similar genes from other plant species (annual herbaceous or perennial tree species). The situation could be much widely different if drought tolerance genes from plants are put together with similar genes in microbes and animals. This area needs to be explored. Opportunities are mind boggling!

Progress in plant breeding for drought tolerance and other traits

Increasing crop production per unit area and per unit time is the only way to achieve the goal of feeding the increasing population. Emphasis will have to be put on developing varieties that give high yields in a shorter period. Drought tolerant varieties will be a primary requirement to economize irrigation water and expand crop cultivation to chronically water-deficient areas. Genes for drought tolerance have been identified in rice (Bg1), barley (hva1), oat (ADC), pea (SOD) and many others cultivated plants. Efforts in this direction have made perceptible progress. For example, osmotin-like protein (OLP) gene from *Solanum nigrum* coupled with UBQ3 promoter of *Arabidopsis* transferred into soybean gave better yield under water stress. Similarly, over-expression of tobacco osmotin gene simultaneously confers tolerance to drought and salinity in wheat, cotton, tomato and soybean. A drought tolerance gene from sunflower placed in wheat has resulted in the development of a drought tolerant variety (HB 4) which is at the verge of commercialization in Argentina. HB 4 has become popular in Brazil, Paraguay, Uruguay, and the United States. Transgenic wheat is being tested in field trials in Australia. GM varieties of maize are under cultivation for a long time in several countries. Triple traits (nitrogen use efficiency, water use efficiency, and salinity tolerance) have been stacked in rice. A barley gene transferred to rice leads to increased grain yield with simultaneous reduction in methane emission from its flooded fields.

Insect control with Bt genes in many crops is history now. Bt cotton is now becoming increasingly popular in many African countries. GM varieties of Bt brinjal developed in India (although not permitted for cultivation in the country of origin) are now established as commercial crop in Bangladesh, and are likely to be released to farmers in the Philippines. The number of Bt brinjal growing farmers in Bangladesh has increased from 20 in cropping season 2013-14 to 27,012 in 2017-18. The Bangladesh government had planned to cultivate Bt brinjal in 36 districts in the 2018-2019 cropping season, and proposes to cover the entire brinjal area under the Bt variety. Transgenic cotton resistant to sucking pests (jassids, aphids, and the virus-vector whiteflies) has been developed by Indian researchers. The agglutinin gene from taro has been demonstrated to impart resistance against mustard aphid by workers at the Bose Institute in Kolkata (India).

Herbicide tolerance is another major area of GMO research as a universal weedicide like glyphosate can protect all crops from monocot and dicot weeds at low cost. Similar success stories are published about disease control following genetic transformation. The tungro virus disease of rice was shown to be successfully controlled by CRISPER-Cas9 editing of the elF4G gene in the tungro susceptible variety IR 64. A weedy fruit plant, ground cherry (sold in Indian markets in the name of *rasbhari*), was transformed to a domesticated crop through CRISPER editing of a single gene. The ZMNBS25 gene of maize causes resistance against bacterial and fungal diseases across species. Late blight resistant potato varieties have been evolved using resistance genes from wild relatives. Transgenic soybean lines constitutively expressing ribonuclease gene PAC1 of the yeast *Schizosaccharomyces pombe* displayed multiple resistance against several viruses.

Genes for drought resistance and other economic traits are not confined to annual herbaceous plants. Several perennial tree species are reported to carry genes that are suitable for transfer into crop plants. Papaya is known to carry drought tolerance trait. The *Arabidopsis* gene AtEDT1/HDG11 confers drought and salt tolerance to cotton and poplar. These examples confirm that genes from herbaceous annuals and perennial tree species are mutually transferable with similar effects. It also supports the proposal made above that annual as well as tree species can be equally good source of strong genes for drought resistance (and also other economically valuable traits). The Indian desert has valuable donors of strong genes for drought tolerance like an annual grass, *Prosopis cineraria,* and date palm.

Genetic transformation has also been attempted to improve nutritional quality of food crops. The story of golden rice does not need repetition. Over-expression of *Arabidopsis* gene PDX11 in potato increased vitamin B6 content to 150% (reported from Hari Singh Gour Central University, India). The SacB gene of *Bacillus subtilis* increases Levan sucrose (fructan) synthesis in tobacco. Similarly, drugs and vaccines can be produced in plants on field scale by transforming plants with the required genes from microbial and other sources.

Season-free agriculture

Crops are restricted to their respective growing seasons primarily due to the photoperiod and temperatures prevailing in a particular region. The genes controlling response to day-length and low/high temperatures are known. The latest technology of gene editing is capable of creating photoperiod-neutral and thermoneutral genotypes. The two sets of genes will enable the plants to grow under all combinations of day length and temperature. In other words, summer crops could be grown in winter (in tropics and subtropics) and winter crops during summer. Any crop could be sown and harvested any time in the year. The once imaginary "Ideal Plant Type" can be created by combining genes for photoperiod and in almost all crop plants. Cropping intensity, with such a possibility of temperature neutrality and traits like dwarfness and earliness, genes for which are known, could be increased to as much as 300%. The concerns of feeding the increasing population will disappear.

Plant biotechnology in the context of climate change

Little information is available about the nature and extent of climate change that would affect agriculture. The most serious changes from the standpoint of agriculture are expected in temperature and rainfall patterns. These changes are likely to be unpredictable in most cases. The future crop varieties may have to face changes in weather conditions within a single cropping season. Under such a situation a variety must be ready to face extreme conditions of opposite nature (high and low or no rainfall, high and low temperatures). Pyramiding genes for opposite phenotypes will be much easier and rapid, through the transgenic and gene editing routes. Crop management technologies will play a vital role, but their efficacy will depend on the attributes of the varieties in the field.

Plant breeding through biotechnology route (new genes and alleles assembled by genetic transformation, gene editing, or both) is expected to succeed with high efficiency because under climate change epiphytotics for all possible stresses will be available in open fields facilitating selection of individual segregants and gene combinations without resorting to off-season nurseries or constructing structures at high cost for screening breeding materials at the plant breeding centre itself.

Need for intensive research on genes and alleles for drought tolerance

Recombination breeding for drought tolerance genes among the crop plants has stood the test of time. However, it must be recognized that there are severe restrictions in depending on the cultivated varieties or their wild relatives as source for creating increasingly stronger drought tolerant genotypes. In this approach, the problem of genetic drag is almost insurmountable. The objective here is not only to develop cultivars for the cropped areas facing water stress. This approach will also help in boosting productivity in the areas that are already under crops. The theme of this Conference is to convert dry areas from gray to green. What is being proposed here is to convert such areas, which include highly arid and even deserts, into perpetually green even if with low yields within reasonable limits. What maximum yields can be achieved in the biotechnologically produced drought tolerant varieties will be known only when we have done it. Today, for example, we do not know what will be the result if drought tolerance genes from the established dryland crops like safflower, horse gram, clusterbean, moth bean etc. are put together. Similarly, what kind of phenotypes will result if strong drought tolerance genes from desert grasses and tree species are transformed into the whole range of cultivated plants? We also do not know how much the known genes for drought tolerance can be further strengthened by gene editing and/or combining them with strong promoters with constitutive function from the best known sources to make crop plants suitable for cultivation under desert conditions. The possibility of making promoter genes also stronger using biotechnology tools is a widely open area.

Answers to these questions can be obtained only by investigating various alternatives and exploring already proven possibilities to create strong drought resistant - tolerance is not enough - varieties. To achieve this goal, a beginning can be made by creating a fully equipped and financially strong centre, or may be, an international institute, preferably under the aegis of the United Nations for which financial support will flow from all nations of the world. Arid lands and deserts are a universal phenomenon. All crops in all countries face spells of short or long water shortages. And if the areas facing severe water stress (water shortage and water salinity) can be made productive the humanity will never face shortage of agricultural commodities. Organizations like the present Conference can motivate the governments of the world to contribute to such an endeavour.

Role of policy regulators in promoting plant biotechnology

The new procedures of plant biotechnology (trangenics and gene editing) have become a target of unjustified criticism and opposition from certain quarters which had no stakes in agriculture. Governments took their scare-mongering seriously and imposed severe restrictions on biotechnology research and delivery of products (GM or gene edited varieties) for commercial cultivation. Farmers were deprived of the fruits of modern science. The climate appears to be changing in the recent times. More and more countries are now willing to adopt biotechnology and are relaxing controls they had initially imposed. In the latest example, the USA has decided not to regulate gene-edited crop varieties. This could be a trend setter in the coming years. Social media played a crucial role in countering the anti-GMO propaganda of the activist NGOs. Now is the time for influential people and groups like the present Conference to convince the governments of all countries about the role plant biotechnology is destined to play in increasing productivity of agriculture in the coming years.

Reference

Agbicodo, A.C.M.E., C.A. Fatokun, S. Muranaka, R.G.F. Visser and C.G. van der Linden. 2009. Breeding drought tolerant cowpea: constraints, accomplishments, and future prospects. *Euphytica* 167: 353-270.

Performance of biofortified pearl millet hybrids for grain yield in northern India

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Abstract

Pearl millet is a dryland resilient crop of the semi-arid tropics in India and Africa. It plays a major role in food and nutritional security in these regions. Dry-zone of northern India lags behind in pearl millet genetic improvement and adoption of hybrids. Aim of this study was to test and identify superior high-iron and high yielding hybrids for adaptation. Two trials with 17 (trial 1, 2016) and 14 (trial 2, 2017) hybrids were conducted in 3 sites each for grain yield, and iron (Fe) and zinc (Zn) density in grains. Analysis of variance showed highly significant variation for grain yield, flowering, Fe and Zn density in both the trials and across environments. Hybrids significantly contributed to total variability for all traits, while the G×E interaction contributed much lower in both the trials across environments. Further, high heritability for all traits suggests relatively low environmental influence on these traits. Trial 1 hybrids had 59-104 mg kg^{-1} Fe density, 35-52 mg kg^{-1} Zn density and 2.2-3.5 t ha^{-1} grain yield. Five hybrids were identified with 19-45% higher yield and >40% higher iron than control. Similar trend was observed in trial 2. Three commercial hybrids had 43-58 mg/kg mean Fe and 29-37 mg kg^{-1} mean Zn with an average yield of 1.9-2.5 t ha^{-1}. Although identified hybrids flowered a week later than controls, they yielded well in rainfed conditions without affecting Fe/Zn density. This is preliminary indication of the potential of ICRISAT high-Fe/Zn parents, and their utilization in hybrid breeding, for development of high iron and zinc hybrids without compromising the grain yield in northern India.

Introduction

More than 2 billion people in the developing countries suffer from the nutritional deficiency of essential micronutrients. About 50% of children and women in India suffer from anemia whereas 52% of children are stunted (NFHS, 2016). Pearl millet [*Pennisetumglaucum* (L.) R. Br.] is staple cereal in drylands, accounting for 20-63% of total cereal consumption in major pearl millet growing states of India (Maharashtra, Gujarat, and Rajasthan). It contributes to higher intake of total Fe (19-63%) and Zn (16-56%) than other cereals (Parthasarathy Rao *et al.,* 2006). Genetic variability for Fe/Zn content and its genetic enhancement as 'Proof of Concept' were demonstrated by biofortification program at the International Crop Research Institute for Semi-Arid Topics (ICRISAT) that led to rapid development of mineral-dense cultivars with partners. Their adoption and utilization in food preparations is highly required to enable improved human nutrition in drylands.

Pearl millet is a major warm-season cereal grown on 28 mha for grain and fodder production in some of the most marginal areas of the arid and semi-arid tropical regions of Asia and Africa. In these regions, pearl millet is a major source of dietary energy and mineral micronutrients. Pearl millet is a highly cross-pollinated crop with open-pollinated varieties (OPVs) and hybrids as the two broad cultivar options. Hybrids are the most dominant cultivars in India, occupying >70% of area under improved pearl millet cultivars, with OPVs cultivated on limited scales. India is the largest producer of this crop with 7.5 mha area and 9.7 m tons of grain production (www.indiastat.com). Here, pearl millet growing area has been categorized into two zones: A-Zone (Dry Zone): and B-Zone (South central zone) (Yadav *et al.,* 2012). B-Zone includes Maharashtra, Karnataka, Andhra Pradesh and Tamil Nadu, with more than 600 mm annual rainfall, heavy soils and mild temperature conditions and it contributes 29% to the total pearl millet production from 26% of the total area in the country. A-Zone represents north-western states, Rajasthan, Haryana, Punjab, Delhi, Gujarat, Uttar Pradesh and Madhya Pradesh, with less than 600 mm annual rainfall. It has sandy to sandy-loam soils. This zone contributes about 71% to the total production from 74% of total area under pearl millet in the country. Within this zone, parts of Rajasthan, Haryana and Gujarat receiving <400 mm of rainfall are grouped into a sub zone i.e. A1 zone. This sub-zone is highly drought prone with average annual rainfall below 400 mm, light sandy soils, and high temperatures. Under this multi-location study performance of iron biofortified pipeline hybrids was evaluated to identify hybrids suitable for A-zone.

Materials and methods

Trial-2016 consisted of 21 entries (17 hybrids, 4 checks) and trial-2017 consisted of 18 entries (14 hybrids, 4 checks) (Table 1). The trials were laid out in randomized complete block design (RCBD) with two replications. Trials were evaluated across three locations during the rainy season of 2016 (Durgapura in Rajasthan and Bawal and Hisar in Haryana) and 2017 (Durgapura and Jaipur in Rajasthan and Hisar in Haryana) in the A-Zone of northern India. Grain yield (GY) and days to 50% flowering (BL) were recorded on plot basis. Grain Fe content (Fe) and Zn content (Zn) were analyzed using XRF at Pearl Millet Breeding XRF Laboratory, ICRISAT, Patancheru (Govindaraj *et al.,* 2016a; Paltridge *et al.*, 2012). The analysis of variance (ANOVA) of all the trials was done following Gomez and Gomez (1984). ANOVA for both individual environments and pooled data was carried out in using the PROC GLM procedure in SAS 14.1 software (SAS Institute Inc., 2015), considering environments factor fixed and genotypes as random factor. Phenotypic correlations were estimated among all the traits and tested for their significance (Snedecor and Cochran, 1989).

Table 1. *Pedigree details of entries in 2016 and 2017 multi-location*

Geno	Seed parent		Pollinator Pedigree
			2016 trial
1	ICMA1 98222	×	MRC S1-155-4-3-B-B-B-B-1-B-B-1
2	ICMA4 02333	×	MRC S1-155-4-3-B-B-B-B-1-B-B-1
3	ICMA1 04999	×	(EERC-HS-6)-B-12-1-1-3-B
4	ICMA4 02333	×	(EERC-HS-6)-B-12-1-1-3-B
5	ICMA1 1502	×	MRC HS-225-3-5-2-B-B-B-1
6	ICMA1 98222	×	MRC HS-225-3-5-2-B-B-B-1
7	ICMA4 03999	×	AIMP 92901 S1-296-2-1-1-3-B-1-3-4-1
8	ICMA4 03999	×	AIMP 92901 S1-15-1-2-3-B-3-B-9-2-1
9	ICMA1 1502	×	AIMP 92901 S1-296-2-1-1-3-1-B-3-B-1
10	ICMA1 04999	×	ICMV 221 S1 -123-B-B-B-B-B-P2
11	ICMA1 00111	×	[(IPC 1617×SDMV 90031-S1-84-1-1-1-1)×AIMP 92901 S1-296-2-1-1-3-B-1]-4-4-5-3-2
12	ICMA4 04222	×	MRC S1-416-2-1-2-3-B-B-B-1-B-B
13	ICMA1 98222	×	MRC S1-97-3-4-B-B-1-B-1-B
14	ICMA1 04999	×	(EERC-HS-6)-B-12-1-1-2-B-P12
15	ICMA1 94333	×	Jakhrana × ESRC II S2-11-B-1-2-1-1-B
16	ICMA1 97444	×	[[(IPC 1617×SDMV 90031-S1-84-1-1-1-1)×AIMP 92901 S1-296-2-1-1-3-B-1]-4-4-2-1 X ICMV 96490-S1-15-4-1-1-2]-29-3-3
17	ICMA1 97444	×	ICTP 8203 S1-121-12-2
18	Check		RHB 177
19	Check		ProAgroTejas
20	Check		HHB 67 Improved
21	Check		Dhanashakti
			2017 trial
1	ICMA1 04999	×	(EERC-HS-6)-B-12-1-1-2-B-P12
2	ICMA4 99444	×	(EERC-HS-6)-B-12-1-1-2-B-P12
3	ICMA1 97222	×	ICMR 12555
4	ICMA1 97444	×	ICMR 12555
5	ICMA1 97444	×	ICTP 8203 S1-121-12-2
6	ICMA1 04999	×	(MC 94 C2-S1-3-2-2-2-1-3-B-B x AIMP 92901 S1-488-2-1-1-4-B-B)-B-2-2-3
7	ICMA1 1502	×	MRC HS-225-3-5-2-B-B-B-1
8	ICMA1 1505	×	[ICMV 96490-S1-15-1-4-3-1 X MRC HS-130-2-2-1-B-B-3-B-B-B-1-3-1]-98-2-2
9	ICMA1 94333	×	(ICMB 08666 x (ICTP 8203 x 40258-B-1)) F3-77-3-1
10	ICMA1 98222	×	MRC S1-97-3-4-B-B-1-B-1-B
11	ICMA1 98222	×	(ICMS 7704-S1-127-5-1 × RCB-2 Tall)-B-19-3-2-1-4-B-1
12	ICMA4 99444	×	ICTP 8203 S1-386-B-B-B-B
13	ICMA1 04999	×	ICMR 12555
14	ICMA1 04999	×	(MC 94 C2-S1-3-2-2-2-1-3-B-B x ICMR 312 S1-3-2-3-2-1-1-B-B)-B-34-1-1
15	Check		RHB 177
16	Check		ProAgroTejas
17	Check		HHB 67 Improved
18	Check		Dhanashakti

Results and discussion

Genotypes performance across environments

In trial-2016, Fe density varied from 59-104 mg kg^{-1} with an average of 78 mg kg^{-1}; Zn density varied from 35-52 mg kg^{-1} with an average of 42 mg kg^{-1} (Table 2). While the grain yield varied from 2.16 to 3.53 t ha^{-1} with an average of 2.73 t ha^{-1}, and days to 50% flower varied from 45 to 56 days with an average of 50 days. In trial-2017, Fe density varied from

60 to 110 mg kg^{-1} with an average of 81 mg kg^{-1}, Zn density varied from 29 to 57 mg kg^{-1} with an average of 40 mg kg^{-1}, and grain yield varied from 1.73 to 2.75 t ha^{-1} with an average of 2.19 t ha^{-1}, and days to 50% flower varied from 46 to 53 days with an average of 50 days. Earlier studies also reported larger variability for both micronutrients and agronomic traits in biofortified hybrids and their parents and segregating progenies (Velu *et al.,* 2008a, 2008b; Gupta *et al.,* 2009; Rai *et al.,* 2012; Govindaraj *et al.,* 2012; Govindaraj *et al.,* 2013; Kanatti *et al.*, 2016b).

***Table 2**. Mean performance for Fe, Zn, GY and BL in 2016 and 2017 multi-location trials*

2016					**2017**				
Entry	**Fe**	**Zn**	**GY**	**BL**	**Entry**	**Fe**	**Zn**	**GY**	**BL**
1	59	36	2323	46	1	60	29	2753	51
2	61	36	2724	45	2	74	33	2053	52
3	75	43	2897	51	3	81	47	2269	50
4	87	39	2702	46	4	76	36	2020	51
5	86	35	2687	48	5	77	36	2283	51
6	76	37	2161	49	6	83	46	2159	51
7	95	47	2637	54	7	90	43	2040	46
8	94	44	2944	56	8	101	44	2225	46
9	104	43	2790	53	9	80	42	2189	52
10	85	50	3532	53	10	64	31	2491	50
11	80	44	2515	56	11	79	39	2388	49
12	70	41	2821	48	12	110	57	1737	49
13	65	37	2936	50	13	80	43	1821	52
14	59	39	3257	51	14	73	39	2246	53
15	77	45	2460	47					
16	78	52	2537	54					
17	69	41	2509	51					
RHB 177	42	30	2444	46	RHB 177	43	27	2567	46
ProAgroTejas	53	33	2734	43	ProAgroTejas	63	31	1655	44
HHB 67 Improved	54	40	2034	44	HHB 67 Improved	53	33	1733	44
Dhanashakti	90	49	2057	48	Dhanashakti	99	52	1504	49
CV (%)	7	13	11	2.7		8	10	14	2.1
Mean	78	42	2731	50		81	40	2191	50
Min	59	35	2161	45		60	29	1737	46
Max	104	52	3532	56		110	57	2753	53

G×E interaction

Significant variability was observed for all the traits (GY, BL, Fe, Zn) in both the trials (Table 3). G×E interaction was significant for all the trails in both the trials. The proportion of G×E variability component, relative to variability due to hybrid component, was in the sequence: 50% flower (14%) <Fe (33%) <Zn(54%) <GY(71%) in trial-2016, and was in the sequence: Fe (21%) <50% flower (33%) <Zn(37%) <GY(86%) in trial-2017. This implies that Fe had lower G×E interaction than that of Zn. Likewise, for GY, G×E interaction component was higher in magnitude and also larger than both the micronutrients and BL. Earlier studies in pearl millet reported significant G×E interaction across the seasons (Gupta

et al., 2009; Velu *et al.,* 2011; Govindaraj *et al.,* 2013; Kanatti *et al.,* 2014a, 2016a). Further, multi-location evaluation of two sets of pearl millet hybrids by Kanatti *et al*. (2014b), reported higher G×E interaction relative to those due to differences among the hybrids denser in Zn than Fe content. Similar results of higher G×E interaction for Zn content than Fe content have been reported in maize (Prasanna *et al.,* 2011). This may apparently imply greater sensitivity and differential response of hybrids for Zn than Fe content to changes in the soil and climatic conditions. And this could also be due to proportionately larger differences among the hybrids for Fe content (59-104 mg kg^{-1} in 2016 and 60-110 in 2017) than for Zn content (35-52 mg kg^{-1} in 2016 and 29-57 mg kg^{-1} in 2017).

Table 3. *Mean square for Fe, Zn, GY and BL in 2016 and 2017 multilocation trials*

		Mean square							
		2016							
Source of variation	**df**	**Fe**		**Zn**		**GY**		**BL**	
Environments (E)	2	12816	**	228	**	39227229	**	702	**
Replications /E	3	132	**	176	**	112573		0.8	
Hybrids (G)	20	1438	**	172	**	794091	**	85	**
G×E	40	237	**	46		281505	**	6	**
Error	60	30		29		83499		1.8	
CV%		7		13		11		3	
		2017							
Source of variation	**df**	**Fe**		**Zn**		**GY**		**BL**	
Environments (E)	2	592	**	444	**	1657465	**	216	**
Replications /E	3	104	*	83	**	14534		14.5	**
Hybrids (G)	17	1611	**	390	**	701417	**	49	**
G×E	34	166	**	72	**	300862	**	8	**
Error	51	34		16		94493		1	
CV%		8		10		14		2	

Table 4. *Genetic parameters and heritability for Fe, Zn, GY and BL in 2016 and 2017 multi-location trials*

Variance components	2016				2017			
	Fe	Zn	GY	BL	Fe	Zn	GY	BL
Vg	217	22	101932	13	252	58	83957	7.5
Vp	257	30	148849	14	279	70	134100	8.8
Vg×e	103	8	99003	2	66	28	103185	3.5
Ve	30	29	83499	2	34	16	94493	1.1
H2 (bs)	0.85	0.74	0.68	0.93	0.90	0.83	0.63	0.85

Heritability of traits

High heritability was observed in both the trials (2016 and 2017) for Fe (85%, 93%) and Zn (74%, 83%) densities and also BL (93%, 85%) (Table 4). Previous studies on pearl millet found that broad sense heritability (h_2bs) varied from 65 to 86% for Fe density and 65 to 84% for Zn density in S1 genotypes of open-pollinated varieties (Gupta *et al.,* 2009; Kanatti *et al.,* 2015) and narrow sense heritability (h_2ns) varied from 45 to 80% for Fe and 45 to 86% for Zn (Velu, 2006; Govindaraj *et al.,* 2016b; Kanatti *et al*., 2016b). Seasons had significant impact on heritability estimates for grain Fe and Zn: high $h_2$bs for Fe (81%) and Zn (70%) in rainy season but moderate in summer (Fe 52% and Zn 44%) season crops (Velu, 2006), whereas variances due to interaction of additive gene effects with the environment (A×E) were much smaller than those arising from interaction of dominance effects with the environment (D×E) (Kanatti *et al.*, 2016b). While the grain yield had lower magnitude of heritability compared to micronutrients and BL, it was 68% in trial-2016 and 63% trial-2017, respectively. Earlier studies in pearl millet reported high heritability (Govindaraj *et al.,* 2010; Sumathi *et al.,* 2010) as well as low heritability (Subi and Idris, 2013) for grain yield.

Correlation among traits

Highly significant and positive correlation was observed between Fe and Zn in 2016 ($r=0.65$, $P<0.01$) and 2017 ($r=0.90$, $P<0.01$) trials (Fig. 1). Earlier pearl millet studies also reported the same (Velu *et al.,* 2008a, b; Gupta *et al.,* 2009; Rai *et al.,* 2012; Govindaraj *et al.,* 2012; Govindaraj *et al.,* 2013; Kanatti *et al.*, 2016b). Similarly, positive correlation between Fe and Zn was also observed in sorghum (Ashok Kumar *et al.,* 2010, 2013), maize (Oikeh *et al.,* 2003, 2004b), rice (Stangoulis *et al.,* 2007; Anandan *et al.,* 2011), wheat (Garvin *et al.,* 2006; Peleg *et al.*, 2009; Zhang *et al.,* 2010) and finger millet (Upadhyaya *et al.,* 2011). Genomic studies in wheat (Peleg *et al.,* 2009), rice (Stangoulis *et al.,* 2007), common bean (Blair *et al.,* 2009; Cichy *et al.,* 2009) and pearl millet (Kumar *et al.,* 2016) have identified common and overlapping Quantitative Trait Loci (QTL) for Fe and Zn densities. The existence of highly significant positive association and predominance of additive genetic control (Velu *et al.,* 2011; Govindaraj *et al.,* 2013; Kanatti *et al*., 2014a) for Fe and Zn densities would be helpful for simultaneous genetic improvement of both the traits. Both Fe and Zn showed significant positive correlation with BL (0.62, $P<0.01$; 0.64 $P<0.01$, respectively) in trial-2016 and both traits had non-significant correlation with BL in trial-2017 (Fig. 1). Previous studies in pearl millet reported significant negative (Velu *et al.,* 2008a), significant positive (Gupta *et al*., 2009) and non-significant (Kanatti *et al.,* 2014b) correlation of Fe with BL and non-significant correlation between Zn and BL (Velu *et al*., 2008a; Gupta *et al.,* 2009; Kanatti *et al.*, 2014). This implies that the relationship of Fe and Zn with BL varies with genetic material used in the studies.

Grain yield did not show significant correlation with Fe in both 2016 and 2017 trials (Fig. 1), whereas with Zn it had significant negative correlation ($r=-0.49$, $P<0.05$) only in trial 2017. Earlier studies in pearl millet (Rai *et al.,* 2012; Gupta *et al.,* 2009; Kanatti *et al.,* 2014 a, b) reported significant negative to non-significant correlation with grain yield and the direction and magnitude of correlation varied with type of genetic material and environment. Such associations might have resulted due to the involvement of *iniadi* germplasm as a common source of high Fe and Zn content in both male and female parents, thereby reducing the genetic diversity between the parental lines for traits associated with heterosis for grain yield. This relationship could also be due to natural negative association between genetic factors for these micronutrients and grain yield (Kanatti *et al.,* 2014b), the resolution of this issue merits further studies through selection experiments.

Per se performance of hybrids

In trial-2016, top five hybrids (H3, H8, H10, H13, H14) for *per se* grain yield had 19-45% higher grain yield than control (RHB 177) (Fig. 2). These hybrids had >40% higher Fe content than control and days to 50% flowering ranged from 50-56 days. In trial-2017, top five hybrids (H1, H3, H5, H10, H11) for grain yield *per se* had 3-12% higher yield than that of control (RHB 177) with >40% Fe density and 49-51 days to 50% flowering. These hybrids can be further included in advanced hybrid trials along with promising hybrids to reconfirm location specific performance.

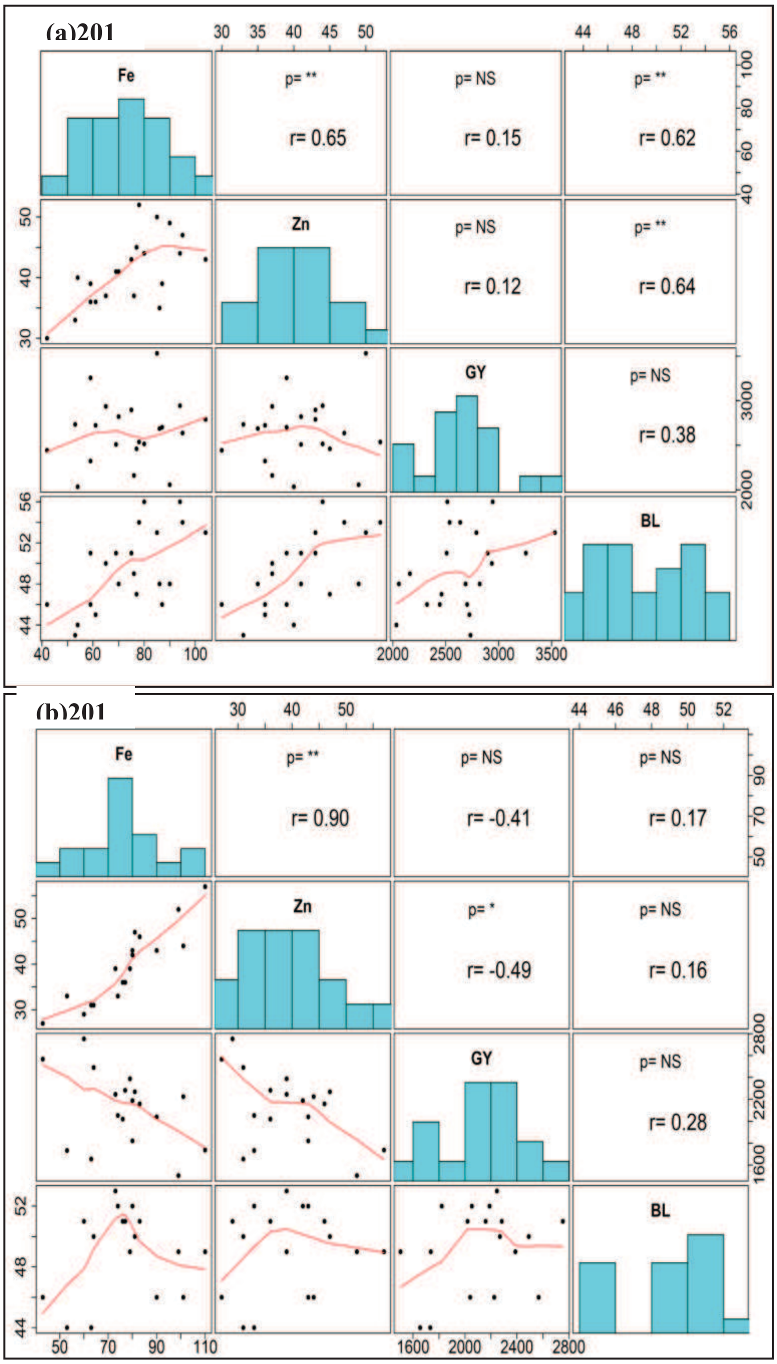

Figure 1. *Correlation among traits in 2016 and 2017 multi-location trials.*

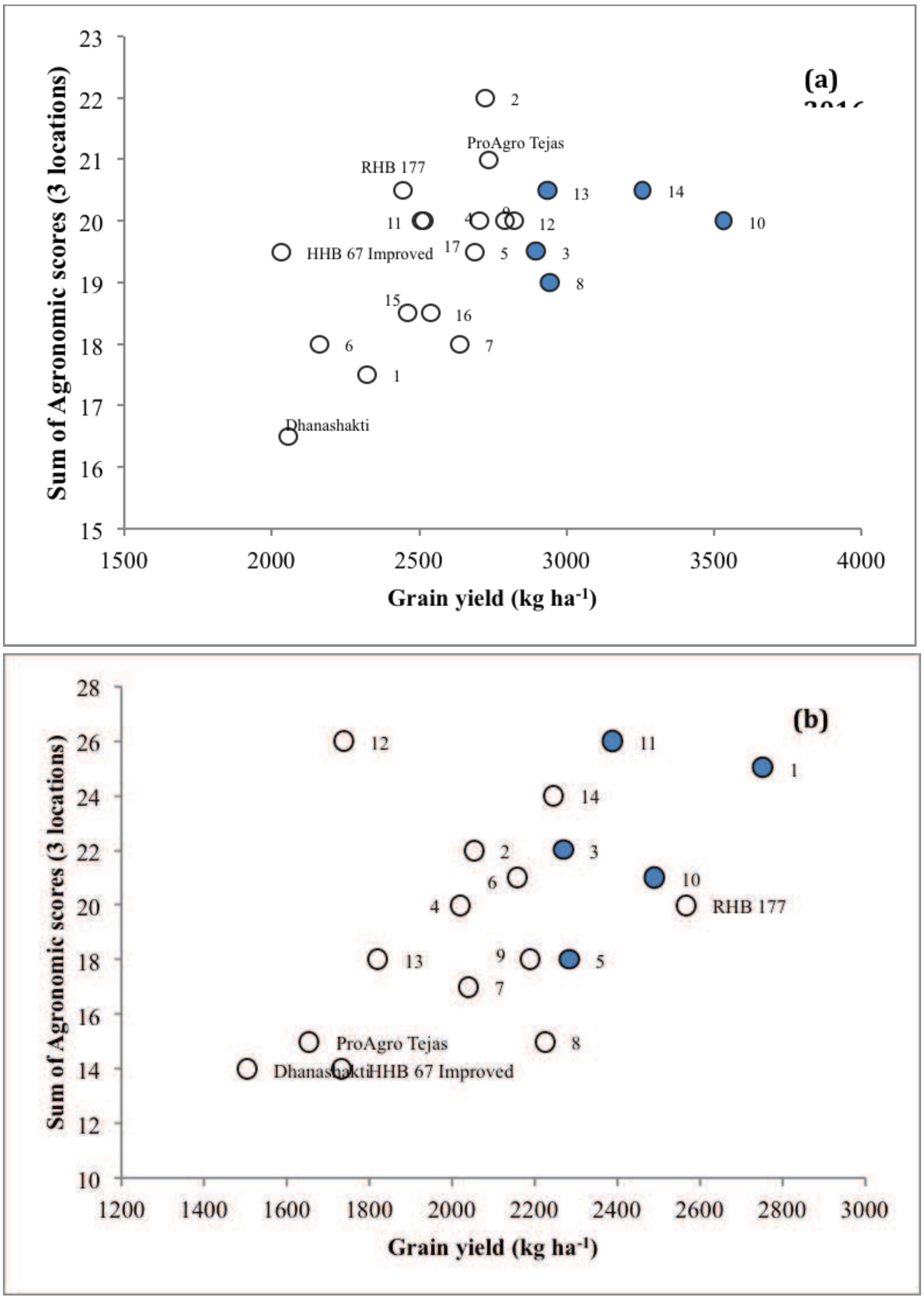

Figure 2. *Scatter plot for grain yield and agronomic score in 2016 and 2017 multi-location trials (solid circles highest top five high-yielding entries).*

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References

Anandan, A., G. Rajiv, R. Eswaran and M. Prakash. 2011. Genotypic variation and relationships between quality traits and trace elements in traditional and improved rice (*Oryza sativa* L.) genotypes. *Journal of Food Science* 76(4): H122-H130.

Ashok Kumar, A., B.V.S. Reddy, B. Ramaiah, K.L. Sahrawat and W.H. Pfeiffer. 2013. Gene effects and heterosis for grain iron and zinc concentration in sorghum [*Sorghum bicolor* (L.) Moench]. *Field Crops Research* 146: 86-95.

Ashok Kumar, A., B.V.S. Reddy, K.L. Sahrawat and B. Ramaiah. 2010. Combating micronutrient malnutrition: Identification of commercial sorghum cultivars with high grain iron and zinc. *Journal of SAT Agricultural Research* 8: 1-5.

Blair, M.W., C. Astudillo, M. Grusak, R. Graham and S. Beebe. 2009. Inheritance of grain iron and zinc content in common bean (*Phaseolus vulgaris* L.). *Molecular Breeding* 23: 197-207.

Cichy, K.A., S. Forster, K.F. Grafton and G.L. HosWeld. 2005. Inheritance of grain zinc accumulation in navy bean. *Crop Science* 45: 864-870.

Gomez, K.A. and A.A. Gomez. 1984. Statistical procedures for agricultural research. 2nd ed. John Wiley & Sons, New York.

Govindaraj, M., K.N. Rai, P. Shanmugasundaram, S.L. Dwivedi, K.L. Sahrawat, A.R. Muthaiah and A.S. Rao. 2013. Combining ability and heterosis for grain iron and zinc densities in pearl millet. *Crop Science* 53: 507-517.

Govindaraj, M., K.N. Rai and P. Shanmugasundaram. 2016b. Intra-population genetic variance for grain iron and zinc contents and agronomic traits in pearl millet. The *Crop Journal* 04(01): 48-54.

Govindaraj, M., K.N. Rai, P. Shanmugasundaram and A.S. Rao. 2012. Efficiency of single plant selection for grain iron and zinc density in pearl millet. *The European Journal of Plant Science and Biotechnology* 6(2): 114-117.

Govindaraj, M., K.N. Rai, W.H. Pfeiffer, A. Kanatti and H. Shivade. 2016a. Energy-dispersive X-ray fluorescence spectrometry for cost-effective and rapid screening of pearl millet germplasm and breeding lines for grain iron and zinc density. *Communications in Soil Science and Plant Analysis* 47(18): 2126-2134.

Govindaraj, M., P. Shanmugasundaram, and A.R. Muthiah. 2010. Estimates of genetic parameters for yield and yield attributes in elite lines and popular cultivars of India's pearl millet. *African Journal of Agricultural Research* 5(22): 3060-3064.

Gupta, S.K., G. Velu, K.N. Rai and K. Sumalini. 2009. Association of grain iron and zinc content with grain yield and other traits in pearl millet (*Pennisetum glaucum* (L.) R.Br.). *Crop Improvement* 36(2): 4-7.

Kanatti, A., K.N. Rai, K. Radhika and M. Govindaraj. 2016a. Tester effect on combining ability and its relationship with line performance *per se* for grain iron and zinc densities in pearl millet. *Crop Science* 56: 689-696.

Kanatti A., K.N. Rai, K. Radhika, M. Govindaraj and A.S. Rao. 2016b. Genetic architecture of open-pollinated varieties of pearl millet for grain iron and zinc densities. *Indian Journal of Genetics and Plant Breeding* 76(3): 299-303.

Kanatti, A., K.N. Rai, K. Radhika, M. Govindaraj, K.L. Sahrawat and A.S. Rao. 2014a. Grain iron and zinc density in pearl millet: combining ability, heterosis and association with grain yield and grain size. *SprigerPlus* 3: 763.

Kanatti, A., K.N. Rai, K. Radhika, M. Govindaraj, K.L. Sahrawat, K. Srinivasu and H. Shivade. 2014b. Relationship of grain iron and zinc content with grain yield in pearl millet hybrids. *Crop Improvement* 41(1): 91-96.

Kanatti, A., K. Radhika, V. Padma, P. Janila, M. Govindaraj and K.N. Rai. 2015. Intra-population variability for grain iron and zinc densities in commercial open-pollinated varieties of pearl millet. *International Journal of Economic Plants* 2(4): 171-174.

Kumar, S., C.T. Hash, N. Thirunavukkarasu, G. Singh, V. Rajaram, A. Rathore, S. Senapathy, M.D. Mahendrakar, R.S. Yadav and R.K. Srivastava. 2016. Mapping quantitative trait loci controlling high iron and zinc content in self and open pollinated grains of pearl millet [*Pennisetumglaucum* (L.) R. Br.]. *Frontiers in Plant Science* 7(1636): 01-16.

National Family Health Survey (NFHS). 2016. NFHS-4-fact sheets for key indicators. International Institute for Population Sciences, Mumbai, India.

Oikeh, S.O., A. Menkir, B. Maziya-Dixon, R. Welch and R.P. Glahn. 2003. Genotypic differences in concentration and bioavailability of kernel-iron in tropical maize varieties grown under field conditions. *Journal of Plant Nutrition* 26(10&11): 2307-2319.

Oikeh, S.O., A. Menkir, B. Maziya-Dixon, R. Welch and R.P. Glahn. 2004b. Assessment of iron bioavailability from twenty elite late-maturing tropical maize varieties using an in vitro digestion/Caco-2 cell model. *Journal of the Science of Food and Agriculture* 84: 1202-1206.

Oikeh, S.O., A. Menkir, B. Maziya-Dixon, R. Welch, R.P. Glahn and G. Jr. Gauch. 2004a. Environmental stability of iron and zinc concentrations in grain of elite early-maturing tropical maize genotypes grown under field conditions. *Journal of Agricultural Science* 142: 543-551.

Paltridge, N.G., L.J. Palmer, P.J. Milham, G.E. Guild and J.C.R. Stangoulis. 2012. Energy-dispersive X-ray fluorescence analysis of zinc and iron concentration in rice and pearl millet grain. *Plant and Soil* 361: 251-260.

Peleg, Z., I. Cakmak, L. Ozturk, A. Yazici, Y. Jun, H. Budak, A.B. Korol, T. Fahima and Y. Saranga. 2009. Quantitative trait loci conferring grain mineral nutrient concentrations in durum wheat × wild emmer wheat RIL population. *Theoretical and Applied Genetics* 119: 353-369.

Parthasarathy Rao, P., P.S. Birthal, B.V.S. Reddy, K.N. Rai, and S. Ramesh. 2006. Diagnostics of sorghum and pearl millet grains-based nutrition in India. *Inernational Sorghum and Millets Newsletter* 46: 93-96.

Prasanna, B.M., S. Mazumdar, M. Chakraborti, F. Hossain, K.M. Manjaiah, P.K. Agrawal, S.K. Guleria and H.S. Gupta. 2011. Genetic variability and genotype × environment interactions for kernel iron and zinc concentrations in maize (*Zea mays*) genotypes. *Indian Journal of Agriculture Sciences* 81(8): 704-711.

Rai, K.N., M. Govindaraj and A.S. Rao. 2012. Genetic enhancement of grain iron and zinc content in pearl millet. *Quality Assurance and Safety of Crops & Foods* 4: 119-125.

SAS Institute Inc. 2015.SAS/STAT® 14.1 User's Guide. Cary, NC: SAS Institute Inc.

Snedecor, G.W. and W.G. Cochran. 1989. Statistical Methods, Eighth Edition, Iowa State University Press.

Stangoulis, J.C.R., B.L. Huynh, R.M. Welch, E.Y. Choi and R.D. Graham. 2007. Quantitative trait loci for phytate in rice grain and their relationship with grain micronutrient content. *Euphytica* 154: 289-294.

Subi, M.I.M. and A.E. Idris. 2013. Genetic variability, heritability and genetic advance in pearl millet (*Penisetum glaucum* [L.] R. Br.) genotypes. *British Biotechnology Journal* 3(1): 54-65.

Sumathi, P., S. Madineni and P. Veerabadhiran. 2010. Genetic variability for different biometrical traits in pearl millet genotypes (*Pennisetum glaucum* LR BR.). *Electronic Journal of Plant Breeding* 1(4): 437-440.

Upadhyaya, H.D., S. Ramesh, S. Shivali, S.K. Singh, S.K. Varshney, N.D.R.K. Sarma, C.R. Ravishankar, Y. Narasimhudu, V.G. Reddy, K.L. Sahrawat, T.N. Dhanalakshmi, M.A. Mgonja, H.K. Parzies, C.L.L. Gowda and S. Singh. 2011. Genetic diversity for grain nutrients contents in a core collection of finger millet (*Eleusine coracana* (L.) Gaertn.) germplasm. *Field Crops Research* 121: 42-52.

Velu, G. 2006. Genetic variability, stability and inheritance of grain iron and zinc content in pearl millet (*Pennisetum glaucum* (L.) R.Br.). Ph.D., Thesis, Tamil Nadu Agricultural University, Coimbatore, India.

Velu, G., K.N. Rai and K.L. Sahrawat. 2008a. Variability for grain iron and zinc content in a diverse range of pearl millet populations. *Crop Improvement* 35(2): 186-191.

Velu, G., K.N. Rai., K.L. Sahrawat and K. Sumalini. 2008b. Variability for grain iron and zinc contents in pearl millet hybrids. *Journal of SAT Agricultural Research* 6.

Velu, G., K.N. Rai, V. Muralidharan, T. Longvah and J. Crossa. 2011. Gene effects and heterosis for grain iron and zinc density in pearl millet (Pennisetumglaucum (L.) R. Br). *Euphytica* 180: 251-259.

Yadav, O.P, K.N. Rai, B.S. Rajpurohit, C.T. Hash, R.S. Mahala, S.K. Gupta, H.S. Shetty, H.R. Bishnoi, M.S. Rathore, A. Kumar, S. Sehgal and K.L. Raghvani. 2012. Twenty-five Years of Pearl Millet Improvement in India. All India Coordinated Pearl Millet Improvement Project, Jodhpur, India

Zhang, Y., Q. Song, J. Yan, J. Tang, R. Zhao, Y. Zhang, Z. He, C. Zou and I. Ortiz-Monasterio. 2010. Mineral element concentrations in grains of Chinese wheat cultivars. *Euphytica* 174: 303-313.

DNA marker technology for conservation of plant genetic resources in Kuwait

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Abstract

The native plants of Kuwait demonstrate remarkable adaptation to the harsh desert climate and ecosystem. Unfortunately, the native plant biodiversity of Kuwait is rapidly depleting over the recent years due to several anthropogenic activities. The understanding of genetic variation in the community is essential for the establishment of effective and efficient conservation practice for desert native plants. We employed the techniques of inter simple sequence repeat (ISSR), randomly amplified polymorphic DNA (RAPDs), sequence related amplified polymorphism (SRAP) and genotyping by sequencing (GBS) for the assessment of genetic diversity of native plant species of Kuwait. We chose Rhanterium eppaposum Oliv. as a model system. The plant is economically and medicinally important and is being destroyed in the country due to anthropogenic interventions. Samples of the plant species were collected from designated locations in Kuwait and subjected to PCR based marker analysis. The four marker systems differed in their discriminatory power but produced comparable results in terms of genetic diversity.

Introduction

Plant genetic resources are the vital elements in sustainable management food, agriculture and forestry. Plant genetic resources comprise the present genetic variation that is potentially useful for the future of humankind. These resources include traditional varieties, landraces, commercial cultivars, hybrids, and other plant materials developed through breeding; wild relatives of crop species; and others that could be used in the future for either agriculture or environmental benefits.

The loss of genetic resources and, as a consequence, the genetic diversity they represent, is a widespread reality. It is therefore vitally important that we develop adequate and effective strategies to conserve these genetic resources (Gle´min *et al.,* 2001). We need to build further on our knowledge of genetic diversity and introduce novel and powerful approaches that will eventually lead to a cost-effective identification of useful genes in germplasm. An effective use of genetic resources will be an important prerequisite for their sustainable conservation.

Humans are now altering the Earth's natural environment and destroying biodiversity at a rate and extent, which are unprecedented in human history. As a result, the economic and cultural life of many societies is faced with substantial threats. In Kuwait such impacts on biodiversity are increasing rapidly and on such a wide scale, that they are threatening the nation's foundation for sustainable development (Bo¨er and Sargeant, 1998). Kuwait does not have a high biodiversity heritage, however, the small numbers of 374 plant species are highly resilient to salt, drought and heat stress. Thus, it is vital that its scarce but highly adapted biological resources are conserved (Omar and Roy, 2010).

Molecular marker technologies are the most advanced and, possibly, the most effective means for understanding the basis of genetic diversity (Mondini *et al.,* 2009). A molecular marker is a measurable character that can detect variation in a DNA sequence. They are efficient and accurate tools with which genetic variation can ultimately be identified and assessed in a rapid and thorough manner. Phylogenetic relationships can be determined, redundancies in a germplasm bank can be identified, and new genes can be discovered.

Many types of molecular markers with different properties exist. A good marker is polymorphic, reproducible, codominant, discriminating and inexpensive. The marker systems that are now being progressively developed and also have shifted from the first and second generation marker systems, such as randomly amplified polymorphic DNA (RAPDs), inter simple sequence repeats (ISSRs) and sequence related amplified polymorphism (SRAPs), to the next generation marker systems, including single nucleotide polymorphisms (SNPs), and Genotyping by Sequencing (GBS) (Lateef, 2015). In view of above we utilized four types of molecular markers viz. ISSRs, RAPDs, SRAPs and GBS to assess the genetic diversity of the national plant of Kuwait - *Rhanterium eppaposum* Oliv.

Materials and methods

Sample collection and DNA isolation

Leaf specimens of *R. eppaposum* were collected throughout the growing season depending upon the availability. The plant was sighted and collected at locations namely Kabd, Maqwa, Salmi, Sabah Al Ahmed Nature Reserve, Om Qaser, Al Maqwa, Mina Abdullah, Nuwaiseeb, Sulaibiya, Al Wafra and Al Abdally. Leaf samples were used to isolate DNA using the GenElute™ Plant Genomic DNA Miniprep Kit (Sigma, St. Louis, MO), as per the manufacturer's instructions. DNA purity (Absorbance ratio A260/A280) and quantity (Absorbance at 260 nm) were measured by the Nanodrop (Thermo Scientific, Carlsbad, CA) and Qubit fluorometer (Thermo Fisher Scientific, Carlsbad, CA).

Twenty-four random RAPD primers, twenty three SRAP primers and seventeen ISSR primers were used for PCR with 20-100 specimens as per the protocol of Al Kaab *et al.* (2016). GBS was done through the most advanced methodology based on next generation sequencing in the University of Minnesota. Data were analyzed employing the GenAlEx 6.5 software (Peakell and Smouse, 2012) and POPGene v 1.32 (Yeh and Boyle, 1997) softwares.

Results and discussion

The molecular markers RAPD, SRAP, ISSR and GBS were found useful for the study of the genetic diversity of the present *R. eppaposum* genotypes, and the numbers of markers tested had satisfactory discriminating powers (Table 1).

The SRAP markers produced total 128 bands out of which 114 were polymorphic. A PIC ~ 0.5 was obtained with these primers; however, their discriminatory index was < 0.5. AMOVA partitioning of genotypes returned with maximum partitioning of 73% within the populations, whereas 27% variation existed among the populations (Fig 1). A PhiPTof 0.271 (P=0.001) was also recorded. SRAP markers are simple, inexpensive, and effective for producing genome-wide fragments with high reproducibility and versatility (Li and Quiros, 2001). Like other dominant markers, SRAPs have demonstrated the ability to elucidate genetic variation at a variety of taxonomic levels (Uzun *et al.,* 2011).

Table 1. *Comparison of four molecular markers used for genetic diversity analysis of Rhanterium eppaposum*

Type	# Primers	NSB	NPB	PIC	H'	PP
RAPD	24	70	68	0.61	0.16	97
SRAP	23	128	114	0.43	0.20	89
ISSR	17	195	182	0.31	0.31	93
GBS	PstI+BtgI	11,231				

The RAPD markers produced polymorphic amplification profiles with a total of 68 polymorphic loci with 97% polymorphism. The PIC of RAPD markers was maximum (0.61); however the *H'* value was minimum (0.16). The AMOVA analysis revealed higher variation within and lower among the populations with a PhiPT of 0.278 (P=0.001)**.** RAPDs have shown systematic utility in discerning between higher-order relationships (Williams *et al.,* 1990); however, studies have shown inconsistencies in data replication (Jones *et al.,* 1997; Costa *et al.*, 2016).

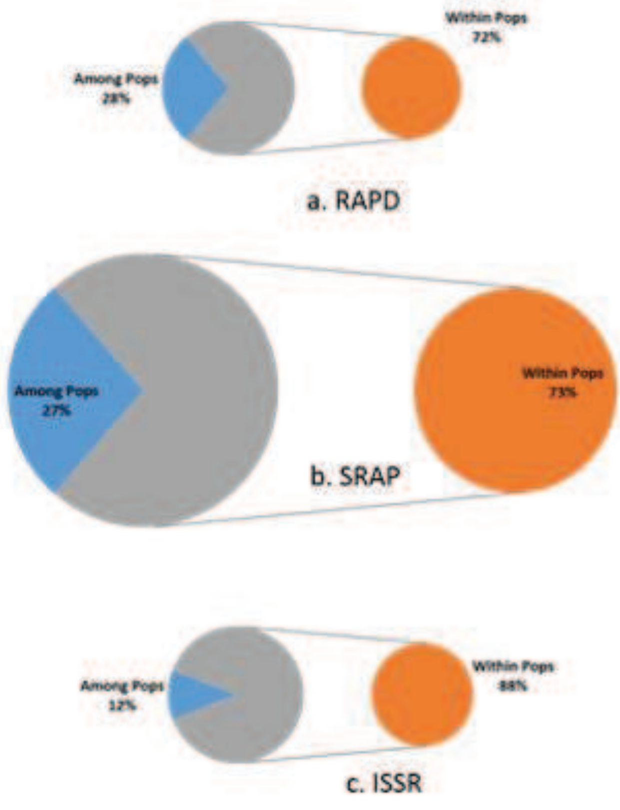

Figure 1. *AMOVA partioning of R. eppaposum genotypes by (a) RAPD; (b) SRAP and (c) ISSR markers.*

The ISSR primers produced amplification profiles in all the samples, and identified 182 polymorphic loci with 92.8%. polymorphism. Polymorphic information content (0.31) and Shannon's diversity index (0.30) indicated a high discriminatory power of the ISSR primers. The AMOVA partitioning resulted into 12% variation among the populations and 78% variation with the population (PhiPT of 0.116; P=0.001). ISSR markers are reproducible, cost-effective and capable of detecting high level of polymorphism. A good genetic marker is defined by its high rate of polymorphism and the ability to generate multi-locus data from the genome under study. The ISSR markers make use of microsatellite sequences that are inherently highly variable and ubiquitously distributed across the genome, at the same time achieving higher reproducibility (Ng and Tan, 2015).

Our studies demonstrated that GBS is a powerful tool for investigating genetic diversity in the native plant species of Kuwait. *R. eppaposum* is a non model species on which molecular studies are lacking internationally. Maximum number of genomic variants (11,231) were obtained through this method. GBS is conceptually simple, but in practice involves many steps using a range of molecular biology skills and requiring bioinformatics analyses (Fu *et al.,* 2014; Baral *et al.,* 2018).

Conclusion

The molecular markers RAPD, SRAP, ISSR and GBS have been found useful for the study of the genetic diversity of *R. eppaposum*. Of the markers studied, GBS technique proved to be the most efficient at discriminating genotypes of *R. eppaposum* as this approach can technically lead to the discovery of thousands of SNPs in one single experiment. Moreover, it can be used for plants that do not have the reference genome available. However, the level of polymorphism revealed by SRAP, ISSR and RAPD could also be appropriate options since they are easier to implement and less costly. Among the latter, ISSR seems to be the best choice as it has a high discriminatory power and stronger replicability. The high genetic diversity within the populations is encouraging for population expansion of *R. eppaposum.*

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References

Al-Kaab, D.H., M.S. Hamdalla, I. Dweikat and J.N. Al-Saedi. 2016. Estimation of the degree of diversity for some Iraqi wheat varieties through ISSR, SRAP and RAPD markers. *American Journal of Experimental Agriculture* 11: 1-11.

Baral, K., B. Coulman, B. Biligetu and Y.B. Fu. 2018. Genotyping-by-Sequencing enhances genetic diversity analysis of crested wheatgrass [*Agropyron cristatum* (L.) Gaertn.]. *International Journal of Molecular Sciences* 19: 2587.

Bo¨er, B. and D. Sargeant. 1998. Desert perennials as plant and soil indicators in Eastern Arabia. *Plant Soil* 199: 261-266.

Costa, R., G. Pereira, I. Garrido, M.M. Tavares-de-Sousa and F. Espinosa. 2016. Comparison of RAPD, ISSR, and AFLP molecular markers to reveal and classify Orchardgrass (*Dactylis glomerata* L.) germplasm variations *PLOS ONE* 11: e0152972. https://doi.org/10.1371/journal.pone.0152972

Fu, Y.B., B. Cheng and G.W. Peterson. 2014. Genetic diversity analysis of yellow mustard (*Sinapis alba* L.) germplasm based on genotyping by sequencing. *Genetic Resources and Crop Evolution* 61: 579-594.

Gle´min, S., T. Bataillon, J. Ronfort, A. Mignot and I. Olivieri. 2001. Inbreeding depression in small populations of self incompatible plants. *Genetics* 159: 1217-1229.

Jones, C., K. Edwards, S. Castaglione, M. Winfield, F. Sala, C.Van Dewiel, G. Bredemeijer, B. Vosman, M. Matthes, A. Daly, R. Brettschneider, P. Bettini, M. Buiatti, E. Maestri and A. Malcevschi. 1997. Reproducibility testing of RAPD, AFLP and SSR markers in plants by a network of European laboratories. *Molecular Breeding* 3: 381-390.

Lateef, D.D. 2015. DNA marker technologies in plants and applications for crop improvements. *Journal of Biosciences and Medicine* 23: 7-18.

Li, G. and C.F. Quiros. 2001. Sequence-related amplified polymorphism (SRAP), a new marker system based on a simple PCR reaction: Its application to mapping and gene tagging in Brassica. *Theoretical and Applied Genetics* 103: 455-461.

Mondini, L., A. Noorani and M.A. Pagnotta. 2009. Assessing plant genetic diversity by molecular tools. *Diversity* 1: 19-35.

Ng, W.L. and S.G. Tan. 2015. Inter-simple sequence repeat (ISSR) markers: are we doing it right. *ASM Science Journal* 9: 30-39.

Omar, A.S. and W.Y Roy. 2010. Biodiversity and climate change in Kuwait. *International Journal of Climate Change and Structure* 2: 68-83.

Peakall, R. and P.E. Smouse. 2012. GenAlEx 6.5: genetic analysis in Excel. Population genetic software for teaching and research—an update. *Bioinformatics* 28: 2537-2539.

Perez, T., J. Albornoz, and A. Dominguez. 1998. An evaluation of RAPD fragment reproducibility and nature. *Molecular Ecology* 7: 1347-1357.

Uzun, A., T. Yesiloglu, Y. Aka Kacar, O. Tuzcu, O. Gulsen, G. Kafa, B. Yildirim and S. Anil. 2011. Genetic diversity of grapefruit and pummelo accessions based on SRAP markers. *Acta Horticulturae* 892: 49-56.

Williams, J., A. Kubelik, K. Livak, J. Rafalski and S. Tingey. 1990. DNA polymorphisms amplified by arbitrary primers are useful as genetic markers. *Nucleic Acids Research* 18: 6531-6535.

Yeh, F.C., and T.J.B. Boyle. 1997. Population genetic analysis of co-dominant and dominant markers and quantitative traits. *Belgian Journal of Botany* 129: 157-163.

Theme 6: Sustainable Intensification and Diversification in Drylands - Arid horticulture, Aquaculture and Protected Agriculture

Lead Lectures and Rapid Presentations

Prospects of protected horticulture in arid and semi-arid regions of India

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Extended Summary

It is a proven fact that protected cultivation is a sound technology to enhance productivity and quality of horticultural crops by providing a technical solution to manage major biotic and abiotic stresses usually encountered under open field cultivation of some high value crops. In the last two and half decades, the area under protected cultivation in various parts of the world like countries of the Mediterranean region, China, South-East Asia, and Africa has increased, adopting different modes of protection shelters for cultivation.

Presently, China is tone of the global leaders in protected cultivation, with an area of around 3.5 mha out of which nearly 96% is only being used for commercial cultivation of fresh vegetables and hybrid seed production. Although, like China, the growth in the use of protected cultivation technologies has also been observed in other developing countries of Asia and Africa, but the success rate has greatly varied. Partly it is because the designs of protected structures did not match the prevailing agro-climatic conditions of the regions. The success of protected cultivation, which emerged from northern Europe, has stimulated its development in other parts of the world. But, it has been now clearly established that mere introduction of a technology from some other parts of the world, without adapting it to the local agro-climatic conditions of the region, cannot be a success. Every technology requires further research, development, extension, training, to adept it to local agro-climatic and socio-economic conditions and protected horticulture technologies are no exception.

India with its diverse agro-climatic conditions has shown an overall growth of around 75,000 ha area under protected cultivation in different forms in the last two and half decades. But the success has varied significantly depending upon the prevailing climatic conditions of various regions and seasons. In North Indian plains, protected cultivation technologies faced a tough challenge of harsh climatic conditions whereas, other areas like Bangalore, Pune and some parts in North-Eastern States, with mild climatic conditions, have achieved high success rate. Basically, the growth of protected cultivation technology in India occurs due to favorable Government policies in terms of subsidies under various schemes with various States, not necessarily due to the perception of the technical benefits of the technology. The technical know-how for adoption of protected cultivation technology under Indian conditions was not there to start with. With time, research and development work carried out by various public sector institutions, in collaboration with developed countries, gradually led to modifications in technical designs of different protected structures suitable for specific needs of prevailing climatic conditions of India. This led to expansion in the area and production under protected cultivation.

Future prospects of protected cultivation in arid and semi-arid regions

An agro-climatic condition of a region is a highly significant factor for the success of any protected cultivation technology. The basic purpose of protected cultivation in arid and semi-arid regions is to address the problems of high temperature fluctuations, low soil fertility and organic matter content, water scarcity, high wind velocity and high solar radiation, peculiar to these regions. In spite of the climatic constraints, these regions offer opportunity to grow high-quality and high-value horticultural crops. The low humidity prevailing there prevents disease and pest epidemics to occur. Taking the advantage of the climate, the existing protected cultivation structures can be modified with respect to the crops and resources available in these regions. Local availability of any crop produce is the first preference compared to a product, which is transported from distant regions, as the former is cheaper and fresh and also meets the local taste and experience. With the socio-economic developments in urban and peri-urban areas and creation of transport facilities, the market access of quality produce raised under protected cultivation has increased.

Protected cultivation of horticultural crops faces important challenges and offers opportunities under arid and semi-arid regions as given below:

Major challenges:

- In arid and semi-arid regions, the extremes of temperatures limit crops that can be cultivated in summer months because of scorching sun and heat storms. During winter months, high diurnal temperature differences create another challenging situation.
- Extreme levels of radiations encountered in the region reduce the adaptability of new crops although these may be more in demand in the market and economical.
- Erratic and very low rainfall (below 200-500 mm) is common feature in the arid/semi-arid region and every 4-5 years drought occurs. Harvesting rainwater and its utilization in best way to manage this challenge.
- The ground water available for irrigation is limited and is of varied quality; generally saline and brackish and in most parts it is still underutilized due to lack of suitable technologies.
- The soils have very low level of organic carbon (i.e. $<0.2\%$ only) and sandy loam to loamy structure having low water holding capacity becomes less productive for crops.
- The high temperature and low vegetation cover in these regions increases the chances of dust storms of high wind velocity causing significant loss to the structure and crops grown there in.

Opportunities:

- The low humidity prevailing in the region is unfavorable for major disease and pest survival. Low vegetation cover also restricts the space for pathogen survival on alternate hosts during non-crop season. Since the arid and semi-arid areas are less prone to major fungal, bacterial and viral diseases, they are of value for protected cultivation of horticultural crops.

- In the western parts of India, with major arid and semi-arid areas, developments are occurring in market access for the disposal of high quality produce on good price. These include:
    - *Local network of roads:* An excellent network of roads is available in these regions for fast transportation of the commodities either to seaports or to international airport located at Jaipur and Ahmedabad.
    - *Dedicated freight corridor:* A dedicated corridor of road and rail network is under development, starting from National Capital to western coastlines of Kandla and Mumbai. This will favor export.
    - *Proposed dry ports in arid region:* A dry port near Jodhpur and one proposed in Chitalwania tehsil of Jalore district are going to become a boom in agriculture enterprise specifically for commodities grown in the region. Sanitized protected cultivation can contribute to meeting the global demand of high quality safe produce of horticultural crops.
- *Vast availability of eroded/degraded lands:* A large track of eroded/degraded land is available in arid and semi-arid regions that can be profitably used for protected cultivation of horticultural crops without needing the diversion of good arable land for this purpose.

Suitable protected cultivation structure for arid/semi-arid regions

In view of the challenges and opportunities for protected cultivation in arid/semi-arid regions, following structures can fit well for successful hi-tech horticulture. Of these, one can select the one specifically suited for crops to be grown (Table 1).

1. Shade net-houses
2. Modified insect proof net-houses
3. Naturally ventilated green-houses
4. Walk-in tunnels
5. High tunnels
6. Plastic low tunnels
7. Temporary plastic walls
8. Plastic mulches

Water management is the most crucial part of the protected cultivation. Drip and micro-sprinkler system fits well in the model; moreover harnessing of solar power for operating the irrigation system can be the added advantage in promoting protected cultivation in western regions. Like design modifications, irrigation systems can also be modified e.g. to have white colour drip lines and laterals in place of existing black colour as white lines will be less affected by high temperature and radiation and will reduce the rise in the temperature of irrigation water running through laterals during peak summer months.

Diversification of use of protected structures in arid/semi-arid regions

Plastic high tunnel can be used for better post harvest drying, as it acts as a protected site and operates like a solar dryer with ventilation. The open sun drying under field reduces the value of the produce by excessive loss of moisture and discolouration, besides getting microbial contamination if drying were done on mud (*Kachcha)* platforms. Drying of *nagauri methi* (green special quality fenugreek), other vegetable crops, *panchkuta, kachri, heena* leaves etc. are potential uses.

Table 1. *Suitable structures for protected cultivation of different horticultural crops in arid and semi-arid regions*

#	Protected structure	Suitable crop	Season
1	Shade net-houses	Leafy and root vegetables; tuberose and green fillers among flowers	Peak summer months (April to August)
2	Modified insect proof net houses	Tomato, cucumber, capsicum, okra, brinjal, other cucurbits	Throughout the year
3	Naturally ventilated green houses	Tomato, cucumber, capsicum	September to March
4	Plastic low tunnels	Mainly cucurbits, strawberry, French bean	December to February
5	Temporary plastic walls	Vegetables, seed spices like cumin	Mid December to mid January
6	Plastic mulches	All kind of vegetables and fruit orchards	Throughout the year

Conclusion

Protected cultivation of some specific agricultural commodities is an innovative idea in agriculture. Gradually, the technologies have now got modernized, particularly with the developments in polymer science. The present scenario of global marketing of produce and local growing is the key to promote these technologies for the benefit of the farmers of the resource-scarce regions. The arid and semi-arid regions are having their uniqueness for producing commodities, which are very much adapted to prevailing agro-climatic conditions. Hence, intervention through protected cultivation will reduce the risk of climatic vagaries and will also expand the cultivation duration of these crops. The prospects of protected cultivation in these regions are very high not only on normal lands but also on eroded and degraded lands. Besides, some of the structures can also be used for drying of quality produce. Protected cultivation for arid regions needs to be expanded under proper technical guidance and also to be carried in a phased manner. The success of a technology solely depends upon the profits farmers might get and protected cultivation technologies offers immense scope of increasing farmer's income in the arid/semi arid regions.

Horticulture based diversification: An option for enhancing farmers' income in drylands

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Abstract

The projected population of India is likely to reach nearly 1.74 billion by 2050. To feed this population there would be a demand of some 199 million tons (Mt) of vegetables and 146 Mt of fruits. Arid horticulture not only ensures sustainable return from the field but it also, to some extent, helps in combating global energy crisis by maximum utilization of natural resources like land, light and water. Considerable area has come up under fruits like aonla (Emblica officinalis), ber (Ziziphus mauritiana), pomegranate (Punica granatum), custard apple (Annona squamosa), fig (Ficus carica), date palm (Phoenix dactylifera), phalsa (Grewia subinaqualis), tamarind (Tamarindus indica), bael (Aegle marmelos), kinnow etc. in different parts of the country. Several drought hardy fruit crops like Capparis decidua, Salvadora oleoides, Cordia myxa, Cordia gharaf, Zizyphus nummularia, Z. rotundifolia and Z. mauritiana are suitable for the areas receiving rainfall <300 mm. Besides providing fruits, these plants produce moisture laden nutritious leaves for animals. Several other fruits such as aonla, pomegranate, bael, date palm, tamarind can be grown in the area having irrigation facilities. The other important fruit crops, which can be grown along with ber in arid regions as component tree, are aonla (in frost-free area), phalsa, karonda (Carissa carandas), goonda/lasora (Cordia myxa), mulberry (Morus sp.), fig (Ficus sp.), bael etc. In semi-arid regions, the suitable component crops with ber are custard apple, wood apple (Feronia limonia), bael, aonla, guava (Psidium guajava), mahua (Madhuca indica) and chironji (Buchania lanzan). Among the vegetable crops, cucurbits like mateera (Citrullus lanatus), ridge gourd (Luffa acutangula), sponge gourd (Luffa cylindrica), bottle gourd (Lagenaria siceraria), long melon (Cucumis melo var. utilissimus), snap melon (Cucumis melo var. momordica), round melon (Parecitrullus fistulosus), kachri (Cucumis spp.) and legumes such as clusterbean (Cyamopsis tetragonoloba) and cowpea (Vigna unguiculata) can be taken successfully. The interest of farmers in adoption of kinnow has increased tremendously due to higher yield potential, better storage life and demand in the market, besides onion, potato, pomegranate, bael, aonla etc. The fertigation and crop regulation are crucial factors in determining productivity. In light of the evidences outlined in this paper, it is clear that alternative farming system involving arid horticulture crops (perennial as well as annual intercrops) stabilizes income, minimizes risks and sustains production under arid ecosystem without ill impact on ecology.

Introduction

The projected population of India is likely to range between 1.64 and 1.74 billion by 2050, when the world population is likely to reach 9 billion. To feed this population, the estimated demands by 2050 are likely to be 199 million tons (Mt) vegetables and 146 Mt fruits.

Similarly, the demand for another important horticultural commodity, i.e. seed spices, by 2050 is predicted to be three folds of the current level. However, the land available for agriculture is shrinking due to increase in population, urbanization and industrial growth. A large chunk of marginal and waste land is available in arid and semi-arid regions, which can be exploited for cultivation of horticultural crops so as to meet the growing demand.

In India, a vast land resource of 39.54 mha (~12% of the total geographical area) and 174 mha (~53% of the total geographical area) falls under arid and semi-arid regions, respectively (Fig. 1). The arid agro-ecoregion encompasses south-western parts of the states of Punjab and Haryana, western parts of Rajasthan, and Kutchh peninsula and northern part of Kathiawar peninsula in Gujarat State. The semi-arid regions include Karnataka, interior Tamil Nadu, western Andhra Pradesh and central Maharashtra. These regions are characterized by extremes of high and low temperatures, low and erratic rainfall, low relative humidity, high potential evapo-transpiration, high sunshine, abundant solar energy and high wind speed, particularly, during summers. These regions consist of vast sandy and other wastelands, which have productivity constraints such as salinity in soil and irrigation water, and low soil fertility.

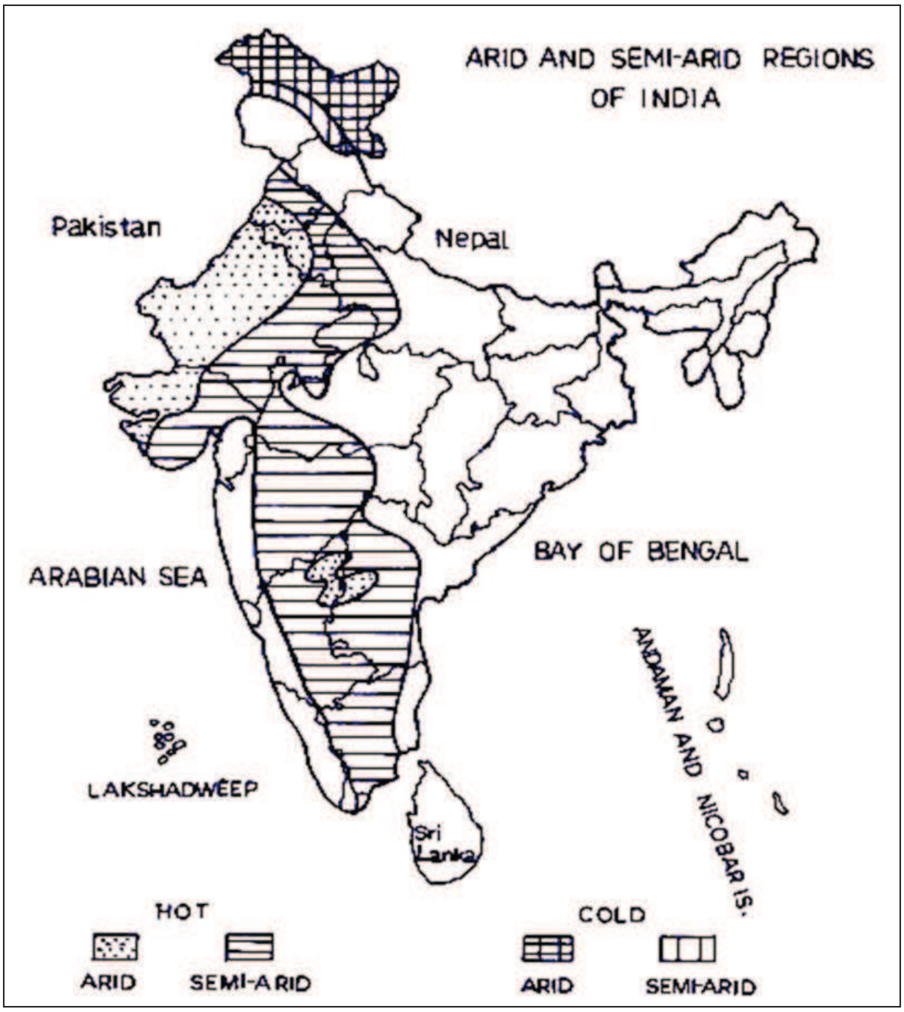

Figure 1. *Distribution of drylands in the country.*

The traditional farming systems, currently in vogue in arid and semi-arid regions of the country, are largely subsistence in nature and are need based. Besides, they are not necessarily efficient in utilization of resources for a given location. Challenges like frequent droughts, the increasing costs of cultivation, lower return for labour and inputs have also made farming in the arid regions a challenging enterprise. Employment opportunities in sectors other than agriculture have tempted many to switch over to other non-agricultural activities. However, the largest section of the rural community is still dependent on farm related activities to make a living. On the other hand, useful technologies have been generated by researchers on many alternative land use systems, which could be adopted to improve farm income. Therefore, the farmers could benefit greatly by resorting to diversification in the farming systems. Diversification of farming systems not only ensures sustainable return from the field but can also help combat global energy crisis by full utilization of natural resources like land, light and water.

Need for diversification

Under the harsh environs of arid and semi-arid regions, poor management of marginal lands results in further land degradation. These marginal lands are not able to sustain arable crops, particularly during the drought years. Therefore, alternate land use systems are needed that can help conservation of available moisture, prevent further land degradation, enrich soil with biomass, improve availability of food, fodder and fuel as well as generate employment opportunities to farming families round the year. The system would ultimately contribute to increased national production and bring prosperity to the farming communities. Although, these lands have their own biophysical constraints but they can be utilized efficiently on sustained basis for fulfilling the basic needs of food, fruit, fuel, fodder etc. through horticulture-based farming systems, such as agri-horticulture system (fruit based agro-forestry systems), by integrating practically feasible, economically viable and eco-friendly technologies.

Tree component in arid and semi-arid agriculture increases production and income, besides imparting stability to the farming system. Horticultural trees, apart from the above advantages, also yield valuable by-products like fodder, and fuel wood, through their annual pruning and fruits. Agri-horticulture system or horti-pastoral system is an agro-forestry system where the tree component is a fruit tree. To maximize farm returns from available natural resources, inclusion of horticultural crops in farming system for diversification seems a viable proposition. Horticultural crops are hardy and are able to give a satisfactory yield under aforesaid constraints, besides providing nutrition, income, employment and social security to the inhabitants of these areas.

Scenario of dryland horticulture

The vast land resources in dry land regions offer great opportunity for horticultural development of the country. Since last two and a half decades, considerable area has come up under fruits like *aonla*, *ber*, pomegranate, fig, kinnow, date palm, *phalsa*, tamarind *etc.* in different parts of the country. The *ber* area has spread from northern states to the western and southern India, from a mere 12,000 ha in 1978 to nearly 85,500 ha in 2016-2017, with a production of 8,95,000 tonnes. Similarly, the area under pomegranate has also leaped to over 2.02 lakh ha. Likewise, *aonla* is presently cultivated on 75,000 ha with the production of 8,25,000 tonnes. The area under date palm cultivation is increasing very fast due to introduction of tissue-culture raised plants. In Bikaner district alone, more than 250 ha area is under date plantation and presently more than 25,000 ha area is covered nationally, mainly in Gujarat, Rajasthan and Punjab (Table 1). This has become possible as a result of systematic research and developmental efforts.

Table 1. *Area and production of arid fruit crops in India*

Crops	1993-94		2016-17		2030 (Estimated)	
	Area (ha)	Production (MT)	Area (ha)	Production (MT)	Area (ha)	Production (MT)
Ber	41256	330048	85500	895000	110000	1210000
Pomegranate	4500	45000	202050	2668950	350000	5000000
Aonla	26000	286000	75000	825000	100000	1300000
Date palm	5000	41000	25000	200000	40000	375000
Sapota	49000	644000	80000	913000	110000	1280000
Tamarind	105000	52500	15280	82300	20000	120000
Others (Custard apple, Fig & *Phalsa*)	6600	30450	15700	131700	35000	350000
Total	142856	1428998	498530	5715950	765000	9635000

Under-utilized horticultural crops constitute another group that needs attention. There is scope to develop large orchards of under-utilized fruits like *jamun*, *mahua, chironji*, *khirni*, wood apple, fig, *karounda*, *lasoda*, Manila tamarind etc. for commercial exploitation, not only for internal consumption but also for export as these fruits are of highly nutritive and are rich in anti-oxidants for health conscious consumers of the modern world. In arid region, farmers are also growing vegetables but only in irrigated areas. Some traditional vegetables like *guar*, *moth*, *mateera*, *kachari*, *tinda*, snap melon *etc.* are grown under rainfed conditions. In India, vegetable seed industry has developed a great deal in the past decade, but the focus is primarily on a few vegetables like onion, tomato, brinjal, chilli, cauliflower, bell pepper, cucumber, okra etc. Public sector should come forward for diversification to specialized indigenous vegetables in each state for domestic market as well as for export.

Impact of diversification using horticultural crops

Income and food security:

With the transition away from subsistence crops to more profitable cash crops like fruits and vegetables, returns to land, labor, fertilizer, and water are significantly higher. The degree of improvement in farm income in the long and medium term will depend on the nature of relative changes in income and expenditure, as well as the extent of home consumption. The income elasticity for fruits and vegetables is reported to be 0.42% and 0.35% respectively, against only 0.05% for rice and -0.06% for wheat. According to various estimates, it was suggested that *khejri* based cropping system can bring net profit of Rs. 75,000-2,25,000 ha/year to growers. Similarly, *ber* based or *aonla* based mulple cropping system can bring 0.7 to 1.0 lakh rupees net profit to growers.

Multiplier effects of agricultural diversification:

As a result of growing consumer demand for highly packaged and processed agricultural products, diversification typically involves the movement away from traditional commodities (requiring minimal secondary processing) toward higher value commodities (requiring significant processing and handling like horticultural crops). Additionally, the new production systems are often more intensive and generate demand for a greater quantity and variety of farm inputs. Because high-value crops, compared to cereals, are more strongly interlinked with other sectors of the economy in terms of providing their outputs and receiving inputs, there is a stronger multiplier effect of the initial increase in income.

Risk and vulnerability:

Successful diversification will often result in a more varied mix of activities - at the regional level of farm enterprises and the vertical level of economic sectors, including new input markets and emerging processing industries. This will reduce community dependency on a narrow range of outputs and, as a result, will reduce vulnerability to shocks from climatic variability and volatility of commodity prices.

Implications for natural resources:

Diversification with horticultural crops can result in improved management of natural resources. It typically facilitates the diversification of traditional monoculture systems - the over production of traditional crops induced by distortionary policies will be avoided - to capitalize on potential synergies of crop rotations, associations and the improved integration of crop-livestock-tree components. As a result of this, land degradation can be reduced, input-use efficiency can be improved, and biodiversity can be preserved.

Employment generation:

Besides income generation, diversification will, in most instances, increase employment for the rural poor. Substantial employment opportunities are generated in seed and planting material production, precision land preparation, and the irrigation, harvesting, cleaning, grading, and packaging of high-value crops.

Horticulture-based cropping systems

Horticulture-based land use is being increasingly considered in developmental plans both in the arid and semi-arid regions. Details of some of the main features of the system are given below:

Suitable crops and varieties:

The diversified cropping system comprises three main components *viz*., overstorey main crop, component crop and understorey intercrops.

Main crop: These are the perennial fruit species having a larger canopy size and prolonged juvenile as well as productive phase. Generally, the crops utilize the entire land after 20-25 years, whereas only 25-30% of land is effectively used up by the main crop up to 10 years. These are planted at wider spacing. Several drought hardy fruit crops like *Capparis decidua, Salvadora oleoides, Cordia myxa, Cordia gharaf, Zizyphus nummularia, Z. rotundifolia, Z.*

mauritiana are suitable for the areas receiving rainfall <300 mm. Besides providing fruits these plants produce moisture laden nutritious leaves for animal. Several other fruits such as *aonla,* pomegranate, *bael* (*Aegle marmelos*), date palm, tamarind *(Tamarindus indica)* can be grown in the area having irrigation facilities (Table 2).

Table 2. *Suitable varieties of different fruits crops*

S. No.	Fruit crop	Variety
1	*Ber*	Gola, Seb, Mundia, Thar Bhubhraj, Thar Sevika, Goma Kirti
2	*Bael*	NB-9. Goma Yashu, Thar Neelkanth, Thar Divya
3	Custard apple	Bala Nagar, Arka Sahan, APK (Ca)-1
4	*Aonla*	Goma Aishwarya, NA-7, Kanchan
5	Guava	Sardar, Allahabad Safeda, Arka Mridula
6	*Lasoda*	Thar Bold
7	*Karonda*	Pant Manohar, Pant Sudarshan, Thar Kamal, CIAH Selection-1
8	Mahua	Thar Madhu
9	Pomegranate	Jalore Seedless, Phula Arakta, Bhgwa, Super Bhagwa, Goma Khatta

Fruit trees in arid zones perform several functions. They can act as a soil stabilizer and prevent water and soil erosion. They also protect the soil better than annual plants. Their extensive roots system improves the soil, and the shade they provide facilitates sustenance of ecosystem. They are an important source of forage for livestock and wildlife at a time when herbaceous fodder is not available for instance *ber,* fig, mulberry etc. They are a source of wood products, including fuel-wood, poles, and lumber. Fuel-wood is almost the only domestic fuel, not only in the rural areas but in some urbanized areas as well. Wood is also used as a construction material. They are a source of food. Many fruits, leaves, young shoots, and roots provide valuable food in the dry season and, therefore, comprise an important food reserve for emergencies. They are a source of non-woody products. Many trees and shrubs yield products, which are important for everyday use by the inhabitants, for industry, and at times, for export. For example, several trees are characterized by a high content of tannin (utilized by the leather industry) in their bark or fruit. In Burma, the *ber* fruit is used in dyeing silk. The bark yields a non-fading, cinnamon-colored dye in Kenya. Other trees and shrubs yield fibers, dyes, and pharmaceuticals. The pollen of many fruit plants is used for honey production (bee keeping). Similarly, The Indian jujube is one of several trees grown in India as a host for the lac insect, *Kerria lacca.*

Component crops: These are fruit species, which are grown in association with the main crop to diversify the cropping system as per the requirement of grower (Table 3). They could be filler crop as well and may be grown only during the juvenile phase of the main crop and uprooted at later stages. The other important fruit crops, which can be grown along with *ber* in arid regions as component tree are *aonla* (*Emblica officinalis*) (in frost-free area), *phalsa* (*Grewia subinequalis*), *karonda* (*Carissa carandas*), *goonda*/*lasora* (*Cordia myxa*), mulberry (*Morus* sp.), fig (*Ficus* sp.), *bael* (*Aegle marmelos*) etc., while custard apple (*Annona squamosa*), wood apple (*Feronia limonia*), *bael* (*Aegle marmelos*), *aonla* (*Emblica officinalis*), guava (*Psidium guajava*)*, mahua (Madhuca indica)* and *chironji* (*Buchania lanzan)* are suitable for growing as component crop with *ber* in semi-arid regions.

Table 3. *Economic analyses of various cropping systems suggested for arid regions*

Cropping system	Net profit (Rs ha-1)	B:C Ratio
Aonla-Ber-Custerbean-Fennel	110500	2.45
Aonla-Ber-Custerbean-Coriander	98700	2.32
Aonla-Khejri-Custerbean-*Ajwain*	93300	2.25
Aonla-Drumstick-Custerbean-Dill	87600	2.16

Ground storey intercrops: The other component of fruit tree-based cropping system is annual crops, which are grown in the interspaces. The intercrop occupies the lower most strata of the system and is grown in the unused interspaces between tree rows. In general, the inter crops are the location specific annual crops, selected as per the climatic and socio-economic suitability. These could be vegetables, pulses and legumes, oilseed, fodder crops, medicinal plants and seed spices. Among the vegetable crops, cucurbits like mateera (*Citrullus lanatus*), ridge gourd (*Luffa acutangula*), sponge gourd (*Luffa cylindrica*), bottle gourd (*Lagenaria siceraria*), long melon (*Cucumis melo* var. *utilissimus*), snap melon (*Cucumis melo* var. *momordica*), round melon (*Parecitrullus fistulosus*), *kachri* (*Cucumis* spp.), and legumes such as clusterbean (*Cyamopsis tetragonoloba*) and cowpea (*Vigna unguiculata*) can be taken successfully. Similarly, *kharif* pulses such as moth bean (*Phaseolus aconitifolius*), mung bean (*Phaseolus radiatus*) and urd bean (*Phaseolus aureus*) and *rabi* legume chick pea (*Cicer arietinum*) can be raised as they are able to withstand extreme aridity. Rapeseed (*Brassica campestris toria*) and mustard (*Brassica campestris*) are important oilseed crops, which can also be included in *ber* based farming system. Pastoral crops such as *sewan* (*Lasiurus sindicus*), *anjan* (*Cenchrus ciliaris*), *dhaman* (*Cenchrus setigerus*) and *karad* (*Dichantnium annulatum*), which grow naturally in pasture lands and rangelands, are suitable choices. The medicinal plants e.g. *gwarpatha* (*Aloe barbadensis* Mill.), *tumba* [*Citrullus colocynthis* (L.) Schrad], *senna* (*Cassia angustifolia* Vahl.), *guggal* (*Commifera wightii*), *dhatura* (*Datura stramonium* L.), castor (*Ricinus communis*), *heena* (*Lawsonia inermis*) etc. can also be grown in interspaces of *ber* trees. Likewise, seed spices like fenugreek (*Trigonella foenumgraecum*), cumin (*Cuminum cyminum*), chilli (*Capsicum frutescens*), coriander (*Coriandrum sativum*), fennel (*Foeniculum vulgare*), etc. can bring extra income to farmers, when grown in *ber* based cropping system. Agri-horti system comprising *Zizyphus* + mung bean provided fruit, fuel wood and round the year employment even in below average rainfall years. This system is recommended for the region having rainfall <250-300 mm. Intercropping of bottle guard during *kharif* season and pea (cv. 'Arkel') and *kasuri methi* in *rabi* season with *ber* plantation did not cause adverse effect on three-year old *ber* trees. Pomegranate has been found compatible with pearl millet, mung bean, isabgol, sorghum and cumin in Jalore district of Rajasthan.

During juvenile phase of fruit tree, there are ample opportunities for raising annual, biennial and perennial crops, which can meet diversified need of farmers. Fruit trees can also be planted in association with forest trees, and they yield wood for packaging and fuel. Multi-storey combinations incorporating large trees, small trees, and ground crops can be used. In low rainfall (300-500 mm) zone, combinations such as *khejri* or *ber* + *ber* or drumstick + vegetables (legumes and cucurbits); in 500-700 mm rainfall zone, combination of mango or *ber* or *aonla* or guava + pomegranate or sour lime or lemon or drumstick + solanaceous or leguminous or cucurbitaceous vegetables; and in 700-1000 mm rainfall zone, combination of mango or jackfruit or *mahua* or palmyrah palm or tamarind or guava + sour lime or lemon or pomegranate or *aonla* + vegetables can be adopted. Mono-cropping of either fruit or seasonal crops is highly risk prone in arid areas, hence to mitigate the effect of total crop failures, fruit based multistory cropping system such as *Aonla-ber*-brinjal-moth bean, *Aonla*-drumstick-senna-moth bean-cumin can be profitably adopted by the farmers of arid region for better cash flow, nutritional and environmental security and sustainable livelihood. In areas where frost is severe *Aonla-Khejri-Suaeda*-moth bean-mustard can be another lucrative option.

Crop diversification studies in *ber* (*Ziziphus mauritiana*) and *aonla* (*Emblica officinalis*) based cropping led to the recommendations that in pre-establishment phase of *ber* orchard, Indian aloe (*Aloe barbedensis*) and clusterbean (*Cyamopsis tetragonoloba)* are the low input and high return crops in arid region. In *aonla* based multi storey cropping system, the crop combination of *aonla*-drumstick-senna-moth bean-cumin recorded highest net return followed by cropping model (*aonla*-*ber*-brinjal-moth bean-fenugreek) under arid ecosystem. In another study conducted at ICAR-CIAH, Bikaner, *aonla* based cropping systems were evaluated for their profitability. It was found that *aonla*-*ber*-clusterbean-fennel was the best cropping system in terms of economic return (Table 3). Besides, researchers have proposed various suitable horticultural crop combinations for agricultural production system under arid regions (Table 4). An experiment conducted at Bikaner revealed that intercropping of annual crops with fruit trees provides the extra income to farmers when fruit trees are in their juvenile phase. Highest total income and net profit was realized with *bael* + groundnut intercropping followed by *ber*+groundnut and kinnow + groundnut (Yadava *et al*., 2006). The highest B:C ratio was recorded with *bael* + clusterbean followed by *bael* + moth bean (Table 5). Under semi arid conditions of Godhra, Gujarat fruit-based farming system like *aonla*/*ber*+okra/brinjal/cowpea have been recommended to the farming community for sustainable production.

Table 4. *Vegetable crop components for cropping system in the hot arid region*

Moisture condition	**High storey crop**	**Medium storey crop**	**Ground storey crop**			**Micro wind break / Biofence**
			Vegetable	**Agronomic crop**	**Grasses**	
Rainfed (rainfall <150-300 mm)	*Khejri*, *Ber*	*Ber*, *Kair*	*Materra*, *Kachari*, Snap melon, *Tumba*	Clusterbean, Moth bean, Pearl millet, Sesame	*Cenchrus*, *Lasirus*	*Ker*, *Phog*, *Khimp*, *Jharber*
Rainfed (rainfall <300-500 mm)	*Ber*, *Lasora*, *Khejri*	*Shenjna*, *Lasora*	*Materra*, *Kachari*, Snap melon, *Tinda*, Brinjal, Indian bean, Clusterbean, Cowpea	Clusterbean, Moth bean, Pearl millet, Sesame	*Cenchrus*, *Dicanthium*, *Pannicum*	*Ker*, *Khimp*, *Jharber*
Irrigated	Datepalm, *Ber*, *Aonla*	Lime, Guvava, Pomegranate	Cucurbits, Chilli, Tomato, Brinjal, Cole crops, Peas, Beans, Onion, Okra, and Leafy vegetables	Cumin, Isabgol, Groundnut, Mustard		*Lasora*, *Shenjna*, *Karonda*

Table 5. *Economics of different agri-horti system in district Bikaner, Rajasthan*

Agri-horti system	Net profit (Rs ha^{-1})	B:C Ratio
Ber + Moth bean	10854	2.06
Ber + Clusterbean	12970	2.33
Ber + Groundnut	20379	2.45
Beal + Moth bean	14310	2.86
Beal + Clusterbean	16054	3.02
Beal + Groundnut	21799	2.75
Kinnow + Moth bean	11015	2.20
Kinnow + Clusterbean	11122	2.10
Kinnow + Groundnut	19830	2.50

Successful models

Intensification of kinnow cultivation: In India, kinnow is grown in Punjab, Rajasthan, Haryana and Himachal Pradesh. It is a commercial crop of some districts of Punjab and Rajasthan, where farmers are earning good income from its plantation. These regions are blessed with good irrigation facility and comparatively better soil conditions than hot arid region of Bikaner. The crop comes up well in hyper hot arid region and ripens about 15 days before than in the traditional growing areas. The fruit quality and longevity are also better. Now, intensive cultivation of kinnow under drip irrigation at 6 m x 6 m spacing has been started by the farmers of hyper hot arid region with yield level of 23 t ha^{-1}. Farmers are getting an average income of Rs. 1-1.5 lakh $year^{-1}$.

High density planting of pomegranate: Pomegranate is spreading in arid and semi-arid regions at very fast rate. A decade before, the varieties like 'Jalore Seedless' and 'G-137' were grown only in some pockets (like Jalore, Sirohi, Pali and Jodhpur district of Rajasthan) but with the introduction of tissue culture raised plants of cultivar 'Bhagwa', it has occupied >15,000 ha area in Rajasthan alone. The high density planting of 'Bhagwa' at spacing of 4.5 m x 3 m (714 plants ha^{-1}) and 4 m x 2.5 m (1000 plants ha^{-1}) under drip system has been adopted by the farmers. The fruit yield of 15 t ha^{-1} have been harvested with net income of Rs. 1.50-2.0 lakh ha^{-1}. The management practices of growing pomegranate in arid region are altogether different from that in the tropical region. Moreover, farmers are facing problem of fruit cracking and nematode in hot arid region of Rajasthan. The fertigation and crop regulation are crucial factors in determining better productivity.

High density planting of aonla: *Aonla* has emerged as main crop of dry land areas after introduction of high yielding varieties and its increasing demand in processing and pharmaceutical industries. Under rainfed conditions of semi-arid region of Gujarat, *aonla* variety 'NA-7' was grown in double hedge-row system of planting, accommodating 260 plants/ha, and gave fruit yield of 22.6 t ha^{-1} and a net returns of Rs. 2,43,035/- ha^{-1} in the 11^{th} year after planting. An increase in yield of 132.39% over conventional square system (100 plants ha^{-1}) planting was recorded in double hedge-row system of planting.

Cultivation of kachri: *Kachri (Cucumis melo*) is an industrial crop grown mainly in arid and semi-arid regions of the country. The dry powder of *kachri* is used as base ingredient of packaged spices. Earlier this cucurbit was found growing in maize field under rainfed conditions of western India. Now, a uniform fruit size and high yielding variety of kachri ('AHK-119') has been developed by ICAR-CIAH, Bikaner. Under limited irrigation, farmers are harvesting about 9 to 12 t ha^{-1} fruits of kachri and earning Rs. 0.75 to 1.25 lakh ha^{-1}. This is very popular on farmers field and has occupied more than 63,000 ha area in Rajasthan, Haryana, Gujrat and Punjab. This variety alone occupies about 70% of total area under *kachri* cultivation.

Low tunnel technology: The low tunnel protectd agriculture technology has revolutionized cultivation of cucurbits in hot arid region of Rajasthan. During summer temperature goes up to 48°C while in winter it falls to sub zero level. Low tunnel technology can be used to raise off-season crop of cucurbits making cultivation more profitable. Plastic low tunnels are miniature form of greenhouses to protect the plants from rains, winds, low temperature, frost and other vagaries of weather. In a study, the sowing of long melon variety 'Thar Sheetal' was done inside low tunnels in the month of January and maintained under drip system. The poly cover was removed when temperature started rising in the month of February, after which flowering and fruiting started. The fruits were available from the end of February to March. About 180 q ha^{-1} fruit yield was harvested, with an income of Rs. 2.0- 2.50 lakh ha^{-1}.

Potato in arid region: In non-traditional areas of hot arid region of Rajasthan, potato cultivars like 'Kufri Chipsona-4' and 'Kufri Frysona' (for processing) and 'Kufri Jyoti', 'Kufri Garima' and 'Kufri Surya' (for table purpose) were introduced to assess their production potential under micro sprinkler system of irrigation. After three years of studies, it was found that these cultivars were agronomically most efficient in resource poor conditions and gave high yield, better quality tubers and good return. With the cultivation of 'Kufri Chipsona-4' under sprinkler system, > 40 t ha^{-1} tubers were harvested in hot arid region of Rajasthan. With this level of production, farmers can get income of Rs. 1.17 lakh ha^{-1}. The quality of potato in terms of appearance and dry matter content is better than in the traditional potato growing areas.

Onion cultivation: Onion is another important vegetable becoming popular in arid region of Rajasthan since last few years. It is grown as *Rabi* crop by planting in December-January and is ready to harvest in May. The productivity is better than in traditional onion growing areas. In Rajasthan, the most popular varieties are 'Nasik Red' and 'Durgapura RO-252' which are giving yield of 35-40 t ha^{-1} under pressurized system of irrigation. At this yield level, farmers are getting income of Rs. 1.0-1.50 lakh ha^{-1}.

Conclusion

In the light of evidences outlined in this paper, it is clear that alternative farming systems involving horticulture-based production system (comprising perennial component and annual intercrops) impart stability and sustainability to production under dry land ecosystems and enhance resilience of communities living there.

References

Arya, R., O.P. Awasthi, J. Singh and I.S. Singh. 2011. Performance of component crops in tree-crop farming system under arid region. *Indian Journal of Horticulture* 68(1): 6-11.

Awasthi, O.P. and A.K. Singh. 2011. Fruit based diversified cropping system for arid region. Pages 157-162 *in* Proceedings of ISMF&MP, Kalyani, W.B.

Awasthi, O.P., I.S. Singh and T.A. More. 2009. Performance of intercrops during establishment phase of aonla (*Emblica officinalis*) orchard. *Indian Journal of Agricultural Science* 79(8): 587-591.

Bhati, T.K., V.S. Rathore, J.P. Singh, R.K. Beniwal, N.S. Nathawat, D.D. Birbal, M. Shamsudheen, B. Ram, P.P. Rohilla, S.S. Rao and P.R. Meghwal. 2009. Alternative farming systems for hot arid regions. Pages 354-382 *in* Trends in Arid Zone Research in India. (Eds. Kar, A., Garg, B.K., Singh, M.P. and Kathju, S.). Central Arid Zone Research Institute, Jodhpur.

Dhakar, M.K., B.B. Sharma and K. Prajapat. 2013. Fruit crop-based cropping system: A key for sustainable production. *Popular Kheti* 1(2): 39-44.

Ghosh, S.P. 2012. Carrying capacity of Indian horticulture. *Current Science* 102(6): 889-893.

Hossain, M.A. 1991. Pruning, training and management of woody plants suitable for agro forestation. *In* Village and Farm Forestry in Bangladesh. (Haque, M.A., ed). BAU & SDC.

Samadia, D.K., B.B. Vashishtha, G.B. Raturi. 2004. Prospects of vegetable production in the arid zone of India. *Pages* 101-116. *in* Proceeding of Impact of Vegetable Research in India. (Sant Kumar, P. K. Joshi and Suresh Pal, eds.).

Yadava, N.D., R.K. Beniwal and M.L. Soni. 2006. Crop diversification under fruit based cropping systems in arid zone of western Rajasthan. *Indian Journal of Arid Horticulture* 1(1): 20-22.

Climate resilient technologies for seed spices

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Abstract

India is endowed with diverse soil and agro-climatic conditions, which favour cultivation of an array of seed spice crops. Seed spices are being grown in arid and semi-arid areas of India and their production and quality are being seriously affected by the adverse effects of climate change. Collection of germplasm that is resilient to climate change and its use in the development of new cultivars tolerant to high temperature, resistant to pests and diseases, short duration and producing good yield under stress conditions will be the main strategies to meet the challenge of climate change. Since the seed spices are mostly winter season crops there is a need to protect them from frost and also to boost their growth through protected structures. The judicious water utilization in the form of drip, mist and sprinkler irrigation will be a key factor to deal with the drought conditions. There is need to develop forecast models specific to the region and crop so that farmer can take precautionary measures to protect their crops from various stresses. To save the crop from sudden change in the climatic conditions after harvesting, farmers should have the facilities for safe storage. Institutional and policy support for these facilities as well as for processing and value addition will enhance the resilience of seed spice growers to changing climates and improve their livelihood security.

Introduction

Seed spices are highly valued crops in arid and semi-arid areas of India. They are mostly grown in Rajasthan and Gujarat, and, on limited scale, in Uttar Pradesh, Madhya Pradesh, Punjab, Haryana and some parts of south India (Lal and Verma, 2018). Among the various seed spice crops, the maximum area is under cumin followed by coriander, fennel fenugreek, *ajwain*, celery, nigella, dill, anise etc. All these crops are mostly grown in *rabi* season.

India is the largest producer, consumer and exporter of seed spices in the world. The area under seed spices is ~18 lakh hectare and production is ~18 lakh tones. India is dependable source of seed spices for importing countries worldwide whose demand has been continuously increasing. The total export value of seed spices is around Rs. 37,000 million, out of which cumin alone contributes to about Rs. 24,000 million annually (DASD, 2017-18).

As per the Intergovernmental Panel on Climate Change (IPCC, 2014), climate change is occurring, and the average global temperature is rising, faster than earlier anticipated, mainly due to emission of green house gases because of anthropogenic reasons. Climate change is affecting agriculture in a number of ways, including through changes in average temperatures, rainfall, and occurrence of climate extremes (e.g., heat waves, cold waves, frost, floods); incidence of old and new pests and diseases; nutritional quality of foods (Hoffmann, 2013; Hatfield *et al*., 2014). Most of the horticultural crops are annual in nature and it seems that these crops will be most affected due to climate change (Verma *et al*., 2015). Hence, there is an immediate need to focus our attention on studying the impacts of climate change on adaptability, growth, development, yield and quality of seed spice crops (Sastry, 2017).

Impact of climate change on seed spices

All the seed spices are very sensitive to temperature in terms of their production and quality. Cumin germination is very sensitive to temperature changes. The crop is generally sown around 15th of November (early winter) when the temperatures start going down but due to climate change if temperature rises during this period cumin germination will be delayed. Increase in temperature may reduce the duration of maturity and increase evapotranspiration of the crop. Increase in day temperature, with increase in difference in the day and night temperatures, adversely affects the growth and brings forced flowering in most of the seed spice crops.

Heavy losses have also been observed due to combined effect of chilling and frost injury. Cumin, coriander, nigella, *ajwain* are very sensitive to frost. Incidence of frost can cause serious loss in yield; even complete failure. Fennel and fenugreek are also affected by frost but growth stage plays an important role. So far, no efforts have been made to identify the sources of resistance against low temperature injury in available germplasm of seed spices crops (Verma *et al*., 2018a,b; Sastry, 2017).

Plant genetic resources (PGR) represent the diverse gene pools including landraces, primitive cultivars, varieties of traditional agriculture, wild and weedy relatives of crop plants, etc. (IPGRI, 1993). They are being utilized for developing improved crop varieties for high yield, superior quality and better adaptation to various stress environments (Bansode *et al*., 2015; Verma *et al*., 2018a). These resources are being adversely affected by increasingly harsh environment because of climate change.

The adoptability and suitability of present cultivars of seed spices may be changed due to increase in the temperature because a particular variety requires specific agro-environment for its growth and development (Aishwath *et al*., 2011; Aishwath *et al*., 2015). The traditional areas of seed spices cultivation may change due to extreme weather conditions and occurrence of diseases, which will reduce the crop production. During the last few years, huge crop loss has seen in cumin due to *Alterneria* blight disease, which is mainly spread by air under cloudy weather conditions. If the cloudy condition lasted for three to four days more than 90 percent crop loss was observed in Ajmer district of Rajasthan. Due to climate change, varieties adapted to a location may no more be suitable for that particular location. For example, 'GC-4' is the main variety of cumin adopted by farmers in all growing areas but it has failed in Ajmer conditions due to occurrence of blight. Similarly, many coriander varieties in Kota region of Rajasthan now get heavily infested by stem gall, which was not much of a problem in the past. Increase in the average temperature would lead to faster growth and development and the crop would mature before time reducing the yield, particularly in crops that are photoperiod sensitive. Increased salt stress in some areas, because of climate change, would also reduce the productivity of the spice crops (Verma *et al*., 2018b).

Most of seed spices crops are mainly cross pollinated and pollination is carried out by honey bees. In seed spices major bee pollinator includes *Apis dorsata, A. florea, A. mellifera* and *A. cerana* (Meena *et al*., 2015). Change in the climate may be a major threat to pollination due to reduced activity of pollinating agents. Increase in temperature has highest adverse effect on pollinator-plant interactions (Hegland *et al*., 2009; Memmott *et al*., 2007). Under high temperature conditions of 40-50°C only *A. dorsata* can work and it completes its foraging activity early in the day. The working efficiency of all other bee species is drastically reduced. In the same way, climatic change associated events of cloudiness, fog, cold winds also hamper the pollinators in their regular pollination activities (Schweiger *et al*., 2010) adversely.

Most seed spice in arid and semi-arid areas are grown under rainfed conditions and shortage of water to these crops is likely to increase in the future because of increased temperature, as the evapotranspiration would increase. Changes in pattern of rainfall due to climate change would increase occurrence of drought and reduce the crop productivity.

Raising temperatures are likely to increase incidence of insect pest infestation in the crops of seed spices. For example, aphid infestation in coriander and cumin is very high if temperatures during the month of January are above normal. Larger difference in day and night temperatures and cloudy conditions during January and February encourage aphids to develop faster. Seed midge (*Systole albipenis*) is another major pest of coriander and fennel; its population is observed to increase when temperatures are lower than usual. As mentioned before, *Alternaria* blight diseases in cumin is likely to be accentuated because of changing climatic conditions. Cumin wilt (caused by *Fusaruim oxysporumsp cumini*) incidence is also going to increase because of rise in moisture stress and soil temperatures. Powdery mildew in fenugreek and coriander is favored by high temperature and high humidity. Normally during the end of January and starting of February month, any large fluctuations in day and night temperatures increase the severity of powdery mildew (Khare *et al*., 2014a,b).

Some of the minor diseases and pests may become major ones in the future. For example, reddening and yellowing in cumin is a recent problem in cumin growing areas and in same way root cracking in coriander has been recently reported physiological problem (Fig. 1) due to variation in day night temperature and moisture stress (Meena *et al*., 2014).

Figure 1*.Yellowing in cumin.*

Adaptive strategies for climate change

Some of the strategies that can make the seed spice growers more resilient to changing climatic conditions are discussed below:

Intensive germplasm collection and selection of suitable crops and varieties: The increase in temperatures may destroy much germplasm line and their wild relatives. So, intensive germplasm collection is needed for future use. Selection of cultivars that are more adaptable to a changing and variable climate will be the main strategy for adaptation to climate change. Some of the varieties developed at ICAR-National Research Centre on Seed Spices, Ajmer are showing tolerance/resistance and adaptability to climate variations. Resilient and adaptive horticultural production systems, which are less vulnerable to climate change and climate variability, should be adopted. Recently NRCSS has developed stem gall tolerant variety 'NRCSS ACr-1' (Ajmer Coriander-1) and released for cultivation in affected areas (Malhotra *et al*., 2016).

Breeding program: Since the seed spice crops are having very narrow genetic base, there is a urgent need to widen it to create more variability in terms of adaptability and resistance to pest and diseases and abiotic stresses. With the available information, breeding for synchrony in flowering and maturity (Sastry, 2017; Verma *et al*., 2017) and erect type with higher sink size is needed so that optimum yields are obtained under irrigated conditions. With the availability of information on the genetics of major morphological traits and the effect of changing climate, breeding for better adaptation to changing climate has to be given high priority (Sastry, 2017).

Genetic enhancement using molecular technologies has revolutionized plant breeding. Advances in genetics and genomics have greatly improved our understanding of structural and functional aspects of plant genomes. The use of molecular markers as a selection tool provides the potential for increasing the efficiency of breeding programs by reducing environmental variability, facilitating earlier selection and reducing subsequent population sizes for field testing. Molecular markers facilitate efficient introgression of superior alleles from wild species into the breeding programs and enable the pyramiding of genes controlling quantitative traits. Molecular marker analysis of stress tolerance in seeds spice crops is limited but efforts are underway to identify QTLs and genes underlying tolerance to stresses (Verma *et al*., 2015). Enhancing and accelerating the development of stress tolerant and higher yielding cultivars of seed spices can thus be achieved through greater use of these molecular technologies.

Water management: An increasing concern about climate change will increase the need for growers to use carbon-neutral practices. The judicious water utilization in the form of drip, mist and sprinkler will be a key factor to successfully deal with the drought conditions. Also, to manage some of the diseases and pests it is necessary to adopt appropriate irrigation technologies that will reduce severity. For reducing the crop damage from frost, use of raised beds and drip irrigation with fertigation has been found promising. Growing cumin crop under rainfed conditions using short duration varieties (like 'AA-93') is another important strategy.

Crop diversification: Mono-cropping is instrumental for degradation of the natural resource base. Besides it fails to ensure stable income to growers and causes crop loss due to biotic and abiotic stresses in the fragile ecosystem of semi-arid and arid regions. With dwindling arable land and increased demand of seed spices, it would be desirable to incorporate these crops into regular agricultural systems as intercrops/mixed crops (Lal and Verma, 2018). The seed spices being arid land spices, they can grow well as component crop in arid fruit orchards of *Aonla* and *Ber.* Similarly, in fennel, *ajowan,* and dill crops, the vegetable crops like clusterbean for green pods, summer squash, chilies, onion, radish and carrot can be intercropped. The seed spices crops have fairly good production potential when they are grown as component crops in orchards or when an intercropping is done in their fields with compatible vegetable crops. This can improve the economy of farmers by giving additional income (Vashishtha and Malhotra, 2003).

Many benefits can be derived from research that improves productivity and biochemical characteristics in some oil producing crops. Petroselenic acid present in coriander can be used for the production of nylon 66. High linolenic oils present in the seed can be used to produce various coating and dying agents and painting inks (Verma *et al*., 2015).

Figure 2*.Fennel crop damaged by hail storm.*

Institutional and policy support for 'secondary agriculture', post-harvest handling and value addition**:** To protect the matured/harvested crop from sudden inclement weather conditions and weather calamities like rain or hail storms (Fig. 2), farmers should have the needed facilities for speedy harvest and storage. Facilities should also be created to do farm level secondary processing, packaging and other value-addition steps to enhance the income (Lal and Mehta, 2013; Lal *et al*., 2015). Needed institutional and policy support would be crucial to enhance the resilience of seed spices growing communities to the changing climatic conditions and to secure their livelihoods.

References

Aishwath, O.P., R. Singh, B.K. Jha and R.S. Mehta. 2015. Growth kinetics and yield of coriander under limed acid soils of eastern plateau hill regions. *International Journal of Seed Spices* 5(1): 49-55.

Aishwath, O.P., M.M. Anwer, K. Kant, Y.K. Sharma and R.S. Meena. 2011. Vulnerability and adoptability of seed spices with climate change. *Technical Bulletin.* Published by Director, National Research Centre on Seed Spices, Ajmer. 13 p.

Bansode, R., S. Kumar, S., A. Mol, L. Malav, M.K. Malav and S.K. Kharia. 2015. Impact of climate change on plant genetic resources. *International Journal of Extensive Research* 3: 6-9.

DASD, 2017-18. Directorate of Arecanut & Spices Development, Calicut. https://www.dasd.gov.in/index.php/statistics.html

Hegland, S.J., A. Nielsen, A. Lázaro, A.L. Bjerknes and O. Totland. 2009. How does climate warming affect plant pollinator interactions? *Ecology Letters* 12: 184-195.

Hoffmann, U. 2013. Agriculture - a key driver and a major victim of global warming. Pages 3-5 *in* Lead Article, Chapter 1.

IPCC, 2014. Climate Change: Impacts, Adaptation, and Vulnerability. Intergovernmental Panel on Climate Change (Eds. J. Houghton, *et al.).* Cambridge University Press, Cambridge, UK.

IPCC. 2007. Climate change: Climate change impacts, adaptation and vulnerability. Summary for Policymakers. Intergovernmental Panel on Climate Change.

IPGRI 1993. Diversity for Development. Rome, Italy: International Plant Genetic Resources Institute.

Khare, M. N., S.P. Tiwari and Y.K. Sharma. 2014a. Disease problems in the cultivation of I. Cumin (*Cuminum cyminum* L.) II. Caraway (*Carum carvi* L.) and their management leading to the production of high quality pathogen free seed. *International Journal of Seed Spices* 4(1): 1-8.

Khare, M.N., S.P. Tiwari and Y.K. Sharma. 2014b. Disease problems in fennel (*Foeniculum vulgare* Mill) and fenugreek (*Trigonella foenum graceum* L.) cultivation and their management for production of quality pathogen free seeds. *International Journal of Seed Spices* 4(2): 11-17.

Lal, G. and R.S. Mehta. 2013. Post harvest handling, processing and value addition of seed spices. *In* Souvenir of National Seminar on Production, Productivity and Quality of Spices. Published by Director, NRCSS, Ajmer and Director, DASD, Calicut.

Lal, G. and A.K. Verma. 2018. Seed species for diversified agriculture to enhance farmers income. Pages 214-219 *in* Shod Chintan: Intensification and Diversification in Agriculture for Livelihood and Rural Development. 10.

Lal, G., R.S. Mehta, B.K. Sharma, A. Bhati and B.M. Barolia. 2015. Influence of storage period and packaging practices on essential oiland organoleptic quality of fennel (*Foeniculum vulgare* Mill) seed. *International Journal of Seed Spices* 5: 74-78.

Malhotra, S.K. 2016. Research and development of seed spices for enhancement of productivity and profitability in the era of climate change. *Indian Journal of Arecanut, Spices and Medicinal Plants* 18(1): 3-19.

Meena, N.K., B. Singh, B.K. Kant, R.D. Meena and R.K. Solanki. 2015. Role of insect pollinators in pollination of seed spices-A review, *International Journal of Seed Spices* 5: 1-17.

Meena, R.D., Y.K. Sharma, B.K. Baranwal, B. Singh and N.K. Meena. 2014. Cumin yellowing: A new viral disease reported. *Seed Spices E-Newsletter*, 6(5): 5.

Memmott, J., P.G. Craze, N.M. Waser and M.V. Price. 2007. Global warming and the disruption of plant pollinator interactions. *Ecology Letters* 10: 710-717.

Sastry, E.V.D. 2017. Climate Resilient Plant for Seed Spices. *Current Trends in Biomedical Engineering & Bioscience* 3(3): 555613.

Schweiger, O., J.C. Biesmeijer, T. Hickler, *et al.* 2010. Multiple stressors on biotic interactions: how climate change and alien species interact to affect pollination. *Biological Review* 85: 777-795.

Vashishtha, B.B and S.K. Malhotra. 2003. Seed Spice Crops: Status and production potential under low rain areas. Abstract in International Symposium for sustainable dry land Agriculture Systems held at ICRISAT Sahelian Centre, Niamey, Niger, December, 2-5, 2003.

Verma, A.K., S. Choudhary, R.S. Meena and R.D. Meena. 2017. RF/225/37/10: A synchronous flowering and early maturing mutant of fennel (*Foeniculum vulgare* Mill.). *Seed Spices E-Newsletter*, 10 (6): 3.

Verma, A.K., S. Choudhary, R.S. Meena, G. Lal and M. Sharma. 2018a. Improvement ofseed spices. Pages 287-314 *in* Phytochemistry of Fruits and Vegetables (Peter, K.V. Ed.). Brillion Publishing, New Delhi- 110005, India.

Verma, A.K., A. Singh and B. Singh. 2015. Climate Change and Horticultural Industry: Impact and Adaptive Strategies. Pages 47-64 *in Horticultural Technology Management* (Kumar U. and Prasad B. Eds.). Jaya Publishing House, Delhi, India (ISBN: 978-93-84337-34-6).,

Verma, A.K., **A.** Singh, R.L. Meena, R.L. and B. Singh. 2018b. Approaches for enhancing salt tolerance in seed spices. Pages 367-401 *in* Engineering Practices for Management of Soil Salinity: Agricultural, Physiological, and Adaptive Approaches. Apple Academic Press, USA. ISBN: 9781771886765.

Fish farming in Egypt

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Extended Summary

The capture fishery sector in Egypt is diverse in nature ranging from marine to freshwater resources. Egypt is bordered by Mediterranean Sea and the Red Sea whereas Suez Canal connects both seas (3000 km). Freshwater resources are represented by River Nile and its branches as well as Lake Nasser and Toshky depression. The four brackish water lakes (Manzala, Burullus, Edku, and Maryut) contribute significantly to fish production in Egypt. Moreover, there are coastal lagoons and depressions (Bardawil and Port Fouad), closed lake (Qarun), depressions (Rayaan) and other lakes and salines as represented by Timsah and Port Fouad. The demand for fish is increasing continuously with the improvement of the local economic situation.

In Egypt, aquaculture is considered as the only available way and effective solution to reduce the gap between fish production and demand (SOFIA, 2018). The aquaculture activities started more than 30 years ago with a simple fish farming technique in traditional extensive farms. In 1993, fish production from aquacultures activity was 54,000 tons representing 14% of the total fish production (GAFRD, 2017). During the last few years, aquaculture activities have grown fast achieving a sharp increase in fish production. In value and quantities, there was significant increase in aquaculture share in total fish production in Egypt in 2017. The production was ~1.4 million tons (82% of the total fish production in Egypt). This development was as a result of the change in farming structures and techniques as the activity attracted many educated farmers and investors. Fish farms and hatcheries are presently dominated by private sector. The production of fry from hatcheries is about 347 billion units of different species, mainly Tilapia, carp, cat fish, sea bream, sea bass and shrimp.

It is planned in the "Egyptian Sustainable Agriculture Strategy 2030" to produce 2.1 million tons fish in 2020 (FAO, 2017). Egypt produces more than 68% of the total aquaculture production in Africa.

Constraints & challenges facing the aquaculture development in Egypt

Major constraints are:

- Limited availability of fresh-water resources,
- Seasonality of production and demand,
- Summer mortalities posing a major challenge for sustainability,
- The absence of a cold chain, cold storage, post-harvest processing and export,
- Tilapia stock quality,
- Limited number of species in aquaculture,

- Limited number of marine hatcheries,
- Feed quality and quantity for fish farming, and
- Limited access to credit.

Future of fish production in Egypt

Following are important considerations for promoting aquaculture in Egypt:

- Value added seafood is one of the potential resources in Egyptian market for export.
- Need for defining the international seafood trade market demand and how it could be met, in terms of quantity and competitiveness of prices.
- Moving away from traditional open ponds and implementing closed and IPRS systems to provide water conservation and sustainability of the aquaculture industry.
- Cooperation to evaluate the available aquaculture potential in every sector.
- Establishment new marine hatcheries for the development of marine aquaculture.
- Development of cage culture and marine farms in the Mediterranean and the red sea.
- Integrated aquaculture, especially in the new reclaimed areas (desert aquaculture).

References

GAFRD. 2017. General Authority for Fish Resources Development. Statistics Year Book. 104 p.

FAO. 2017. FAO Yearbook of Fisheries and Aquaculture Statistics, 2017. 108 p.

SOFIA. 2018. State of World Fisheries and Aquaculture Meeting the Sustainable Development Goals. Food and Agriculture Organization, United Nations. Rome. 227 p.

Sustainable rainfed agriculture in India: Strategies and policy framework

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Extended Summary

Rainfed agriculture, accounting to 55% of the net sown area in India, is crucial to country's economy and food security since it contributes about 40% of country's food basket, supports 40% of human population, two third of livestock population, and further influences livelihoods of 80% of small and marginal farmers. Even if full irrigation potential is created, still 40% of net cultivated area will remain as rainfed. The key challenges in rainfed agriculture are erratic monsoon, climate risks, production risks, poor operational land resource base and market risks (CRIDA, 2015). Several development programmes like watershed development were initiated for improving rainfed areas. The *"Everything Everywhere"* approach of taking up all major interventions uniformly across the country has not paid much dividend. The developmental approach in rainfed areas did not fully capture aspects like biophysical resources, socio-economic profile, infrastructure, livelihood etc. neglecting agro-ecology specific interventions befitting to the natural resource endowment, social capital, infrastructure and socio-economic conditions (NRAA, 2012).

The cropping pattern in rainfed areas is largely driven by management, monsoon (south-west) and often with market influence. Traditionally, in core rained areas, mixed or intercropping predominate and provide resilience to aberrant weather conditions. Of late, the cropping patterns in rainfed areas are witnessing shifts to monocropping, particularly to rainfed cotton replacing food crops. Currently, there is an imbalance between natural resource endowment and cropping patterns in rainfed areas. The shifts in climate and rainfall variability, poor soil quality in a resource domain (i.e. agro-climate zone) etc. have been impacting productivity, profitability and stability of rainfed crop production systems. This calls for concerted efforts in agro-ecology specific crop alignment in a resource domain.

One such strategy could be agro-ecology specific potential crop zoning, which refers to specific regions/areas of crops and cropping systems that are bio-physically suitable and also have high productivity and potential to spread. The methodology for such zoning has three steps i.e. (i) soil-site characterization, (ii) bio-physical suitability evaluation of crops based on soil-site information and (iii) linking of bio-physical suitability maps to the relative spread and productivity maps of reference crops and cropping systems (Ramamurthy *et al*., 2018). The potential crop zones have similar biophysical setting in respect of soils, site characteristics, rainfall, temperature, length of growing period, suitable for a specific crop/cropping system, and have potential to respond similarly for similar kind of management practices. This crop zoning is anticipated to enable bridging yield gaps, quality soil management, crop intensification/diversification/substitution, crop planning based on

market intelligence to regulate cropped area and production to realize higher commodity prices, contingency plan implementation on real-time basis, building resilience at agriculture landscape level, developing commodity crop centric value chains and providing safety nets (weather based crop insurance) (Ravindra Chary *et al.,* 2017). The strategies specific to various potential zones of the base crop are given in Table 1.

Table 1. *Strategies for various potential zones of base crops*

Potential zone of the base crop	Strategies
Highly potential zone	• Technological interventions (soil, water, crop, land, energy, based) for higher water productivity, profitability and stability of the base crop • Sustained, quality and adequate quantity seed production of the base crop • Development of total, cost effective and energy efficient farm mechanization of the base crop • Development of the value chain, weather indices based insurance etc. of the base crop • Strengthening base crop based traditional rainfed integrated farming systems
Moderately potential zones	• Base crop based crop diversification/intensification (intercropping/double cropping) • Strengthening traditional rained farming systems/agroforestry systems
Marginally potential and non-potential zones	• Replacing base crop/crop substitution with alternate crops/cropping systems

Source: Ravindra Chary *et al.* (2017)

Diversifying within farm for sustainable intensification and green capping

Evolving Rainfed Integrating Farming Systems models by strengthening predominant traditional rained farming systems in prioritized rainfed districts is necessary for enhancing resource use efficiency and livelihoods, food and nutritional security, staggered employment and income. Suggested strategies for strengthening traditional rainfed farming systems are given in Table. 2.

Next step is promotion of proven agro-ecology specific alternate land use/agroforestry systems for risk resilience and staggered income, biomass production and soil carbon sequestration.

Table 2. *Suggested strategies for strengthening traditional rained farming systems*

Rainfall zone (mean annual rainfall)	Strengthening predominant traditional rainfed farming systems	Agro-ecology specific components along with efficient ***in situ*** and ***ex situ*** rainwater management practices
< 500 mm	Livestock-crop based	Small ruminants, nutritious cereals/millets
500-750 mm	Crop-horticulture - livestock based	Small/large ruminants, predominant rainfed crops and dryland horticulture
750-1000 mm	Crop-horticulture-livestock-poultry based	Predominant rainfed crops, dryland horticulture, agri-hortisystems, rainfed vegetable crops, small/large ruminants, improved b reeds of poultry
> 1000 mm	Multiple enterprise based on multiple water use	Predominant rainfed crops, lowland rice with water saving technologies, dryland horticulture, vegetable crops, other high value crops, agri-hortisystems, small/large ruminants, improved breeds of poultry, fish and other income generating enterprises like seed production, apiary, mushroom cultivation etc.

Source: Ravindra Chary *et al.*, 2017

Delineation of rainfed agro-economic zones - A policy framework towards sustainable rainfed agriculture

Delineation of Rainfed agro-economic zones (RAEZs) is proposed as a Mission Mode target resource domain approach for drought proofing rainfed areas towards sustainable rainfed agriculture and also to achieve desired level of environmental protection. The three steps for delineating RAEZs (Ravindra Chary *et. al*. 2017) are as follows:

Step-I	:	Selection of prioritized rainfed districts based on Rainfed Areas Prioritization Index (NRAA, 2012)
Step-II	:	In a prioritized rainfed district, identification of climate/drought vulnerable blocks/tehsils based on Climate Vulnerability Index
Step-III	:	The highly climate/drought vulnerable blocks/tehsils within each prioritized rainfed district may be delineated as *'Rainfed Agro-Economic Zones*' (RAEZs)

RAEZ could be an entirely a new target domain/micro-level approach and two pronged i.e. watershed and rainfed integrated farming systems based. Here, sustaining the land resources, stabilizing rainfed farming, enhancing the adaptive capacity of the small and marginal rainfed farmers to climate risks would be focal. Instead of individual and piecemeal interventions the entire rainfed crop-based production system will be targeted to develop as Rainfed Agro-Economic Zones (RAEZs), which would act as hubs of sustainable rainfed agriculture development. The functional mechanism has to be developed at RAEZ level in a rainfed district in a consortium mode, involving all the concerned stakeholders and convergence of all relevant programmes.

Conclusion

Stability and profitability of rainfed farming is need of the hour at the backdrop of climate, production and market risks. The technology targeting and upscaling in rainfed areas should match with natural resource endowments. For this purpose potential crop zoning, and diversification within farm could be the strategies for sustainable rainfed agriculture. Further, a policy for Mission Mode Rainfed Agro-economic Zone centred approach for drought proofing rainfed areas is the way forward for sustainable rainfed agriculture.

References

CRIDA. 2015. Vision 2050, ICRA-Central Research Institute for Dryland Agriculture, Hyderabad, India. 36 p.

NRAA. 2012. Prioritization of Rainfed Areas in India, Study Report 4, National Rainfed Area Authority (NRAA), New Delhi, India. 100 p.

Ramamurthy, V., S. Chattaraj, S.K. Singh and R.P. Yadav. 2018. Identification of potential areas for crops. *Current Science* 115 (5): 955-961.

Ravindra Chary, G., K. Sammi Reddy, V. Ramamurthy, S. Bhaskar and Ashok Dalwai. 2017. Sustainable Agriculture and Doubling Farmers Income in Rainfed Areas: Challenges and Strategies. In Vol. VI "Strategies for Sustainability in Agriculture" Doubling of Farmers Income. Submittedto DAC&FW, MoAFW, GoI (www.agricop.nic.in).

Intensification and diversification of dryland production systems with winter pulses in South Asia

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Extended Summary

There is tremendous pressure on agriculturally productive lands due to urbanization, industrialization and the use for various other purposes; thus, in South Asia, availability of agricultural land is decreasing significantly. However, there is ample scope to increase system productivity and overall food production in mono-cropped lands by introduction of second and even third crop in the existing cropping systems; bringing short duration crops in narrow window in between two crops; inter-cropping and mixed-cropping with companion crops. Thus, cropping intensity can be increased, and farmers can generate extra-income and food and get better nutrition. Such opportunities can be exploited in 'rice-fallow' lands where winter pulses like lentil, grasspea, pea and chickpea can be successfully grown. Rice-fallows imply to those lowland *Kharif* sown rice areas, which remain uncropped during winter months due to various reasons. Rice fallows are widely spread in South Asia (15.0 mha) of which 11.65 mha lies in India itself.

In vast majority of the areas of eastern and central India, western Nepal and northwestern and southern Bangladesh, such rainfed ecosystem is prevailing. Besides, in Bangladesh, eastern Nepal and eastern India, super-early pulse species can be introduced in short window of <90 days in between *Kharif* rice and spring rice. Of all crop plants of economic importance to humans, none probably has been suitable for so many useful traits as pulses that contribute to human, animal and soil health improvement. Pulses are also important for diversification of resilient production and food systems. It is estimated that pulses can be grown in 3-4 mha in India, 0.5 mha in Bangladesh and 0.24 mha in Nepal in rice-fallow rainfed agro-ecosystems.

Pulse crops play a significant role with respect to efficient use of land and water resources, and for judicious intensification and diversification of various production systems. They are essential components in daily diet of the people in the region, most particularly to low-income people for nutritional support, thus termed as "house of nutrients". Pulse crops are rich in protein, quality carbohydrate, essential macro and micro-nutrients and vitamins. Efforts are underway to increase pulse production through two-pronged strategies: improving productivity vertically, and horizontal expansion through system intensification. Under various initiatives, the International Center for Agricultural Research in the Dry Areas (ICARDA), in collaboration with national partners of Bangladesh, India and Nepal, has developed appropriate production technologies including suitable varieties, which are being disseminated among farmers. The government of India is implementing a targeted program in rice-fallows of eastern Indian states under National Food Security Mission (NFSM) and success has been achieved there to increase pulses and oilseeds production.

Several production constraints prevail in rice-fallow system that include biotic and abiotic stresses, poor crop establishment and management, lack of awareness by farmers on modern method of cultivation including the use of quality seed of high yielding varieties and integrated pest management, poor linkage to market and government price support policies, etc. To address these issues, some of the technological interventions have been promoted: appropriate varieties and production technologies, seed priming, enhanced seed rate, use of *Rhizobium* culture and phosphorus solubilizing bacteria (PSB), foliar spray of 2% DAP solution, appropriate weed management and use of zero-tillage systems. Besides technological advances, some of the R&D issues like periodical mapping of rice fallows, mechanization of field operations, policy issues such as water harvesting, establishing village seed hubs, rural credit, marketing infrastructure and containing menace of stray animal are also being addressed.

In South Asia, winter pulses (lentil, grasspea, chickpea and pea) are grown on residual soil moisture that remains in soil after cessation of monsoon, in harvested rice fields under rainfed conditions. Terminal drought severely affects productivity of these pulse crops. Depending upon intensity and length of winter temperature, soil type, texture and residual moisture, selection of crops and varieties are made. Besides, mapping of fallows at harvest stage of rice crop using satellite imagery and drone technology provides an opportunity to understand length of fallow period, soil moisture status, information on soil type, etc. to decide appropriate selection of crops/varieties. For example, in India, early maturing (<110 days) lentil varieties, 'Moitree', 'HUL-57', 'IPL-81', 'NDL-1' and 'KLS-218' performed well in light soil with residual moisture at shallow-depth level, as lentil has short tap root system. These varieties performed well in Assam, Tripura, Manipur, Meghalaya, West Bengal and Bihar with a yield potential of up to 1720 kg ha^{-1} under rice-fallows. The most adapted varieties under rice-fallows in Bangladesh are 'BARImasur-4', 'BARImasur-5' and 'BARImasur-7". In Nepal, 'Khajurah-2', 'Sekhar', 'Simal' and 'Sindur' are suitable for rice-fallow cultivation.

Grasspea is a well-adapted pulse crop suitable for clay, clay-loam and saline-soils under rainfed cropping grown for human food, and for quality fodder for animal. Low-ODAP (<0.1%) grasspea varieties, 'Ratan', 'Prateek', 'Nirmal' and 'Mahatiwara' are successfully grown under rice-fallows in India, specifically in Chhattisgarh, Assam and West Bengal states. In Bangladesh, 'BARIkhesari-2' and 'BARIkhesari-3' are popular among farmers.

Chickpea grows well in heavy clay soil with moisture in deeper layers. Chickpea varieties 'Anuradha' and 'Udai', with yield potential of 1882 kg ha^{-1} and 2213 kg ha^{-1}, respectively have been identified for rice-fallow cultivation in the state of West Bengal, India.

In Bangladesh, super-early lentil variety, 'BARImasur-9' (<85 days) has been successfully introduced in between *Kharif* rice and spring rice in traditional lentil-growing areas.

In intercropping and mixed cropping systems, lentil, grasspea, pea and chickpea are successfully grown with sugarcane, mustard, linseed, wheat and coriander with appropriately adjusted seeding rates to maximize land use efficiency. Besides, in agroforestry system, lentil and grasspea are grown in mango and guava orchards when trees are at early growth stage, thus increasing cropping intensity and yielding extra production.

Although various initiatives have yielded good successes in technology development and delivery for new niches, but this can be further enhanced through consolidated R&D efforts: addressing research gaps, adoption of pilot projects in system approach, mechanization, periodic mapping of target areas, enhancing farmers’ awareness, generation of crop-specific information, creation of community water reservoirs for supplemental irrigation; creation of marketing infrastructure, etc.

Sustainable intensification through agri-horti-silvi-pasture in dryland areas

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Abstract

Climate change has become an important area of concern for India and hence to improve the resilience of dryland agriculture, the available climate resilient technologies were demonstrated on farmers' field in a holistic way under NICRA project in five selected districts of Karnataka during 2011-18 through Krishi Vigyan Kendras. As an important natural resource conservation activity trench cum bunding was done in all the selected villages to conserve soil and moisture in the drylands. Massive plantings were undertaken in the trenches to promote agri-horti-silvi-pasture to enhance green cover, supplement fodder during lean period, increase farm income and achieve carbon sequestration. In Nagenahalli of Tumkur, dryland fruit crops like tamarind, amla, cashew and jamun, along with forest trees Melia dubia, silveroak, pongamia, teak, neem, and Acacia planted in 43.6 ha area gave a survival rate of 74.2% with an annual average rainfall of 899 mm/year. In Mahalingapura village of Gadag, mango, minor fruit crops and cashew planted along forest trees of 2-3 years old seedlings of teak, silveroak and Meli dubia in trench cum bund treated area of 157.7 ha resulted in 56.3% survival with an annual average rainfall of 363.9 mm/year. The plantings in Raghuttahalli of Chikkabalappur (134.5 ha), Melakunda village of Belagavi (44.4 ha) and Siddanuru village of Davanagere (24.5 ha) with fruit crops like mango, tamarind, cashew, amla, lemon, drumstick, Jackfruit, jamun and forest trees viz., Melia dubia, silveroak, Acacia auriculiformis, pongamia and neem on bunds of fields, which has helped farmers in conserving moisture and reducing soil erosion. The survival rate was 70% in Chikkabalapur (655.65 mm/year), 30.9% in Davanagere (555.3 mm/year) and 25.6% in Belagavi (431.24 mm/year) districts. In Kalaburagi, 2.5 ha was planted with Meli dubia, teak, lime and drumstick with 55% survival (745 mm rainfall per year).

Introduction

Dryland farming has a distinct place in Indian agriculture occupying 67% of the cultivated areas and servicing 44% of the human and two thirds of the livestock population in these regions. The sustainability of dryland area is endangered due to over exploitation of natural resources beyond their carrying capacity (Katyal and Das, 1992).

Drylands have harsh environment and suffer from a number of constraints such as low and uncertain rainfall, limited irrigation, low moisture, poor and degraded resource base, declining soil fertility, low productivity, and inadequate attention paid by policy makers and scientists, etc. However, the basic problem of dryland areas is one of a vicious cycle that starts with degradation of the natural resource base through poor management leading to low productivity and low income (Sharma *et al.,* 2012).

An ideal system for dry land areas should have a judicious mix of crops, trees, and grasses; only then the natural resources will be judiciously utilized and returns maximized without any detrimental effect on environment (Pratap Narain, 2008). Diversified farming system, involving crops, fruit trees, agroforestry, animal husbandry and farm mechanization, is the only option for sustaining the livelihood and pave the ways for profitable agriculture in drylands. In this respect, agri-horti-silvi-pasture provides plenty of opportunities of preventing further degradation of marginal lands and also obtain additional income.

Materials and methods

The study was conducted in a farmer participatory-research mode under National Innovations in Climate Resilient Agriculture (NICRA), through Krishi Vigyan Kendras (KVKs), under ATARI, Zone XI, to promote the sustainable intensification through agri-horticulture-silvi-pasture in dryland agriculture at selected drought/heat prone districts of Karnataka during 2011-18. To improve the resilience of agriculture by application of existing knowledge and technology on farmers' field in selected districts of Tumkuru (Drought), Gadag (Drought/heat), Chikkaballapura (Drought/heat), Davanagere (Drought/heat), Belgaum (Drought/heat), Gulbarga (Drought/heat) in Karnataka, a total of 1250 farmers were demonstrated agri-horticulture silvi-pasture system. As an important natural resource conservation activity, trench-cum-bunding was done in all the selected villages to conserve soil and moisture. In most of the trench-cum-bund treated lands, massive plantings were undertaken in the trenches to enhance green cover, provide supplementary fodder during lean period, increase farm income and achieve carbon sequestration. Horticulture crops like mango, tamarind, *aonla,* cashew, jack fruit, sapota and lemon and agro forestry crops like *Acacia auriculiforis*, silver oak, pongamia, teak and neem were planted in 407.2 ha area (Table 1).

Results and discussion

In D. Nagenahalli of Tumkur district, dryland fruit crops tamarind (7 ha), *amla* (4 ha), cashew (2 ha) and *jamun* (0.5 ha), along with forest trees like *Melia dubia* (15 ha), silveroak (2 ha) as wind breaks, pongamia (1 ha), teak (1 ha), neem (0.1 ha), and *Acacia auricuarifolias* (7 ha) were planted in trenches-cum-bund treated area in conjunction with basin mulching and intercropping with nitrogen fixing legume crops in 43.6 ha among 318 farmers to reduce soil erosion, to avoid direct splash of rain, keep soil intact, and ensure fodder to goat and sheep during summer (Fig. 1).

Mango (4.5 ha), minor fruit crops (22 ha) and cashew (2 ha) were planted along with 2-3 years old trees of teak (5.2 ha), teak + silveroak (120 ha) and *Melia dubia* (4 ha) for drought proofing and to promote agroforestry system in Mahalingapura village of Gadag district among 183 farmers in 157.7 ha (Fig. 2). Even under prolonged drought condition plant survival was around 65-70% (Table 1). Seedlings were planted on the bunds, which helped in conservation of soil moisture and reduced soil erosion (Nimbolkar *et al*., 2016).

In S. Raghuttahalli of Chikkaballapura district, 180 farmers were demonstrated planting of fruit crops mango (50 ha), tamarind (48 ha), cashew (5 ha), *amla* (0.5 ha), lemon (3 ha) and forest trees viz., *Melia dubia* (10 ha), silveroak (5 ha), *Acacia auriculiformis* (1 ha), pongamia (5 ha) in 134.5 ha to reduce risk from aberrant weather conditions and increase green coverage in the area to protect the soil and moisture. Similarly planting of *Melia dubia* (1 ha), drumstick (0.5 ha), teak (0.5 ha) and lime trees (0.5 ha) on bunds of fields were successfully demonstrated in dry land areas of Melakunda village of Kalaburgi district among 60 farmers in 2.5 ha that helped the farmers in conserving moisture and reduced soil erosion (Table 1).

Figure 1. *Promotion of agri+ horticulture at NICRA village of Tumkur district.*

Figure 2. *Promotion of cashew orchard along with agriculture at NICRA village of Gadag.*

Table 1. Dryland horticulture crops and forest trees planted in NICRA villages

KVK	Average rainfall (mm)	Soil type	Crops	Area (ha)	Farmer (No)	Climate resilient technology adapted	Survival %
Tumkur	899	Hillock area and red loamy soil	Mango	4.0	29	Trees were planted adjacent to trenche-cum- bunds; basin mulching; intercropping with nitrogen fixing legume crops	70
			Tamarind	7.0	41		71
			Amla	4.0	21		76
			Cashew	2.0	19		85
			Melia dubia	15.0	110		85
			Acacia auriculiformis	7.0	25		72
			Silver oak	2.0	15		69
			Pongemia	1.0	20		75
			Teak	1.0	11		65
			Neem	0.1	10		68
			Jamun	0.5	17		81
			Total	*43.6*	*318*		*74.3*
Gadag	363.9	Red gravelly sandy soils having shallow to medium soil depths	Mango ('Alphonso')	4.5	10	Diversification through introduction of fruit and forest crops for drought proofing. Promotion of tree-based farming system for enhancing the bio-mass production	73
			Teak seedlings	5.2	13		20
			Minor fruit crops	22	35		60
			Teak + silver oak	120	110		40
			Cashew ('Vengurla')	2.0	05		80
			Melia dubia seedlings	4.0	10		65
			Total	*157.7*	*183*		*56.3*
CB Pura	655.6	Red soils and Red loamy soils	Mango	50.0	180	Demonstration of tree-based cropping system	70
			Tamarind	48.0			
			Cashew	5.0			
			Melia dubia	10.0		.	
			Jamun	5.0			
			Lemon	3.0			
			Moringa (Nugge)	2.0			
			Amla	0.5			
			Silver oak	5.0			
			Acacia aurculiformis	1.0			
			Pongemia	5.0			
			Total	*134.5*	*180*		*70*
Davanagere	555.3	Wastelands Farm bunds	Mango	2.0	04	Trench-cum-bund formation	56.2
			Minor fruit crops	2.0	10		22.0
			Jamun	0.5	02		24.0
			Jack fruit	0.5	03		15.0
			Tamarind	1.0	10		12.5
			Amla	0.5	02		10.0
			Teak	5.0	21		35.0
			Silver oak	5.0	21		38.3
			Melia dubia	5.0	15		47.0
			Neem	1.0	05		43.0
			Honge	2.0	10		37.12
			Total	*24.5*	*103*		*30.9*
Belagavi	431.24 mm	Red soil-60% Black soil-40%	Mango Sapota	12	89	Dry land horticulture and Forest plants, grown as hardy crop.	5
			Teak	8	89		5
			Mango	3.2	34		40
			Guava	6.0	10		5
			Lime	0.2	02		55
			Custard apple	2.5	58		25
			Lime	0.5	44		40
				12.0	80		30
			Total	*44.4*	*406*		*25.6*
Gulbarga	745	Shallow to medium deep black soils	*Melia Dubia*	1.0	60	Planting on bunds of fields to control soil erosion	55
			Drumstick	0.5			
			Teak	0.5			
			Lime	0.5			
			Total	*2.5*	*60*		*55*

Dryland horticulture and forest trees were planted as hardy crops in trench-cum-bund of degraded ridge lands in Yadagud village of Belagavi district among 406 farmers in 44.4 ha (Fig. 3). In Siddanuru village of Davanagere district, wastelands and farm bunds were utilized by planting mango (2 ha), *jamun* (0.5 ha), jackfruit (0.5 ha), tamarind (1 ha) and *amla* (0.5 ha). Forest trees teak (5 ha), silveroak (5 ha), *Melia dubia* (5 ha), neem (1 ha) and pongamia (2 ha) were planted in trench-cum-bund treated area among 103 farmers in an area of 24.5 ha to reduce soil erosion and to improve water holding capacity.

Figure 3. *Promotion of mixed dryland horticulture.*

Growing crops with fruit trees are highly economical and minimize the risk occurring with sole cropping in low rainfall areas. Trees help in nutrient pumping from lower strata to the crop root zone (Kenneth *et al.*, 1999). The increase in productivity through this system could be due to capture of more growth resources like light, water or due to improved soil fertility (Pamo *et al.,* 2001).

Conclusion

Loss of biodiversity and ecosystem functioning due to agricultural intensification and deforestation is a major threat from changing climates in dry areas. Hence, alternate land use system has immense importance in these areas. In the present study of agri-horti-silvi-pasture system, the tree growth conserves soil moisture, improves soil fertility and protects crops against scorching and desiccating effects of hot winds. The trench-cum-bund also has helped to conserve soil and moisture during rainy period and led to 55% survival of plants in spite of long drought spells. This apart, the planting of dryland agri-horti-silvi-pasture trees has created greater awareness among the farmers about the role of trees in improving soil and water conservation besides helping in improving micro climate and carbon sequestration in the long run. Further, the integration of fodder trees provided the much needed top-feed for sustenance of livestock during lean period.

References

Katyal, J.C. and S.K. Das. 1992. Stability in dryland agriculture - Potential and Possibilities. *Indian Journal of Dryland Agricultural Research & Development* 7(1): 1-4.

Kenneth, R.M., Shopland Tourjee and Michele Warmard. 1999. Agroforestry, Horticulture and the Evolution of cropping systems. *Horticuture Science Journal* 34(1): 1-3.

Nimbolkar, P.K., Chandrakant Awachare, Subhash Chander and Firoz Husain. 2016. Multistoried cropping system in horticulture - A sustainable land use approach. *Indian Journal of Agricultural Sciences;* 8 (55): 3016-3019.

Pratap Narain. 2008. Dry land management in arid agro ecosystem. *Journal of Indian Society of Soil Science* 56(4): 337-347.

Pamo, T.E., G.D. Assontia and C. Njehoya. 2001.Comparative growth performance of West African dwarf goat supplemented with *Calliandra calothyrsus*, *Leucana leucocephala*or cotton seed cake in west Cameroon. Pages 713-714 *in* Proceedings of XIX International Grassland Congress, Brazil.

Sharma, C.U. and V. Sharma. 2012. Sustainability of agroforestry systems on acid soils for livelihood security. *Indian Journal of Agroforestry* 14(2): 27-36.

Theme 7: Livestock, Rangeland and Agroforestry Management

Lead Lectures and Rapid Presentation

Edible cactus for food, nutrition and environmental security in dry areas

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Abstract

Several species of cactus (Opuntia ficus-indica) are found growing as wild plants in arid and semi-arid areas of the world. Many species are edible, providing fruits and vegetable, and serve as source of renewable energy, medicinal products and colouring dye. These plants have been commercially exploited in countries like Mexico, Brazil, Argentina, Italy, South Africa, USA, Morocco, Tunisia, Israel etc. So far, no major efforts have been made in Asia to explore these species as a crop for food, nutrition and livelihood security. Cultivation of cactus as a commercial crop is not popular in India. Several species are found naturally growing as wild plants in wastelands, as protection fence on field boundaries or as decorative plant in homes and gardens. Because of their highest water use efficiency per unit dry matter production and tolerance to drought and high temperatures, cactus species have ample scope for cultivation in arid and semi-arid areas that support livelihood of more than 60% population. This paper summarizes about 25 years of research and development efforts for promotion of edible cactus in India.

Introduction

Cactus (*Opuntia ficus-indica*), commonly known as prickly pear, belongs to the family Cactaceae. In local parlance in northern India, cactus is called *nagphani* or *danda thohar*. In Tamilnadu, it is commonly known as *chapathi balli*. Family Cactaceae is reported to contain about 130 genera and nearly 1500 species, which were originally native to the New World. Cacti have a special carbon dioxide fixation pathway, Crassulacean acid metabolism (CAM), and are ideally suited to water-scarce dry zones of the world as an alternate source of food and fodder (Wessels, 1988; Mizrahi *et al.,* 1997; Singh and Felker, 1998; Han and Felker, 1997). Being water-use efficient, they are highly useful in arid and semi-arid environments, particularly because they can withstand prolonged dry spells or even a complete failure of the monsoon. However, the cactus is not merely a hardy ornamental plant, as is commonly believed; it is a storehouse of virtues that have been commercially unexploited so far in India. In addition, certain genera, such as *Optuntia* and *Nopalea* have economically useful plant parts. Different parts of the cactus can be used as fruit and vegetable for human consumption, fodder for cattle, and raw material for various industries to prepare plywood, soap, dyes, adhesives and glue, pharmaceutical products for treating blood sugar and various other disorders, and cosmetics such as shampoo, cream, and body lotions, etc. (Table 1) (Barbera *et al.,* 1995; Pimienta, 1994). The fruits of domesticated *Opuntia* cultivars are sold as a desert fruit in the markets of the USA, Chile, Mexico, Brazil, North Africa, Spain, Italy, and Greece. Similarly, the tender young pads of *Optunia* and *Nopalea* species, known as *nopalitos,* are extensively used as a fresh green vegetable in Mexico and Texas, USA. Even its seeds can be used as a flavouring agent. Use of cactus pear as a source of waterproofing paint for homes has also been reported (*The Hindu*, June 27, 2002).

Table 1. *Uses of Opuntia species*

Food	Fruits and fruit peel, juice, pulp, alcoholic beverages, jam, syrup
Forage	Stems/ cladodes, fruits, seeds, cultivated as forage shrub
Energy	Biogas, ethanol, firewood
Medicine	Diarrhoea (stem), diuretic (flower, root), amoebic dysentery (flower), diabetes (stem), hyperlypidemy (stem), obesity (fibres), antiflamatory (stem)
Cosmetics	Shampoo, cream, soaps, body lotions
Agronomic	Hedges and fences, mulching, soil improver, wind break, organic manure
Others	Adhesives and glues, pectin, fibres for handicrafts, paper (stem), dyes (fruit), rearing of *Dactyloptusoccus* on cladodes, antitranspirant, ornamental

Many species of cactus are found growing either as wild plants in arid and semi-arid regions of India or as an ornamental plant in urban homes and gardens. Generally, these species are used as live fences to protect agricultural fields from human and animal encroachments. With few exceptions, there has, so far, been no major attempt to cultivate this plant as a horticultural or fodder crop in India. In countries such as Mexico, USA, Spain, Italy, and in northern Africa, where the crop is commonly known, it already forms an integral part of the people's dietary requirement. In addition to the excellent quality and flavour of the fresh fruit, the young leaves serve both as a vegetable and as a salad dish and the immature fruit is used to make mock gherkins.

Edible cactus introduction in India

It is reported that cactus was introduced in India by British as dye crop during World War II. The ICAR-Central Arid Zone Research Institute (CAZRI) at Jodhpur made some introductions in 1970's but efforts were not very successful as the plant did not fruit under Jodhpur conditions. The Nimbkar Institute in Maharashtra also made some introductions from Dr. Peter Felker's collections in Texas, but crop did not spread to other areas because of lack of the coordinated effort at national and local levels. The author of this paper, who worked in Dr. Felker's laboratory as post doctoral FAO Fellow for four months in 1991, introduced five promising clones of edible cactus viz. '1270', '1271', '1280', '1287' and '1308' from Dr. Felker's collections in Taxas. This introduction formulated base for systematic research on cactus for further evaluation in different agro-ecological regions of the country.

Germplasm multiplication, evaluation and testing in different regions

The five clones introduced from Texas were planted in pots for multiplication. Nearly within a year, sufficient material was generated for experiments in microplots and in the field. Simultaneously, an orchard was established for supply of material to different research centres in the country (Fig. 1). Those clones have so far been successfully tested at Agra, Jhansi and Lucknow in UP, Bikaner and Jodhpur in Rajasthan, Baramati (Maharashtra), Bharuch (Gujarat) and several other stations (Fig. 2, 3, 4, 5). At most of the places it is used as fodder for animals. Most of these clones, however, also produced edible fruits. The quality/taste rating of the fruits by 25 people is reported in Table 2.

Figure 1. *Dr. Judith Ochoa from Argentina inspecting edible cactus orchard at Karnal, Haryana, India.*

Figure 2. *Dr. Peter Felker from Centre for Semi Arid Forest Resources, Texas A & M University, USA and Dr. Nick from HDRA, UK inspecting the cactus performance at CSSRI, Karnal, Haryana, India.*

Figure 3. Dr. Enrique Aries, FAO 'Cactus Net' Coordinator on a visit to cactus experiments at Karnal, Haryana, India.

Figure 4. Cactus clones planted at the experimental farm of National Research Centre on Agroforestry, Jhansi (Bundelkhand Region).

Figure 5. Evaluation trial for sodicity tolerance in which growth is markedly reduced in high pH soil medium.

In the recent past, International Centre for Agriculture in Dry Areas (ICARDA) initiated a mega project to evaluate and promote cactus cultivation for livelihood and environmental security in dry and drought prone areas of the country. Following this effort, a large scale introduction of germplasm has been made in India from the countries where cactus is cultivated as a commercial crop. This ICARDA-ICAR collaborative project needs to be further strengthened to develop package of practices for fodder, fruit and vegetable production in different regions of the country. Private sector partners, including NGO's, are coming forward to promote cactus cultivation in drought prone areas as biofence, soil and water conservation options, and as fodder, fruit and energy crop. Demand is increasing; the Central Soil Salinity Research Institute (CSSRI), Karnal sold cactus cladodes worth more than one lac rupees to various public and private agencies in the recent past. The vegetable clone '1308' was the fastest in sprouting (it took only 57 days) and fruit clone '1287' took maximum days (100 days) for sprouting (Table 3).

Tolerance to high pH: Performance of clone '1270' was evaluated for tolerance to high pH in ceramic pots each filled with 20 kg soil, with pH ranging from 8.1 to 10.0. Survival, growth and fruit production were drastically reduced when pH was raised beyond 9.2 (Fig. 5). There was a significant negative effect of pH of the medium on the initial sprouting of cladodes. The sprouting initiated after 54 days of planting at pH 8.1, whereas it took about 90 days at pH 10.0. The plants continued to survive at 10.0 pH but biomass production was almost negligible.

Table 2. *Rating of cactus fruit based on sweetness and taste on 0 to 10 scale by 25 respondents*

Score	Number	General remarks
8 and above	06	• Needs improvement for less seeds and more sugar • It is juicy and tasty
6 to 8	17	--
Less than 6	02	--

Table 3. *Days taken for growth initiation and number of cladodes formed by different cactus clones*

Clone and characteristic*	Days for sprouting	Cladodes / plant
1308 (V)	57	6
1270 (FF)	68	4
1271 (F)	91	3
1280 (F)	98	2
1287 (F)	100	1

* V = vegetable; FF = forage and fruit; F = fru

Method of planting: Establishment and survival of transplanted cladodes (unrooted) took 6 and 12 months after planting (Table 4). Erect planting gave 100% survival of plants after one year for clones '1270', '1271', and '1280'. Clones '1308' and '1287' recorded 83% and 75% success, respectively. Flat planting showed poor establishment for all clones. This may be because flat -planted cladodes were completely covered by a 2.5 cm thick layer of soil, while erect-planted cladodes were only partially buried in soil. In the latter case, sprouting took place from above ground parts of cladode. Rotting of cladodes was markedly higher when they were completely buried in the soil.

Table 4. *Percent survival of cladodes 6 and 12 months after flat and erect planting*

Clone	After 6 months		After 12 months	
	Flat	Erect	Flat	Erect
1270	83	100	17	100
1271	50	100	33	100
1280	33	66	17	100
1287	50	92	42	75
1308	17	100	--	83

Number of cladodes per plant: 'Clone1271' produced the maximum (18.4) cladodes per plant at 2 years of age (Table 5), closely followed by '1270 type' (18.1). The number of cladodes was minimum in clone '1308' (9.1), followed by '1287'. Both were at par but lower than others. Singh and Solanki (1999) reported that in arid zones of India, clone '1308' grows profusely when provided with sufficient water and fertilization during early stages of growth. However, at this site large damage by rabbits in clone '1308' was noticed, and growth was affected adversely. The fleshy nature of cladodes, due to higher moisture content in this clone, encouraged the damage by wild animals.

Average weight of cladodes: The average weight of cladodes (Table 5) was a maximum of 555 g in the case of clone ‘1271’, and was significantly higher than other types, followed by ‘1280’ (460 g cladode^{-1}). Clones ‘1270’ and ‘1287’ recorded an average weight of 340 g and 360 g, respectively, while ‘1308’ type recorded a significantly lower average weight (95 g cladode^{-1}). Biomass production after 2 years of plantation was significantly higher in clone ‘1271’ (Table 5).

Table 5. *Average number of cladodes per plant, weight of cladode, and biomass yield*

Type	Cladodes per plant	Average weight of cladode (g)	Biomass (kg plant^{-1})
1270	18.09	340	18.56
1271	18.42	555	30.61
1280	13.38	460	18.14
1287	10.34	360	11.15
1308	9.14	95	2.61
CD at 5%	2.41	75.18	1.57

Fruit production: Fruit production potential of cactus varies with climate, soil, variety and cultural practices. Under Texas conditions, where the rainfall is about 550 mm, fruit yields of 130 clones varied from 0.5 to 55 t ha^{-1}. It is reported that 7 clones yielded more than 20 t ha^{-1}. The fruit yield in four clones planted at Karnal varied from 5 to 15 kg plant^{-1} after 6 years. Clone ‘1270’ topped in fruit production closely followed by clone ‘1287’.

Fodder for livestock: The forage quality of cactus is reported almost comparable with several cultivated fodders. Its chemical composition, as forage crop, is reported to be as: moisture content 85-90%, crude protein 5-12%, P 0.08 to 0.18%, Ca 4.2%, K 2.3%, Mg 1.4% and energy 2.6 M cal kg^{-1}. The experiments conducted in Texas, Mexico and Brazil revealed that the forage quality can be improved by application of fertilizers, mainly N and P. Indian experience testifies that the cactus is a preferred forage species for wild animals.

Figure 6. *Cactus grown as a commercial fruit crop in Mexico.*

Post harvest value addition, marketing and trade

Cactus has been commercially exploited as fruit, fodder, vegetable and as dye crop in Mexico, Brazil, Argentina, South Africa and several other countries. Mexico is the largest producer and exporter of cactus value-added products. Several big farmers in Mexico have raised cactus plantations of 10 to 20 ha for export purposes (Fig. 6, 7, 8, 9). However, no major efforts have been made so far on marketing, value addition and trade issues of cactus in India.

Figure 7. *Several dishes made from the fruit and cladode of cactus.*

Figure 8. *Fruit harvesting and packaging in Mexico for marketing.*

Figure 9. Automatic machines for grading of cactus fruits in Mexico for export.

Efforts for promotion of cactus in Bundelkhand region - Cactus day celebration

The preliminary investigations carried out for two years with five clones of edible cactus in shallow-depth red soils of the rainfed Bundelkhand region clearly showed that edible cactus can be established successfully under these situations as an alternate source of forage, fruit, and vegetable during lean periods. Cactus cladodes remain green, even during May and June, when no other green fodder is available for milk cattle under Bundelkhand climatic situations. This characteristic makes this plant highly relevant for planting in fodder-scarce areas, particularly to supplement forage requirements during drought.

During fruiting season, a cactus day was celebrated in the cactus field at Jhansi in the Bundelkhand region of India by the National Research Center for Agro-Forestry (NRCAF), Jhansi. All the scientists, technical, and supporting staff of NARCAF participated in this event and tasted the fruit of this newly introduced crop (Fig. 10). All liked the taste and sweetness of the fruits (Fig. 11).

Figure 10. *Cactus Day celebration during fruiting season.*

Figure 11. *Freshly picked fruits of clone '1270' from cactus planted at Jhansi.*

Under the World Bank aided National Agricultural Technology Project, a project on developing live fencing practices with a budget of about US $400,000 is in operation at seven locations in India. In this project, edible cactus is being exploited as a successful live fence to protect agricultural fields from wild animals, particularly blue bulls and other stray animals. An average yield of 30 kg green biomass per plant in two years in the case of clone '1271', with no irrigation and fertilization, showed that nearly 37.5 t ha^{-1} of green fodder could be produced from soils that normally are considered unsuitable for other crops. Furthermore, there is a need to study the compatibility of cactus under agroforestry systems in this region. Since consumption of cactus-pears and *nopalitos* is almost unknown in this region, a strong extension service effort would be necessary to create awareness regarding nutritive value and different methods of utilization. A good extension service must also take into account not only the need for multiplication and supply of planting material but also popularization of the package of practices for cultivation.

Cactus in national drought management planning

The ICAR (Indian Council of Agricultural Research) has recently prepared a document on National Drought Management. Short-term and long-term strategies for moderating the present drought impact and drought proofing for the future have been suggested. In the long-term planning, planting of cactus on all kinds of wastelands, on field boundaries, roadsides, etc. in all the drought prone areas of the country has been strongly emphasized. On account of multipurpose uses of cactus, a cactus crop may prove a boon for the rehabilitation of degraded sites including wastelands. The low cost of establishing and producing the crop, as well as its tolerance to drought, make cactus imminently suited to becoming a viable future industry in India. The Thar desert in Rajasthan, Rann of Kutch in Gujarat, southwestern parts of Haryana, Bundelkhand, and other similar rainfed areas prone to severe drought would become very productive by the introduction of cactus.

Future direction

Since cactus has good potential for the arid and semi-arid India, it would be helpful if we could produce a research and development plan involving people having similar interests to import and exchange *Opuntia* germplasm. To start with, a centre for germplasm collection and its maintenance should be identified. Possibilities must be explored for international collaboration involving people from those countries where the crop is commercially cultivated and has already become a part of their dietary requirements. Also, there is a need for a coordinated effort within the country to promote cactus and its linking with the already existing international network on cactus.

References

Barbera, G., P. Inglese and E.B. Pimienta. (Eds.) 1995. Agro-ecology, cultivation and uses of cactus pear, FAO, Rome. 215 p.

Han, H. and P. Felker. 1997. Field validation of water use efficiency of CAM plant *Opuntia ellisiana* in south Texas. *Journal of Arid Environments* 36: 133-148.

Mizrahi, Y., A. Nerd and P.S. Nobel. 1997. Cacti as crops. *Horticultural Review* 18: 291-321.

Pimienta -Barrios, E. 1994. Prickly pear (*Opuntia* spp.) - A valuable fruit crop for the semi-arid lands of Mexico. *Journal of Arid Environments* 28: 1-11.

Singh, Gurbachan and Peter Felker. 1998. Cactus: New world foods. *Indian Farming*. April-June, 26-31.

Singh, Gurbachan and K.R. Solanki. 1999. Edible cactus: a potential crop to generate export from arid lands. Paper presented in the IVth Agricultural Science Congress, Jaipur. February 21-24, NAAS/RAU, Bikaner, India.

Sustainable grassland management, livestock production and ecosystem services in arid and semi-arid tropics

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Extended Summary

Grasslands represent a wide variety of ecosystems and consist of 26% of the world's total land area and 70% of agricultural land (Conant, 2010). Over the years grasslands have been one of the foundations of human activities and civilizations by supporting production from grazing livestock. This is still the situation, particularly for developing countries where 68% of grasslands are located. These grasslands have been utilized by livestock, particularly to produce meat and milk and to lesser extents fibre and draught power. This has arguably been at the expense of many other current and potential functions of grasslands. However, perspectives and perceptions of the most appropriate roles and functions of grasslands have been changing in recent decades.

There has been recognition that there are numerous regional, national and global issues with which utilization of grasslands are linked. These include the function of grasslands to provide social and cultural needs for many rural societies, their role in reducing greenhouse gas emissions, as water catchments, and the preservation of ecosystem biodiversity (Ghosh and Mahanta, 2014).

The global demand is increasing for food, which must be met without unacceptable adverse effects on ecosystem. There are more than 800 million people in the world with very low income, and an additional 200 million in the more marginal arid and semi-arid areas, who are highly dependent on grasslands for their livelihoods. Hence grasslands need to be better managed in order to best fulfil various functions. However, knowledge is often lacking, particularly for tropical grasslands. The knowledge that is available from the much more extensive studies of temperate grasslands often cannot be directly applied to tropical grasslands. Optimal management of tropical grasslands is challenging, especially given the diversity of agro-ecological contexts, the animal production constraints and soil-plant-animal interactions.

Optimal management for defined production, environmental and social targets will generally include inventories and assessments of the grasslands and grazing animals available and knowledge of the important herbage-animal relationships. The contribution of livestock to regional or national economies in developing countries like India is often under estimated by statistics which identify only saleable livestock food products (Thomas and Rangnekar, 2004). Apart from saleable livestock products, grasslands provide a variety of social and economic goods, and cultural services which constitute important components of the agricultural economy (Table 1). Many of the rural poor depend on livestock primarily as a security and safety net, and this role is often more important than that of livestock as a commercial enterprise.

Table 1. *Contributions of grassland based livestock production systems*

- Opportunity to produce otherwise scarce high-quality foods such as meat and milk
- Provision directly and indirectly of employment and economic activity, including for disadvantaged social subgroups
- Provision of household security and greater ability to deal with seasonal fluctuations such as crop failure and other disasters
- Transport of goods and people and a work force for various agricultural activities
- Contribution to soil fertility and crop yields (especially in marginal situations) while contributing to the recycling of by-products and reduction of wastes
- Control of weed and crop pests and diseases
- Provision of fuel as manure and biogas
- Opportunities for tourism as an industry (eco-tourism)
- Catchment areas for water supply to control runoff and to maintain water quality for urban supply and estuarine and marine environments
- Contribution to the national identity and to cultural and religious aspects of rural societies. In many countries these are important for social stability and social structures.

Source: Boval and Dixon (2012)

Grasslands of India play a major role in the economy of the country as these are used as pastures/forage resources for domestic grazing animals. They are also source of livelihoods of thousands of people as grass is also used as fuel, shelter and for various traditional activities. The estimates of grasslands and shrub lands in India vary from 3.7% to 12% of the total area (Krishnan *et al.*, 2012).

Grasslands in India are the least understood and the most underestimated natural habitats. Indian grasslands are also most neglected and abused ecosystems in the country. According a report by the Forestry Commission, nearly 40% of these protected grassland areas suffer from livestock grazing and fodder extraction. Grassland ecosystem in India varies depending on the factors like climate, soil, rain and geographical location. The species of grasses found in these grasslands has a great effect on their ecosystem. The native and naturally occurring grass species maintain a continuum of the mechanism of ecosystem as compared to introduced ones.

The functioning of the system very much depends on the biotic and abiotic components. The biotic components of the system are classified as producers (i.e. grasses, shrubs, herbs, mosses, lichens, algae, cyanobacteria etc.), consumers (cow, buffalo, goat, sheep, wild animals etc.) and decomposers (fungi, worms, bacteria etc.). The abiotic components are climate, parent material and soil, topography and natural resources, which are needed for biotic components. Many grassland improvement practices like introduction of legumes for better quality of forage, reseeding of grasses species for maintaining population and different soil and water conservation techniques need to be followed to obtain better provisioning services from these systems.

Grassland degradation is causing decline in ecosystem condition and widespread biodiversity loss, leading to reduced provision of ecosystem services and it may cause the irrevocable loss of ecosystem functions such as soil and soil moisture retention, regulation of water flows, and regulation of carbon and nitrogen cycles. Ecological restoration is regarded as a major strategy for re-establishing and increasing the provision of ecosystem services as well as reversing biodiversity losses, but conflicts can arise, especially if single services are targeted in isolation, and the recovery can be slow and incomplete. In addition, a lack of scientific understanding of the factors influencing provision of ecosystem services and of their economic benefits limits their incorporation into land-use planning and decision making (Haung *et al.,* 2014).

Many ecosystem services from grasslands are valued differently by various stakeholders, in which local stakeholders may tend to value productive services and specific ecosystem services such as hydrological services, while international valuations may apply to niche products or for biodiversity conservation services. Restoration of converted grasslands may improve ecosystem services functioning, in some cases to levels comparable with non-degraded grasslands, but may not be able to fully restore ecosystem service provision to that of natural grassland.

References

Boval, M. and R.M. Dixon. 2012. The importance of grasslands for animal production and other functions: A review on management and methodological progress in the tropics. *Animal* 6(5): 748-762.

Conant, R.T. 2010. Challenges and opportunities for carbon sequestration in grassland systems: A technical report on grassland management and climate change mitigation. FAO, Rome.

Ghosh, P.K. and S.K. Mahanta. 2014. Carbon sequestrations in grassland systems. *Range Management and Agroforestry* 35: 173-181.

Huang, L., X. Xu, Q. Shao and J. Liu. 2014. Improving carbon mitigation potential through grassland ecosystem restoration under climatic change in northeastern Tibetanplateau. *Advances in Meteorology* 2014. http://dx.doi.org/10.1155/2014/379306.

Krishnan, P., R. Ramakrishnan, S. Saigal, S. Nagar, S. Faizi, H.S. Panwar, S. Singh and N. Ved. 2012. Conservation across landscapes: India's approaches to biodiversity governance. United Nations Development Programme, New Delhi, India.

Thomas, D. and D.V. Rangnekar. 2004. Responding to the increasing global demand for animal products: Implications for the livelihoods of livestock producers in developing countries. *In*: Owen E Eta (Eds.) *Responding to the Livestock Revolution: The role of globalization and implications for poverty alleviation*. British Society of Animal Science, Midlothian, UK. pp. 1-36.

Agroforestry for development of dry Areas

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Extended Summary

Farmers of dry areas regularly face drought, high temperature, and insecurity for food, nutrition and fodder. Both, human and livestock populations equally suffer due to regular crop failure, and poor productivity of livestock further enhances food insecurity. Therefore, small holders of dry areas urgently require a diversified and integrated agriculture system to increase sustainability of dryland agriculture; provide alternative sources of nutritious food and fodder; reduce heat stress and increase the availability of water, organic carbon and nitrogen content of soil to enhance the resilience to climate extremes.

Agroforestry is defined as the practice and science of the interface and interactions between agriculture and forestry, involving farmers, livestock, trees and forests at multiple scales, which offers solutions to above mentioned challenges, and small holders of dry areas can easily adopt and practice the system.

Scientifically defined and implemented agroforestry systems provide innovative solutions to the challenges of dry areas. Besides delivering solutions to the local problems of the small holders living in dry areas through enhanced production of diverse and nutritious food, agroforestry enormously contributes towards international goals to increase tree cover, reduce soil degradation, sequester high amounts of carbon and sustainably increase the resilience to climate change.

To mainstream agroforestry, and harness its full potential in dry areas, small holders need policy support; access to proven agroforestry technologies, inputs, credit, and forward and backward linkages to market; insurance facility for planted trees, and strong support from extension services. A global status of dryland agroforestry was presented and some of the success stories shared in the conference.

Therapeutic utility of desert camel in using milk as functional food and using camelid nanobody in immunotherapy

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Abstract

Camel milk is a boon for human health as its milk contains all the essential nutrients found in bovine milk. Therefore, it has been used in different regions in the world including India, Russia and Sudan, as a treatment for a series of diseases such as dropsy, jaundice, tuberculosis, asthma and leishmaniasis or kala-azar. Besides, camel milk has other therapeutic properties (anti-carcinogenic, anti-diabetic and anti-hypertensive, renoprotactive). It has been recommended for children who are allergic to bovine milk. Camels produce antibodies (Abs) including a unique Ab that lacks light chains. The variable antigen-binding domains derived from these Abs, named 'nanobodies' (Nbs) are single domain antibodies having size of ~15 kDa, which are easy to produce and their modularity makes them amenable for the generation of multivalent complexes. The Nbs are being explored as therapeutics for various diseases, including oncology, inflammatory, infectious and neurological diseases, and imaging. In addition, their potential for use in the diagnosis and monitoring of diseases is also explored.

Introduction

The total population of camels in the world is estimated to be about 28 million, with Somalia having the largest herd worldwide (FAO, 2012). Camels are divided into two different species belonging to the genus *Camelus*. Dromedary camels (*Camelus dromedarius*, one humped) that mainly live in the desert areas (arid and semi-arid), and Bactrian camel (*Camelus bactrianus*, two-humped), which prefer living in the cooler areas. India has 0.40 million camels distributed mainly in Rajasthan, some parts of Gujarat, Haryana, Punjab and a few in the rest of the states. Owing to farm mechanization and mechanical means of transportation, utility of camel as draught animal has been reduced significantly.

Under the harsh conditions of desert ecosystem, camels have the capability to produce more milk than any other species and for longer periods of time (Farah *et al.,* 2007), while their feed requirements are modest (Wilson, 1998). Their average daily milk production is estimated to be between 3 - 10 kg (Farah *et al.,* 2007). The yield can increase to 20 litre per day under improved feed, husbandry practices, water availability and veterinary care (FAO, 2006).

Camel milk is a boon for human health as its milk contains all the essential nutrients found in bovine milk (Patel, 2018). Therefore, camel milks have been used in different regions in the world including India, Russia and Sudan, as a treatment for a series of diseases such as dropsy, jaundice, tuberculosis, asthma and leishmaniasis or *kala-azar* (Abdelgadir *et al.,* 1998). Besides, camel milk has other therapeutic properties: anti-carcinogenic (Magjeed, 2005), anti-diabetic (Agrawal *et al.,* 2007), anti-hypertensive (Quan *et al.,* 2008) and renoprotactive potential (Afifi, 2010). It has been recommended for children who are allergic to bovine milk (El-Agamy *et al.,* 2009).

Similarly, the members of the Camelidae (including camels and llamas) produce antibodies (Abs) including a unique Ab that lacks light chains. The variable antigen-binding domains derived from these Abs are named 'nanobodies' (Nbs) or single domain antibodies having size of ~15 kDa (Muyldermans, 2013). They are easy to produce and their modularity makes them amenable for the generation of multivalent complexes. However, antibodies from camels have been favored for biotech development because they are easier to handle. The Nbs are being explored as therapeutics for various diseases, including oncology, inflammatory, infectious and neurological diseases, and imaging. In addition, their potential for use in the diagnosis and monitoring of diseases is also explored.

Now camel husbandry practices are aimed for milk production and use of its immunology for human health. ICAR-National Research Centre on Camel (NRCC), Bikaner is a dedicated research institute working for promoting camels for human health. The details of utility of camel is described below.

Immunotherapy using camelid antibodies

As mentioned above, members of the Camelidae produce, in addition to the conventional antibodies (Abs), a unique type of antibodies lacking the light chains (Fig. 1). The variable antigen-binding domains derived from these Abs are named 'nanobodies' (Nbs) or single domain antibodies having size of ~15 kDa (Muyldermans, 2013). Nbs exert high specificity and affinity and, when properly selected, are more stable than conventional Abs. Furthermore, their toxicity and immunogenicity are both low. They are easy to produce and their modularity makes them amenable for the generation of multivalent complexes. The antibodies from camels have been favored for biotech development because they are easier to handle.

Nbs have a natural tendency for binding epitopes that are inaccessible to conventional antibodies. The innate supremacy of nanobodies as a renewable source of affinity reagents, together with their high production yield in a broad variety of expression systems, minimal size, great stability, reversible refolding and outstanding solubility in aqueous solutions, and ability to specifically recognize unique epitopes with subnanomolar affinity, have made them a useful class of biomolecules for research and various medical diagnostic and therapeutic applications.

Nanobodies versus conventional antibodies

Camelid IgG antibodies have a highly soluble antigen-binding V-domain, known as VHH, or nanobody, due to its size in the nanometer range. Nanobodies have a hydrophilic side that corresponds to the light chain of a VH antibody domain. Because nanobodies do not bind light chains, they are not complicated by the solubility and aggregation problems found in

VH domains of conventional antibodies. They also lack the CH1 domain of a conventional antibody, which connects to the light chain and interacts with the VH domain.

Advantages of nanobodies

Nanobodies have a number of advantages due to their single-domain structure. Libraries created from immunized camelids have full functional diversity, in contrast with the reduced diversity of conventional antibody libraries. Thus, high-affinity antigen-binding nanobodies can be isolated by screening a limited number of clones from immune libraries, without prior selection using display technologies. The single-domain structure also enables molecular manipulation. Nanobodies can be engineered into multivalent formats to increase affinity or to produce bispecific antibodies. Nanobodies are also expected to be more suitable for single-cell production of a mixture of antibodies (oligoclonal antibodies) because they eliminate domain mispairing. Nanobodies are functional even at 90°C, in contrast to conventional antibodies. This increased stability is attributed to greater hydrophilicity of the VL interface region. Nanobodies can also recognize unusual antigenic sites such as enzyme active sites, and can thus be used as enzyme inhibitors. The greater stability of nanobodies makes them very versatile in terms of potential applications. Additionally, following *in vivo* administration, they rapidly diffuse throughout the body and have good tissue penetration. Unfortunately, their small size is below the renal cut-off, leading to rapid renal clearance.

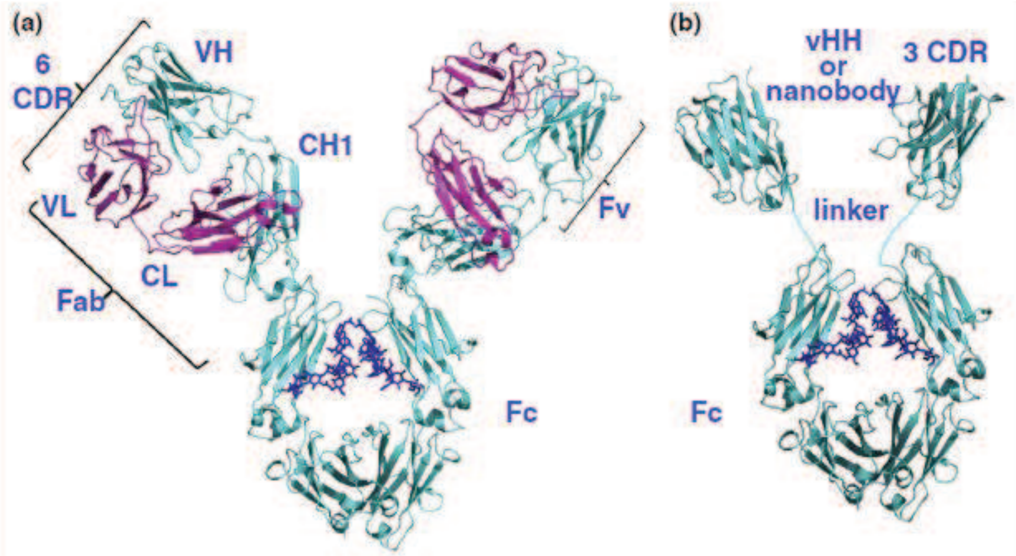

Figure 1. Classical and camelid nanobodies: (a) Composite representation of a classical IgG, with heavy (blue) and light (magenta) chains. Two recognition modules, a Fab fragment (VH, VL, CH1, CL) and a Fv fragment (VH, VL), are identified. Six Complementary Determining Regions (CDRs) form the antigen-binding surface. (b) Composite representation of a camelid IgG, with a heavy chain only (blue). The CH1 domain is replaced by a linker. The recognition module is a unique immunoglobulin domain called VHH or nanobody, with three CDRs.

Nanobody applications: Nanobodies have promise in the field of oral immunotherapy because they are stable at a range of pH levels and can bind their target in the presence of high concentrations of agents that disrupt hydrogen bonds in water. Other examples of therapeutic applications for nanobodies include sleeping sickness, infant diarrhea, dental cavities, and sepsis. Nanobodies are free of many of the complications and side effects found with conventional antibodies.

Nanobodies in therapeutics: Given their single-domain and hydrophilic nature, Nbs are well expressed in economic production systems, such as bacteria (*Escherichia coli*) and yeast (*Pichia pastoris* and *Saccharomyces cerevisiae*), yielding high batch-to-batch consistency. Nbs are well also expressed in probiotic bacteria and, when they are expressed in *Lactobacillus paracasei* or *Lactococcus lactis*, they are called 'lactobodies'. These are useful for the delivery of Nbs against pathogenic enteric bacteria. Additionally, because they are encoded by only a single gene (Vhh) comprising (approximately) 360 base pairs, Nbs are very modular and can be easily covalently linked to other molecules or prodrugs. As a result of their single-domain nature and intracellular robustness, Nbs are suitable for expression as intracellular proteins. These so-called 'intrabodies' can interact with intracellular targets, making it possible to target proteins that are otherwise inaccessible. This approach is particularly attractive because Nbs can readily fold in different reducing intracellular environments (e.g., the nucleus or cytosol). Additionally, Nbs retain antigen binding capacity in the absence of disulfide bonds, which are not formed inside cells.

Nbs in treatment of cancer: Nanobodies have potential to become important cancer therapeutics in the near future, displaying unequalled and unprecedented efficacies in treatment. In contrast to mAbs, they are distributed homogeneously in tumor tissue. As anti-cancer biological agents, Nbs can be used as antagonistic drugs. Additionally, they can be decorated on nanoparticles (NPs) that can be filled with other (small-molecule) anticancer drugs for active targeting to the specified tumor cells.

Nbs incorporated into drug delivery systems: Nbs can also be chemically attached to the surface of other drug delivery systems, such as nano sized drug carriers or NPs, which can then be encapsulated with nonspecific drugs for active delivery to the site of interest. Additionally, it permits administration of larger drug doses simultaneously, which could reduce the administration frequency and immunogenicity.

Nbs in targeted radionuclide therapy and photodynamic therapy: Radioimmunotherapy (RIT) is the combination of radiation therapy with Ab immunotherapy and has become an attractive strategy in cancer treatment because it allows the selective destruction of cancer cells and constitutes less invasive radiotherapy: the Ab recognizes and binds the surface of the primary tumor site and disseminated disease tissue and thereby delivers high doses of radiation directly to the tumor without any damage to healthy tissue.

Nbs used for* in vivo *medical imaging: The use of radiopharmaceuticals in medical imaging has become widespread. This technique enables not only easy, noninvasive investigation of biological processes, but also early detection of disease and monitoring of disease progression and response to therapy. Furthermore, their potential can be extended to other diseases in which activated inflammatory cells have crucial roles in pathogeneses, such as type I diabetesmellitus and atherosclerosis.

Nbs to combat infections: Antibodies are natural defense molecules against bacterial, viral and parasite infections. It is well established that polyclonal antibodies are more effective at combating such infections than monoclonal antibodies. However, the possibility to screen thousands of antigen-specific Nbs from immune VHH libraries, in conjunction with their intrinsic capacity to target epitopes, which are cryptic for conventional antibodies, has provided access to a number of neutralizing Nbs against a myriad of pathogens. A successful Phase I clinical trial with Nbs targeting respiratory syncytial virus has demonstrated the potential of Nbs to combat infections. Alternatively, the strict monomeric nature of Nbs facilitates their fusion with molecules with innovative effector functions, such as enzymes or toxic molecules, in order to eradicate the pathogen.

Nbs targeting viruses: To fight viruses and prevent their spread, Nbs can interfere at different levels of the viral replication cycle, such as by preventing virus-cell attachment, viral entry, and viral uncoating. Nbs can also be used to broaden our understanding of viral cell-cell transmission. A Nb directed against hepatitis C virus (HCV) specifically prevents viral cell entry and cell-cell transmission. The possibility of expressing Nbs as intrabodies might be an advantage in the treatment of viral infections.

Nbs targeting bacteria: Currently, bacterial infections are mainly treated with antibiotics. Because of development of antibiotic resistance and the high cost of treatments, an alternative therapeutic approach is required. Nbs to combat bacteria can be raised against bacterial surface proteins to block bacterial attachment to host cells. Based on this principle, Nbs against the lectin domain of F18 fimbrial adhesin of the enterotoxigenic *E. coli* (ETEC) and Shiga toxin-producing *E. coli* (STEC) prevented attachment in vitro. Nbs might be prone to proteolytical cleavage, although to a lesser extent than Abs; however, the challenge in tackling enteric pathogens in particular is to design orally administered Nbs that survive the gastrointestinal tract. Another elegant approach is the development of Nbs that are not directed against the bacteria as such but against their virulence factors, such as the secreted enzymes that are pathogenic or confer resistance against antibiotics.

Nbs against parasites and fungi: The use of Nbs against parasites is new but is gaining attention. This is illustrated by using Nbs against African trypanosome parasites, such as the potent trypanolytic Nb An46 via antigenic variation of the variant-specific surface glycoprotein (VSG) on the densely packed surface of the Afican trypanosome parasite, these hemoparasites have evolved a potent immune evasion system to avoid Ab mediated elimination; this makes Nbs an attractive alternative to bind the difficult-to-reach conserved VSG epitopes. The fungus *Malassezia furfur* is implicated in the formation of dandruff and Nbs against the cell wall protein Malf1 remain stable in shampoos that prevent dandruff formation. Nbs are highly suitable for this approach because they remain stable under harsh conditions, such as high urea concentrations, and the presence of both nonionic and anionic surfactants can easily be selected during panning.

Nbs as neutralizing and/or detoxifying agents: Current antivenoms are polyclonal immunoglobulin fragments purified from the blood of venom-immunized horses and sheep. However, these antivenoms are often associated with low potency, variable efficacy and severe adverse effects (e.g., serum sickness). This low potency is mainly attributed to a poor immune response of host animals because most toxic compounds within venom are small and poor immunogens. Owing to their small size and the absence of an Fc region, Nbs diffuse rapidly through the body and reach a tissue bio distribution that closely matches that of the small venom toxins. As a result, a bispecific Nb against the toxic molecules in scorpion venom was shown to possess, a higher neutralization capacity than the current anti-scorpion toxin immunotherapy (Hmila *et al*., 2010). Intact camelid IgG antibodies and, in particular, their Nb derivatives are equally or more potent than the conventional antivenoms in neutralizing the lethal, hemorrhagic and coagulopathic effects of west African viper (*Echis ocellatus*) venom [Harrison *et al*., 2011]. The camel IgG antivenom (monospecific) is supposed to be more efficacious than currently used equine anti-venoms or hence will serve as a better choice in treating snake specific envenoming. Nbs are directed against bacterial compounds or toxins, for example the Nb against *Neisseria meningitidis* lipopolysaccharide (LPS), which causes meningitis in young children. The anti-LPS Nb blocked binding of LPS to target cells of the immune system, which abolished LPS signaling in whole blood. Antitoxin Nbs were also successfully generated to neutralize the cholera toxin (staphylococcal enterotoxin B), the *Clostridium difficile* toxin (CDT), the Shiga toxins, and the toxins from *Bacillus anthracis* (anthrax). Additionally, multiple Nbs against the dangerous botulinum neurotoxins (A and E) have been described and some provided prophylactic protection when given as a genetic therapy using an Nb-expressing adenovirus vector. Finally, even Nbs expressed as intrabodies, for example against the *Salmonella typhimurium* toxins, proved to be efficacious in vitro. This approach is necessary because this pathogen is intracellular and secretes its toxin directly into the cytosol of the host cell.

Nbs used as diagnostics: Nbs could be exploited not only as therapeutic agents, but also for diagnostic purposes or used in detection of biothreat organisms or agents. For example, a Nb against recombinant N protein (prND85) of a Hanta virus strain was used in enzyme-linked immunosorbent assays (ELISA) and could rapidly detect the native viral antigen in serum samples. Also, species-specific Nbs against Taenia and Brucella were developed that enable the easy distinction between different bacterial species. Such Nbs can also be included in other systems; they can act as capture agents in enzyme immunoassays (EIA) or surface plasmon resonance (SPR) assays for the early and highly accurate diagnosis of viral, bacterial, or fungal infections. Additionally, rapid and sensitive detection assays for influenza H3N2 and H5N1 were developed using a double-sandwich ELISA model in which biotinylated Nbs were immobilized onto the surface of streptavidin-coated plates. NRCC in collaboration with Bhaba Atomic Research Center (BARC), Mumbai, is doing research on development of cameline single domain antibodies-based diagnostics and therapeutic modules against human and animal diseases. In this study, single domain antibody of camel was raised against Tg, a protein for diagnosis of thyroid cancer and indigenous IRMA diagnostic kit was developed. Similar kind of nano antibodies has been raised and is being used to identify the specific protein of tuberculosis organism.

Nbs against inflammation: Strategies to alleviate the inflammation are mainly anti-inflammatory drugs and drugs that interfere at the cytokine level. Given that tumor necrosis factor (TNF) is a major key player in inflammation, it is not surprising that anti-TNF Nbs have been developed, as discussed below. The Nbs were effective inflammation suppressors in the mouse collagen-induced arthritis model, and might be a promising and cost-effective alternative treatment for RA because current anti-TNF therapeutics imposes a heavy economic burden on health services. Furthermore, autoimmune diseases can also be tackled with anti-IgG Nbs to deplete auto-IgG by plasmapheresis, a blood purification method. Patients with systemic lupus erythematosus (SLE) or Goodpasture syndrome were treated with hemodialysis and the auto-Abs were effectively removed from the blood on an affinity column that used the anti-IgG Nbs as ligand. Eventually, this approach could be extended to other autoimmune diseases that involve many auto-IgGs (e.g., myasthenia gravis).

Immunotherapy to intervene in the intrinsic immune system: Previous approaches aimed to reduce the proinflammatory functioning of cytokines; but several cytokines also have anti-inflammatory, anticancer, or antiviral properties. Unfortunately, the intrinsic toxicity of these cytokines has hampered their use in medicine. However, this dilemma can be circumvented by linking the cytokines - mostly engineered in a less toxic and/or less active form, to Nbs that guide the so-called 'immunocytokines' to the desired target cells. This 'activity-by-targeting' approach was validated for mutant type I IFNs fused to a Nb targeting the murine leptin receptor and led to antiviral activity on targeted cells.

Nbs in neurodegenerative and other amyloid disorders: There are currently only symptomatic treatments for neurodegenerative disorders; no disease-modifying or neuroprotective therapies that alter the natural disease course are available. Alzheimer's disease is the most common neurodegenerative disease, characterized by the cerebral deposit of aggregated amyloid-b (Ab) peptideplaques and formation of neurofibrillary tangles, resulting in dementia and loss of cognitive functions. Ab plaques are formed via proteolytic cleavage of a large precursor protein, amyloid precursor protein (APP), by enzymes such as Beta-site APPcleavage enzyme (BACE-1). Nbs that are selective for different amyloid (precursor) peptides have been produced, and Nbs that can prevent the formation of mature Ab fibrils by stabilizing Ab protofibrils have been identified. The finding that blood brain barrier (BBB) transport is possible via the Nb platform is of paramount importance because, unlike conventional Abs, several Nbs were reported to cross that barrier, partially because of the absent Fc-receptor-mediated efflux to the blood.

Conclusion and future perspective

Fresh camel milk and their products are a good nutritional source for human health. Extensive research is needed to confirm these proposed health benefits. Possibility of benefit of Nbs, the Camelidae Nbs will make a substantial difference in therapy, diagnostic screenings and research. Besides Nbs developed to combat cancer, diseases such as amyloidoses, viral infections or toxin envenoming could be treated with future Nb-based therapeutics. For diagnostic applications, Nbs developed for noninvasive *in vivo* imaging of tumors and lesions definitely have great potential. In addition, their application as a highly specific probe on microarrays or in novel biosensors will grow steadily in the very near future.

There is an urgent need of having a policy in place to conserve and improve the camel breeds considering their milk production ability, utility of camel milk, its special immunology features; and also looking into fast decline in camel population in India.

References

Abdelgadir, W.S., T.K. Ahmed and H.A. Dirar. 1998. The traditional fermented milk products of the Sudan. *International Journal of Food Microbiology* 44: 1-13.

Afifi, M.E.M. 2010. Effects of camel's milk on cisplatin-induced nephrotoxicity in Swiss albino mice. *American Journal of Biochemistry and Biotechnology* 6(2): 141-147.

Agrawal, R.P., S. Budania, P. Sharma, R. Gupta and D.K. Kochar. 2007a. Zero prevalence of diabetes in camel milk consuming Raica community of north-west Rajasthan, India. *Diabetes Research and Clinical Practice* 76: 290-296.

El-Agamy, E.I., M. Nawar, S.M. Shamsia, S. Awad and G.F.W. Haenlein. 2009. Are camel milk proteins convenient to the nutrition of cow milk allergic children. *Small Ruminant Research* 82: 1-6.

Farah, Z., M. Mollet, M. Younan and R. Dahir. 2007. Camel dairy in Somalia: Limiting factors and development potential. *Livestock Science* 110: 187-191.

Harrison, R.A., D.A. Cook, C. Renjifo, N.R. Casewell, R.B. Currier and S.C. Wagstaff. 2011. Research strategies to improve snakebite treatment: challenges and progress. *Journal of Proteomics* 74(9): 1768-1780.

Hmila, I., D. Saerens and R.A. Ben Abderrazek. 2010. Bispecific nanobody to provide full protection against lethal scorpion envenoming. *FASEB Journal* 24(9): 3479-3489.

Magjeed, N.A. 2005. Corrective effect of milk camel on some cancer biomarkers in blood of rats intoxicated with aflatoxin B_1. *Journal of the Saudi Chemical Society* 9: 253-263.

Muyldermans, S. 2013. Nanobodies: Natural single-domain antibodies. *Annual Review of Biochemistry* 82: 775-797.

Ochoa, T.J. and T.G. Cleary. 2009. Effect of lactoferrin on enteric pathogens. *Bio-chimie* 9: 30-34.

Patel, R.K. 2018. Camel milk- A boon for human health. *International Journal of Trend in Scientific Research & Development* 2(4): 2543-2546.

Quan, S., H. Tsuda and T. Miyamoto. 2008. Angiotensin I-converting enzyme inhibitory peptides in skim milk fermented with *Lactobacillus helveticus* 130B4 from camel milk in Inner Mongolia, China. *Journal of the Science of Food and Agriculture* 88: 2688-2692.

Wilson, R.T. 1998. Camels. London, UK: MacMillan Educational Press Ltd. CTA series.

Climate resilient dairy production systems in India

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Abstract

Dairy production has become an important component of rural livelihood system and has strong socio-cultural link. The improvement in dairy production will be important in the coming years because of climate vulnerability and increase in demand of dairy products. Rise in surface temperature will hasten livestock vulnerability to heat stress, diseases occurrence and availability of feed and fodder resources, which may reduce milk production. Several climate smart practices are developed and refined under field conditions for implementation viz. better shelter systems, restoration and management of pasture lands, manure management and crop-livestock integration. An integrated farm approach needs to be adopted for reducing the impact of climate stress on livestock. There are three major possible options viz., physical modification of the environment, genetic improvement of heat tolerant breeds and improved nutritional management to minimize the effects of climate stresses on dairy production. Introduction of silvi-pasture system can be a successful integrated farming approach that provides feed as well as shelter during summer months to dairy animals. To enable the farmers for climate resilient dairy production, a favorable policy environment in terms of access to micro-credit, assured market and veterinary services need to be created and socio-economic and technical constraints addressed.

Introduction

Dairy production is considered important for achieving much needed socio-economic change, improved income and quality of life and equity (Rangnekar, 2006; Misra *et al.,* 2010). India ranks first in milk production in the world accounting for 19% of global production. The production is around 176.35 million metric tons (2017-18), with annual growth rate of 6.38% during the last four years that has outpaced global milk production rate (2.09%). The per capita availability of milk has gone up to 375 g day^{-1}, which is more than the world average of 294 g day^{-1}.

According to the livestock census 2012, the country has about 57% of world buffalo and 16% of world cattle population with 94 million in-milk cattle and buffaloes. The average productivity of in-milk cattle and buffalo is about 4.95 kg d^{-1} (2017-18), which unfortunately is far below the productivity levels of in-milk dairy animals in developed nations. The low productivity is owing to adverse impact of climate change, use of low external input, rising feed and fodder costs, lack of support services, price volatility due to integration with global market and lack of awareness of livestock farmers on scientific animal management.

Climate change has both direct and indirect impact on efficiency and profitability of dairy farming. The existing climate models showed that the average annual temperature in most parts of the country remains above the thermo-neutral zone (TNZ) of cattle and buffaloes. Climate change projections for India have suggested that temperature will increase by 2.3 -

4.8°C, along with increased humidity. The increase will be throughout the year, and will be more pronounced in the northern parts of India (Sanjay *et al.,* 2017). These hot-humid conditions, with rise in summer temperature (April to June), would possibly aggravate heat stress and further adversely impact the productive and reproductive performance of dairy animals. The milk yield of cattle and buffaloes in India may be reduced by 10-20% due to climate change depending upon the breed and production levels (Upadhya *et al.,* 2013). Variability in weather and extreme events (e.g. excessive rain in short time, frequent drought, heat, cold etc.) due to climate change may cause the shortage in the fodder availability and may further increase the gap in demand and supply of feed and fodder for livestock. Though technologies to improve productivity of dairy animals under changing climate do exist, however, the rate of adoption in smallholder farming systems is generally low, because of several constraints (Misra and Ponnusamy, 2019).

An overview of Indian dairy production system

Rearing of dairy animals in India has broader social and economic dimensions. About 73 million rural households, mostly small and marginal farmers and landless labourers are engaged in dairying. The systems of rearing are complex and often based on traditional socio-economic considerations, mainly guided by the available feed resources. Low capital investment, short operating cycle and steady returns, make dairying a preferred supplementary livelihood options for rural households (Rath, 2019). Cattle and buffalo farmers have organized themselves into dairy cooperatives for milk collection and marketing. Medium to large herds of cattle and buffaloes also exist in the urban areas, mainly for supply of milk. The existing dairy production systems can broadly be classified into (i) small holder production with little or no land, and (ii) commercial production. The former is an important component of agriculture and contributes to sustainability, resilience and stable family income and it works as an insurance against crop failure due to weather vagaries. The system also provides manure for crop production and animals are used for rural transport. It is one of the most important self-employment generators for the rural masses. While the share of women in crop production activities is about 40%, it is about 70% in livestock production. This is mainly because women have the responsibility of nutritional security in the family and the livestock enterprises provided them a cash flow.

The smallholder dairy production systems are presently contributing >90% of national milk production. The farm structure in India is changing - the number of household farms with 1-5 milk animals is declining, while family farms with 10-50 dairy animals are increasing (Anonymous, 2017). Presently, 79% of the cattle and buffaloes live on small holder farms, whereas 20 years ago this was almost 84%. Indian dairy sector is thus characterized more by 'production by masses than mass production'.

Majority of farmers in India is practicing traditional methods of rearing, resulting in poor economic returns and low productivity. The average milk yield of crossbred cows in India is around 7.15 kg d^{-1} as against an average milk yield of 5.15 kg d^{-1} and 2.54 kg d^{-1} of a buffalo and indigenous/non-descript cow. The important factor determining the price of milk is mainly the fat and sometimes SNF percentage. Since buffalo milk contains higher fat content compared to that of native cows and crossbreds, the farmers prefer to rear buffaloes over cows (DADF, 2018). Another unique feature of dairy farming in India is their peri-urban or urban nature, making it preferred activity for households with poor educational background and limited natural resources. The expanding market for dairy products offers an opportunity for the small farmers, and even for those who do not have access to land and capital resources, to augment their income and livelihood through dairy production utilizing common pool resources.

Impact of climate change on dairy production

Studies have indicated negative impacts of climate change on dairy farming. The direct effects are mainly because of the heat stress on the livestock that affects production in multiple ways. The indirect effects include reduction in availability of feed and fodder and increased spread of existing vector-borne diseases to the cooler areas and emergence and spread of new diseases. The negative effects of climate change are already visible in areas with high ambient temperatures and low rainfall, and frequent droughts (IPCC, 2001). The ambient temperature beyond TNZ is stressful to the animals. The temperature-humidity index (THI) range between 70 and 75 is found best for performance of dairy animal. When it exceeds 80, which happens normally in North India during summer and hot-humid conditions, there is an increase in body heat storage beyond its capacity to tolerate especially in temperate/ crossbred cattle and buffaloes. In eastern part of India, where there is high humidity, rise in minimum temperature reduces average daily milk yield of the crossbred animals.

Different species have different sensitivities to ambient temperature and humidity. The capacity to tolerate heat stress is much higher in tropical breeds of cattle than crossbreds of temperate breeds. This is mainly due to the fact that tropical breeds of cattle can dissipate excessive heat more effectively by sweating, whereas crossbreds have relatively low ability to sweat. During hot-humid conditions the thermoregulatory capability of temperate and crossbred cattle and buffaloes to dissipate heat by sweating and panting are compromised, leading to heat stress during hot-humid conditions. In more than 85% places in India livestock experience moderate to high stress during the day in April, May and June and THI ranges from 75-85 at 2.00 PM (Upahyay *et al.,* 2013). The THI exceeds 85 at about 25% places of India during May and June. Even in the morning, THI level remains high during these months and on an average exceeds 75 at 75-80% places in India. The THI greater than 75 affects growth and milk production of high producing cows and buffaloes. THI above 80 severely impacts their health and production. The congenial THI for optimum production from dairy animals (i.e. 70) is during January and February at most places in India and only about 10-15% places have this optimum THI during summer and hot humid season. Buffaloes and high producing cows suffer most at high ambient temperatures associated with high humidity (THI >80) and therefore, severe heat stress often leads to loss in their performance due to physiological responses and energy expenditure (Singh *et al.*, 2017).

Buffaloes are more sensitive to heat stress due to black coat color and lower density of sweat gland, and therefore are not able to maintain their core temperature during heat stress (Marai and Habeeb, 2010). Hot dry summers with limited access to water affect buffalo's heat expressions particularly from March to June, when animals have relatively non functional gonads with less number of sperms in semen of males and poor expression of heat in females, mainly due to higher thermal heat loads that animals are unable to dissipate. Non-availability of water further affects buffaloes adversely during summer.

A change in temperature with changes in photoperiodicity can lead to reproductive malfunctioning due to hormonal events. Heat stress also has adverse effect on reproduction starting from symptoms and duration of estrus, size and development of follicles in the ovary and early embryonic development (Rensis and Scaramuzzi, 2003). Dairy animals exposed to heat stress after first week of insemination had reduced fertilization rate. High temperatures coupled with high humidity modulated follicular dynamics and estrus expression leading to increased incidence of silent estrus and summer anoestrus in buffaloes (36.6% - 59.5%) in India (Das and Khan, 2010).

Climate also has indirect effects on livestock performance by affecting the quantity and quality of crop residues, pasture grasses, crop biomass and distribution of livestock diseases and vectors. The global warming may increase the lignifications in plant tissues and cause a shift from C_3 grasses to C_4 grasses. Livestock diseases are strongly influenced by climate change induced modification of environmental conditions (FAO, 2006). Incidence of parasitic and viral diseases is likely to increase. Rise in ambient temperature and relative humidity will favour growth and spread of insects/vectors in susceptible population. Temperature has direct effect on survival of vector and seasonality of pathogen transmission, whereas, rainfall can have impact on the risk of transmission of vector-borne diseases. Incidences of FMD, HS and tick fever are likely to be more frequent due to climate change (NAAS, 2013). The higher infestation of ticks (Kumar *et al.,* 2004) and clinical mastitis was reported during hot and humid season (Singh *et al.,*1996) due to rise in THI. It is anticipated that with increased environmental temperature, microbial load in milk will also increase, causing early deterioration of milk quality and spoilage and thus will lead to public health issues.

Strategies for climate resilient dairy production

To increase climate resilience in small holders' dairy production system, an integrated farming approach needs to be adopted. There could be four major possible strategies to minimize the effects of climate change on dairy production; (i) physical modification of the environment, (ii) improved nutritional management, (iii) genetic improvement of heat tolerance of breeds, and (iv) crop-livestock integration.

Physical modification of the environment

Temperature-humidity index (THI) has been used as a weather safety index to monitor and reduce heat-stress-related losses (NRC, 1981). Under TNZ, dairy animals maintain body temperature without much energy utilization and this zone is considered as comfortable zone. The TNZ varies from 15-25°C for crossbred cattle and 15-28°C for indigenous cattle (Singh and Upadhyay, 2009). The comfort zone range of ambient temperature for growth and reproduction in buffaloes is 13-18°C, relative humidity of 55-65%, wind velocity of

5-8 km h^{-1} with a medium level of sunshine (Payne, 1990). The upper limit of TNZ has more significance in tropical and subtropical climate. The upper critical temperature is lower in exotic breeds and their crosses than indigenous breeds. The behavioral and physiological relationship is used to evaluate the adaptive capacity and welfare of animals. The ambient temperature around 25°C is found to be suitable to achieve maximum productive performance under tropical climatic conditions. Based on THI, the level of heat stress can be classified as comfortable (<72), mild (72-80), medium (80-90) and severe (>90). The high producing crossbred cattle show decreasing yield when the THI rises above 74. The threshold level of THI may vary from breed to breed, level of production and adaptability of the animals in different agro-climatic conditions. The more drastic reduction in milk yield was observed in high yielding dairy animals than low yielders due to high metabolic rate resulting in more heat production.

Provision of shed: The adverse effects of heat can be reduced by adopting simple and basic rules of animal shed design (shape, orientation and thermo-physical properties of construction material, ventilation, etc.). The environmental modifications attempt to reduce heat stress by reducing the solar radiation and temperature around the animal. The provision of shade (natural or artificial) is one of the simplest and most cost-effective methods to minimize heat stress. Shade provides protection from direct sunlight and allows cooling effect of wind. Productive and reproductive performance of Holstein Frisian cows can be increased by providing adequate shade during summer. Provision of shade helped in maintaining the productive performance and reduced the radiant heat load up to 30% (Blackshaw *et al.,* 1994). Trees provide shade to animals and have cooling effect due to transpiration of water from their leaves. The silvi-pasture system or plantation of fodder trees in grazing area provides feed as well as shelter during summer (Sastry *et al.,* 2012). Artificial shades have been used with success for heat-stressed animals in confinement or in intensive situations. East-west orientation is most suitable design of shed under hot arid condition (CAZRI, 2012). Various types of roofing materials can be used for shade structures. The most effective is a reflective roof such as that of white asbestos (Sastry *et al.,* 2012).

Cooling during summer: There are many methods of cooling during hot and dry conditions, but evaporative cooling is the most effective. During summer season, significant impact of evaporative cooling was observed during late gestation in Murrah buffaloes (Aarif and Aggarwal, 2015). The cooling effect using mist fans (3 hours each in forenoon and afternoon) showed significant improvement in milk yield in lactating Holstein Friesian cows as compared to control groups (Reyes *et al.,* 2010). Cattle housed in pens and cooled by water spray and fans showed improvement in milk production, milk fat and postpartum reproductive performance, calf birth weight, etc. compared to non-cooled Holstein Friesian cows in hot and dry conditions (Singh *et al.,* 2017).

Improved nutritional management

Livestock diets, usually dominated by crop residues and other low-quality feeds, require inclusion of more energy-rich feeds to increase productivity. Various feeding strategies have been tried to alleviate the adverse effect of climate change with varying degrees of success.

Good feeding practices alone can help in methane mitigation by one fourth in poorly fed animals. The aim of nutritional management is to maintain water balance, nutrients and electrolytes intake to satisfy the special needs, such as vitamins and minerals during climate stress.

Strategic supplementation: The crop residues provide an inexpensive feed source, but these feeds are generally of low digestibility, and deficient in crude protein, minerals and vitamins. Lower digestibility of such feeds decreases animal productivity and enhances methane emissions through enteric fermentation. Improving the digestibility of feed rations by improving the quality of crop residues, or supplementing diets with concentrates will reduce CH_4 emissions. Other existing feed management practices in mixed farming systems include the use of improved fodder species and forage legumes. The depressed feed intake in hot weather is commonly considered as an adaptation to reduce metabolic heat production. It has been suggested that low crude protein or fiber diets should attenuate the depressed intake associated with heat stress. Practically, two main nutritional strategies are adopted to minimize the reduction of energy and nutrient intake under heat stress: (i) using energy or protein concentrate diets to overcome the low DM intake and (ii) using low increment diets to improve DM intake. Whatever the species, several studies have shown that increasing the energy content of the diet via fat addition can partially overcome the effect of heat stress. In fact, this practice not only increases the energy intake but also reduces the diet heat increment. Some approaches have been successful, such as decreasing fiber intake in order to allow the rumen to function properly, adding fat supplementation (mostly because of its high-energy content and low heat increment) and implementing increased concentrate diets with caution to avoid metabolic disorders. Strategic supplementation of fatty acids according to physiological stage can selectively benefit immune function, maximize production and improve reproductive responses.

The alteration in electrolyte status must be corrected by mineral supplementation. The primary avenue for heat loss under heat stress are sweating and panting. Cattle lose large amount of minerals via sweat (especially potassium and sodium). In heat-stressed lactating cows, potassium and sodium supplementation above NRC recommendations resulted in 3-11% increase in milk yield. It has been observed that mineral mixture and antioxidant supplementation protected the animals from the adverse effects of heat stress on feed and water intake, respiration rate and rectal temperature (Sejian, 2013). Reduction in postpartum estrus interval, days to first insemination, service period, services per conception and increase in the conception rate in Karan Fries cows was recorded due to supplementation of Zn (Patel *et al.,* 2016).

The combination of vitamin-E and Zn supplementation showed an improvement in immunity during *peripartum* period and improved the milk yield in Sahiwal cows (Chandra *et al.,* 2014). Vitamin C supplementation has been found to ameliorate the adverse effect of heat stress and worked as immune-modulator (Ganaie *et al.,* 2013). The supplementation of sodium bicarbonate stimulates saliva production and direct-fed microbes or yeast are also helpful in maintaining rumen pH in heat stressed cattle and buffalos.

Chopping of fodder*:* Chopping of fodder should be popularized for judicious use at farm level. Feeding chaffed feed avoids wastage and prevents selective consumption. The net biological value of the feed also improves. Misra *et al.* (2006) reported that chaff-cutter use reduced wastage of the fodder up to 30%. Feeding of chopped roughage reduces the energy waste in chewing and helps in adopting strategic supplementation, improves palatability of less preferred roughages by mixing with highly palatable fodder, improves digestibility and the net biological value of the feed (Singh and Prasad, 2002).

Schedule of feeding: Some simple alterations in feeding programs can help the animal to cope with climate stress. Stall-fed cattle given access to feed only during the cooler hours of the day enhanced the animal's ability to cope with heat stress during summer time episodes without adversely affecting growth performance. In fact, these feeding strategies (limiting feed intake and/or feeding duration) prevent the metabolic peak and environmental heat loads from occurring simultaneously. In cattle, provision of fresh feeds through multiple feedings (especially during night) can also encourage the frequent feeding bouts and increase daily feed consumption under heat stress (Misra *et al.,* 202). In extensive systems, manger and water troughs must be in a shade. Increasing the number of feedings per day may entice animals to take more meals and keep feed fresher, thus increasing total daily consumption.

Water management: Water is an essential nutrient for dairy animals, especially during a thermal stress. Water intake during heat stress is a limiting factor for survival and performance, as water has a fundamental role in the heat exchange system for temperature regulation and maintenance of hydration balance. The response to increased temperatures on water demand by livestock is well known. Water intake of *Bos indicus* increases from about 3 kg per kg DM at 10°C to 5 kg at 30°C, and to about 10 kg at 35°C (NRC, 1981). In hot conditions, water losses increase (evaporation by panting and sweating) and water ingested in feed and generated by metabolism is reduced. Consequently, drinking water consumption has to increase to cover the requirements of a heat-stressed animal. Cows acclimatized to 21.1°C and then exposed to 32.2°C for two weeks showed increased water consumption by 110%, and water looses from the respiratory tract and from the skin surface increased by 55% and 177%, respectively, at the higher temperature (Pathak and Prasad 2012). In tropical climate, a key husbandry practice is to provide an abundant and clean source of drinking water close to the feeding area. Studies have demonstrated that a provision of cool water would improve animal performance by absorbing heat energy. An experiment conducted at CAZRI, Jodhpur on water intake of arid cattle reveals that the average water intake of Tharparkar was 49.1 and 52.9 litres day-1 for stall fed and grazing animals, respectively, and was lower than of the Rathi cattle (58.2 and 59.4 litres day-1). In dry regions an increased need of drinking water, as a consequence of prolonged exposure to high environmental temperature, is often coincident with a reduction of water availability and forage water content and quality.

Genetic improvement of heat tolerance

The nature has endowed India with some of the best breeds of cattle (Gir, Sahiwal, Tharparkar, Rathi, Kankarej, Hariana and Ongole), buffaloes (Murrah, Surti, Nili-Ravi, Banni, etc.) and other species of livestock (Misra *et al.*, 2012). These breeds are well known for their ability to tolerate extreme hot weather conditions. There are clear genetic differences among breeds in resistance to heat stress, as tropically-adapted breeds maintain lower body temperature during heat stress than non-adapted breeds. Considerable variation exists even between individuals within a species/breed for heat stress. High heat tolerance of local breeds is generally correlated with their small size, low-production level and some special morphological traits (properties of the skin or hair, sweating capacity, tissue insulation, special appendages, etc.) compared to exotic and crossbred breeds (Govindaiah *et al.,* 1980).

Improving animal adaptation to climatic stress can be achieved either by selection in stressed conditions or by introgressing 'heat adaptation' genes from a local breed into a commercial breed. Methane emission per unit of productivity may be reduced by selecting more productive animals. In addition, animal breeding will need to give more emphasis on indigenous cattle, breed temperatures, lower quality diets, and greater disease resistance to develop types that are better suited to survive, grow and reproduce even with poor seasonal nutrition, and high parasite and disease pressure. The identification of variation in gene expression during thermal stress may support the genetic selection programmes. Further, it has been found that genetic makeup also affects cooling capacity. Residual feed intake can be used as a selection tool for selecting the animals for lower enteric CH_4 emission for better productivity (Waghorn and Hegarty, 2011).

Maintaining multi-species and multi-breed herd is a strategy adopted by many traditional dairy farmers to buffer against climatic and economic adversities. Such traditional diversification practices are useful to increase climate resilience. The small farms in rural areas are therefore more climate resilient because of their diverse species portfolios, the ease with which they can shift between species and diversify, and their reliance. The temperate breeds of livestock should be bred with tropically adapted breeds, which are not only resilient to heat stress and poor-quality fodder, but also to parasites and diseases.

Crop-livestock integration

Integrated farming system consisting of variable proportions of crops, grasses, shrubs, trees and livestock makes best use of available resources and minimizes the risk of weather vagaries. Several farming systems involving trees, fruits, grasses and crops have been studied for their suitability in different agro-ecosystems. It has been observed that the areas falling in <250 mm rainfall zone have predominance of grasses and shrubs; hence pasture development with livestock rearing is the major proposition for such areas. Areas with 250-350 mm rainfall are suitable for agroforestry and mixed farming; while areas receiving more than 300 mm rainfall are suitable for agroforestry, arable crops, crop diversification and dairying.

A number of agronomic and livestock management practices are available, which have proven to be effective in delivering multiple benefits. Better quality of fodder helps in reduction of enteric methane emission per unit of milk production as well as in higher productivity. Leguminous fodders in the diet of cattle and buffaloes also lower the methane emission per unit of productivity. In order to maintain the vigour of the grass and legumes, and also to meet the needs of the livestock, grazing resources may be subjected to one of the following grazing systems: (i) continuous grazing, (ii) deferred grazing, (iii) rotational grazing, and (iv) deferred rotational grazing, for a given site at a specific period as per requirement (Misra *et al.*, 2012).

The way forward

Climate change mitigation and achieving food security are the two major challenges in present day situation and both the issues must be addressed on priority basis. Dairy sector can offer substantial potential for climate change mitigation and adaptation. Mitigation options are available along the entire supply chain and are mostly associated with feed production, enteric fermentation and manure management. Information on comprehensive biological responses under varied environmental conditions is required to reduce the likely impact of climate change on dairy farming.

The options to improve the resilience of dairy production systems to reduce the adverse impact of climate change includes: integration of dairy animals with crop production with advanced husbandry practices (feed, nutrition and management), conservation and improvement of indigenous breeds which are adapted to the environment and has certain degree of disease resistance, popularization of scientifically designed animal housing with proper ventilation, refined feeding and manure management practices, and timely and precise weather forecasting for better planning and management in order to increase the efficiency of dairy production. Cattle breeding policy needs to be transformed towards the resilience to climate change, for each agro-climatic zone. Efforts are required for surveillance, diagnosis and prudent vaccination programmes to decrease the incidences and spread of diseases endemic to India.

Various extension methods can be deployed to create awareness among the farmers about importance of scientific livestock production management in changing climate. Progressive farmers who have adopted climate smart technological interventions should be used as role models for wider dissemination of interventions. A continuous dialogue with stakeholders is essential to generate viable information for sustainable adoption of recommended husbandry practices. Training and on-farm trials could create awareness among farmers regarding the adoption of climate resilient dairy practices. Use of weather information and early warning systems to assist rural communities in managing the risks associated with rainfall variability is a potentially effective option for climate change adaptation.

References

Aarif, O. and A. Aggarwal. 2015. Evaporative cooling in late-gestation Murrah buffaloes potentiates immunity around transition period and overcomes reproductive disorders. *Theriogenology* 84(7): 1197-1205.

Anonymous. 2017. National Action Plan for Dairy Development Vision 2022. Ministry of Agriculture & Farmers Welfare, Krishi Bhawan, New Delhi.

Blackshaw, J.K. and A.W. Blackshaw. 1994. Heat stress in cattle and the effect of shade on production and behaviour: a review. *Australian Journal of Experimental Agriculture* 34(2): 285-295.

CAZRI 2012. Annual report 2011-12. Central Arid Zone Research Institute, Jodhpur, India.

Chandra, G., A. Aggarwal and A.K. Singh. 2014. Effect of vitamin E and zinc supplementation on liver enzymatic profile of pre-and post-partum Sahiwal cows. *Indian Journal of Animal Sciences* 84(5): 507-510.

DADF. 2018. National Action Plan for Dairy Development Vision 2022 DADF, MoAFW, 2018 http://dahd.nic.in/about-us/divisions/cattle-and-dairy-development

Das, G.K., and F.A. Khan. 2010. Summer anoestrus in buffalo - A review. *Reproduction of Domestic Animal* 45: 483-494.

FAO. 2006. Livestock a major threat to the environment. Remedies urgently needed. FAO, Rome.

Ganaie, A.H., O.K. Hooda and S.V. Singh. 2013. Effect of vitamin C supplementation on immune status and oxidative stress in pregnant Murrah buffaloes during thermal stress. *Indian Journal of Animal Sciences* 83(6): 425-4311.

Govindaiah, M.G., K.N.S. Sharma and R. Nagarcenkar. 1980. Density of sweat glands in *Bos taurus* X *Bos indicus* cross-breed dairy cattle. *Indian Journal of Animal Genetics and Breeding* 2: 25-30.

IPCC. 2001. Technical summary: contribution of Working Group I to the Third Assessment Report

Kumar, A. 2005. Status of oxidative stress markers in erythrocytes of heat exposed cattle and buffaloes. Dissertation, National Dairy Research Institute, Deemed University, Karnal.

Marai, I.F.M and A.M. Haeeb. 2010. Buffalo's biological functions as affected by heat stress-a review. *Livestock Science* 127: 89-109.

Misra, A.K., K.V. Subrahmanyam, B. Shivarudrappa and Y.S. Ramakrishna. 2006. Experiences on participatory action research for enhancing productivity of dairy animals in rainfed agro-ecosystem of India. *Journal of SAT Agricultural Research* 2: 1-14.

Misra, A.K. and K. Ponnusamy. 2019. Approaches for enhancing productivity in animal production systems with special reference to dairy animals. Pages 34-45 *in* Innovations in Animal Production for Sustainability and Doubling farmers Income. Proceedings of National conference and XXVI Animal Convention of the Indian society of Animal Production and management. 23-25 January 2019. College of Veterinary Sciences, Mannuthy, Thrissur, Kerla, India.

Misra, A.K., A.S. Sirohi and B.K. Mathur. 2012. Strategies for managing livestock under environmental stresses in drylands of India. *Annals of Arid Zone* 51: 219-243.

Misra, A.K., C.A. Rama Rao and K. Ravishankar. 2010. Analysis of potentials and problems of dairy production in rainfed agro-ecosystem of India. *Indian Journal of Animal Sciences* 80(11): 68-75.

NAAS. 2013. Climate Resilient Agriculture in India. Policy Paper No. 65, National Academy of Agricultural Sciences, New Delhi. 20 pp.

NRC. 1981. Effect of Environment on Nutrient Requirements of Domestic Animals. National Academy Press, Washington, DC.

Patel, B., N. Kumar and V. Jain. 2016. Zinc supplementation improves reproductive performance of Karan Fries cattle. *Indian Journal of Animal Reproduction* 38(1): 20-22.

Pathak, K.M.L. and C.S. Prasad. 2012. Adaptation and mitigation strategies for addressing climate change issues in livestock. www.niam.res.in/pdfs/DDG%20AS.pdf

Payne, W.J.A. 1990. Cattle and buffalo meat production in tropic. Intermediate Tropical Agriculture Series. Longman Science and Technology, Harlow.

Rangnekar, D.V. 2006. Livestock and livelihoods of the underprivileged communities in India: A review. International Livestock research Institute, Nairobi, Kenya. 72 p.

Rath, D. 2019. Key note address of 47th Dairy Industry Conference, Patna. *Indian Dairyman* 71: 3:16-21.

Rensis, F.D. and R.J. Scaramuzzi. 2003. Heat stress and seasonal effects on reproduction in the dairy cow-a review. *Theriogenology* 60: 1139-1151.

Reyes, A., L. Álvarez-Valenzuela and F.D. Correa-Calderón. 2010. Comparison of three cooling management systems to reduce heat stress in lactating Holstein cows during hot and dry ambient conditions. *Livestock Science* 132(1-3): 48-52.

Sanjay, J., M.V.S. Ramarao, M. Mujumdar and R. Krishnan, R. 2017. Regional Climate Change Scenario. Pages 285-304 *in* Observed climate Variability and Cliamte Cahnge over Indian Region. Editors: M.N. Rajeevan and Shailesh Nayak, Springer Geology, DOI 10.1007/978-981-10-2531-0.

Sastry, N.S.R., C.K. Thomas and R.A. Singh. 2012. Livestock Production Management. Kalyani Publishers, Lucknow.

Sejian, V. 2013. Climate change: Impact on production and reproduction: Adaptation mechanisms and mitigation strategies in small ruminants: A review. *The Indian Journal of Small Ruminants* 19(1): 1-21.

Singh, K. and C.S. Prasad. 2002. Potential of nutritional technologies in improving livestock productivity. Pages 132-146 *in* Technology Options for Sustainable Livestock Production in India. Proceedings of the workshop on Documentation, Adoption and Impact of Livestock Technologies in India. (Eds. P. Birthal and P. Parthasarthy Rao). ICRISAT-Patancheru, India.

Singh, K.B., D.C. Nauriya and M.S. Oberoi. 1996. Studies on occurrence of clinical mastitis in relation to climatic factors. *Indian Journal Dairy Science* 49(8): 534-536.

Singh, S.V, and R.C. Upadhyay. 2009. Thermal stress on physiological functions, thermal balance and milk production in Karan Fries and Sahiwal cows. *Indian Veterinary Journal* 86 (2): 141-144.

Singh, S.V., R. Devi and Y. Kumar. 2017. Seasonal variation in skin temperature, blood flow and physiological function in zebu (*Bos indicus*) and Karan fries (Tharparkar X Holstein Friesian) cattle. *Indian Journal Dairy Science* 70(1): 96-103.

Upadhyay, R.C., O.K. Hooda and A. Aggarwal. 2013. Indian livestock production has resilience for climate change. Page 286 in Climate Resilient Livestock and Production System. (Eds. Singh S.V. *et al*.). National Dairy Research Institute, Karnal, Haryana, India.

Waghorn, G.C. and R.S. Hegarty. 2011. Lowering ruminant methane emissions through improved feed conversion efficiency. *Animal Feed Science Technology* 166-167: 291-301.

Theme 8: Post-harvest Management, Value Chain, Renewable Energy, Farm Mechanization and Automation

Lead Presentations

Renewable energy programme and policies of India

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Abstract

Energy has navigated the economic, social, employment, and environmental transformations across the globe but excessive use of fossil fuels has led to global warming, climate change and higher risks for the society. In 2018, growth in energy consumption was 4.6% in India, 3.1% in China and 2.2% globally. India has pledged to reduce GHG emission by 33-35% by generating 40% power from renewable sources. During 2009-2017, installed capacity of solar energy grew by 800% and bio-energy by 20% in India. Roof top solar market of India grew @ 88% CAGR in the last five years till 2018. The OPEX market share of rooftop solar increased in India from 2% in 2012 to 35% in 2018. Solar installation capacity in 2017-18 grew by 72% over the previous year. The feed in tariffs (FIT) of solar and wind power reduced by >7 times during this period. Co-generation of solar and wind power with inter cropping can enhance overall land productivity by 30-60%. It will also sequester CO_2 @ 600 t ha^{-1} $year^{-1}$ and realize many other environmentally benign externalities. Photo-voltaic efficiency of 20-22% of silica cells for capturing solar radiation is 4 to 5 times more than the photosynthetic efficiency of less than 5%, making major difference for the land utilization. GOI has launched Indian Rupees (Rs.) 480 billion (One US$ = Rs. 65) investment portfolio for replacing existing electric and diesel pumps with solar energised ones as well as installation of new solar pumps (with 60% subsidy). Grid connected solar power plants set by the farmers have been exempted from energy wheeling charges. Liquid (ethanol) and gaseous (bio-gas) bio-fuels and atomic energy are being experimented after the passing of the relevant acts since 1948. Recent (2018) policy of 2G technology for the non-grain ligno-cellulosic surplus biomass and damaged food grains has now made biofuels financially viable. Bio-CNG is cheaper than the imported fossil CNG. Anaerobic digestion of crop residues, animal dung, and domestic, industrial, sewage and other solid wastes also leaves behind bio-manure, and recycles plant nutrients. This 'Waste to Energy and Wealth Programme' mitigates GHG emissions tremendously. Road shows are being held to attract investment with enabling policy of fiscal, financial and other incentives for ease of doing business to produce biofuels.

Introduction

The traditional agenda of food security, poverty and non-inclusive growth has led to excessive use of fossil fuels, production of green house gases, air pollution, environmental degradation, and climate change increasing the vulnerability of agriculture. In spite of that, there was a significant growth in coal consumption in the years prior to 2017 in Pakistan (26.2%), Philippines (12.0%), Bangladesh (7.3%), India (4.8%), China (0.5%) and the developing countries of other continents (BP, 2018). The resulting air pollution caused 9 million pre-mature deaths, disabilities, lowered productivity of human being, increased medical expenses and caused 2-3% loss in GDP in China and India in 2016 (IHME, 2018).

India is committed to reduce green house gases (GHG) emissions by 33-35% and generate 40% power from renewable resources by 2030, over the bench mark level of 2005. It has done fairly well in harnessing solar-, wind- and hydro power; and other alternative sources of renewable energy are being promoted. Mixed feed stocks of bioenergy from various sources of biomass like surplus residues of crops, animal dung, sewage, solid, domestic and industrial wastes have tremendous potentials. Residues or digestates of anaerobic digestion recovers and recycles nutrients to sustain soil health, productivity and production (Chandra *et al.,* 2017; Candia-Garcia, 2018).

Energy is one of the key inputs for the rural economic growth, as it permits mechanization of agriculture for increased productivity and production, and for the well being of the farmers and other agrarian stakeholders. After three years of stabilization of growth in carbon emission, coal and energy consumption has been observed again in 2017. Children with under-developed immunity, aged people with degraded immunity and women cooking with solid fuel are vulnerable to the pollution. Nine million pre-mature deaths globally, and 2 million each in India and China, have been reported for 2017 (IHME, 2018). India is a signatory to all agreements on Climate Change. Air polluting fossil fuels, contributing 64.67% to the world's energy, are the main culprit of environmental degradation and their substitution by clean and green renewable energy is being called upon (Table 1).

The world GDP growth is co-related positively with energy consumption and negatively with energy efficiency. Higher agriculture production, productivity and growth is also directly related to mechanization and energy consumption. Therefore, reducing vulnerability, mitigation and adaptations to climate change by replacing fossil fuel with alternative renewable energy including bio-fuels is internationally accepted option.

Table 1. *Grid connected installed capacity from all sources in India as of 31 May 2018*

Source	Installed capacity (MW)	Share
Coal	196,957.50	57.20%
Renewable	114,425.60	33.27%
Gas	24,897.46	07.23%
Diesel	837.63	00.24%
Nuclear	6,780.00	01.97%
Total	*343,898.39*	*100.00%*

Renewable energy sources in India

As per the latest estimates (2017), India has an estimated renewable energy potential of about 900 GW, consisting of 750 GW (83%) of solar energy, 102 GW (11%) from wind, 20 GW (22%) from small hydropower systems and 25 GW (2.8%) from bio-energy. About 94% of the total renewable energy is contributed by solar and wind with relatively higher potentials in coastal regions and cold and hot deserts of India. Tremendous progress has been made in harnessing solar and wind energy. Installed capacity of bio-energy of 57,260 MW witnessed 20% growth and solar energy 800% growth by 2017, over the base year of 2009. India is among the topmost ten countries having higher growth rate in renewable energy. As on June 30, 2018 the renewable energy generated electricity, including that from large hydro-electric projects, contributed 33% to the total installed capacity of 71.32 GW. Another 7% growth is required to meet 40% target by 2030. The latest achievements are given in Table 2 and 3.

Table 2. *Grid connected installed renewable power capacity of India from all sources as on March 31, 2018 and target by 2022*

#	Source	Installed capacity (MW)	Target (MW)
1.	Large hydro-electric	45,403 (65.8%)	-
2.	Wind	34,046 (49.3%)	60,000
3.	Solar	21,651 (31.4%)	100,000
4.	Biomass	8,701 (12.6%)	10,000
5	Small hydro-electric*	4,486 (06.5%)	5000
6.	'Waste to power'	138 (00.2)	-
	Total	*69,022 (100%)*	*1,75,000*

*Number of water mills, micro-hydel units: 26,90,172**.**

Table 3. *Off-grid power capacity in MW (EQ) in India as on March 31, 2017.*

Sources	MW (EQ)
Biomass	661
Standard product unit systems	539
Biomass gas in fuel	163
Waste to energy	175
Aero generator	3
Family bio-gas	49
Total	*1590*

Wind and solar energy

Enabling policies, good governance, innovative programmes, incentives, subsidy, investment portfolios in the public and private sector, establishment of national power grid and competitive marketing has led to very high growth in the wind and solar energy generation in the country. India is also very advanced in the manufacturing technologies for wind power with more than 40% efficiency. However, both of these energies are land demanding (@ 2.5 ha MW^{-1}). Progressive policies of leasing land, contracting and liberal changes in land uses were given top priority in the implementation programme. China dented dominance of USA in solar manufacturing and world prices of panels dropped by 80% between 2008-2013. Recently (August 2018), India has introduced anti-dumping tariff and non-tariff barriers against import to prop-up manufacturing of solar panels within the country. India is well placed in the manufacturing of wind power plants. As a result of all these developments, the country witnessed a steep fall of more than 7 times in tariffs in last 10 years (Fig. 1). India's first large scale floating solar plant of 50 MW with a tariff of Rs. 3.29 kwh^{-1} ((One US$ = Rs. 65) has also been approved in the state of UP by SECI in November, 2018. Out of 7 largest solar plants of the world four are in India. It will also reduce CO_2 emission @ 599 t ha^{-1} $year^{-1}$ as compared to generation of energy from coal.

Further scope for increase in efficiency of irradiance conversion

The most competitive tariffs in Fig. 1 have been realized with less than 20% efficiency of the silica solar panels which, of course, depend on many factors. About 30% is the upper limit of efficiency of traditional single junction technology, 46% of multi-junction and 63% with longer wave length technology (Table 4). Sakimoto *et al.* (2017) from Japan reported that bacterium *Moorella thermoacetica*-CDs found at the bottom of sea bed with very diffused light retains toxic cadmium on its cell wall in the form of sodium sulphide as a stress response mechanism. These tiny particles act like solar cells with 80% of solar-chemical efficiency conversion against 20% of silica solar panels and 4% in photosynthesis. However, optimum cost is the ultimate criteria of commerce and cadmium is very expensive as of now. However, it indicates that there is a lot of scope of generating renewable energy and mitigating GHG production in the futuristic technologies. Efficiency of wind power conversion in to energy is about 40% in India.

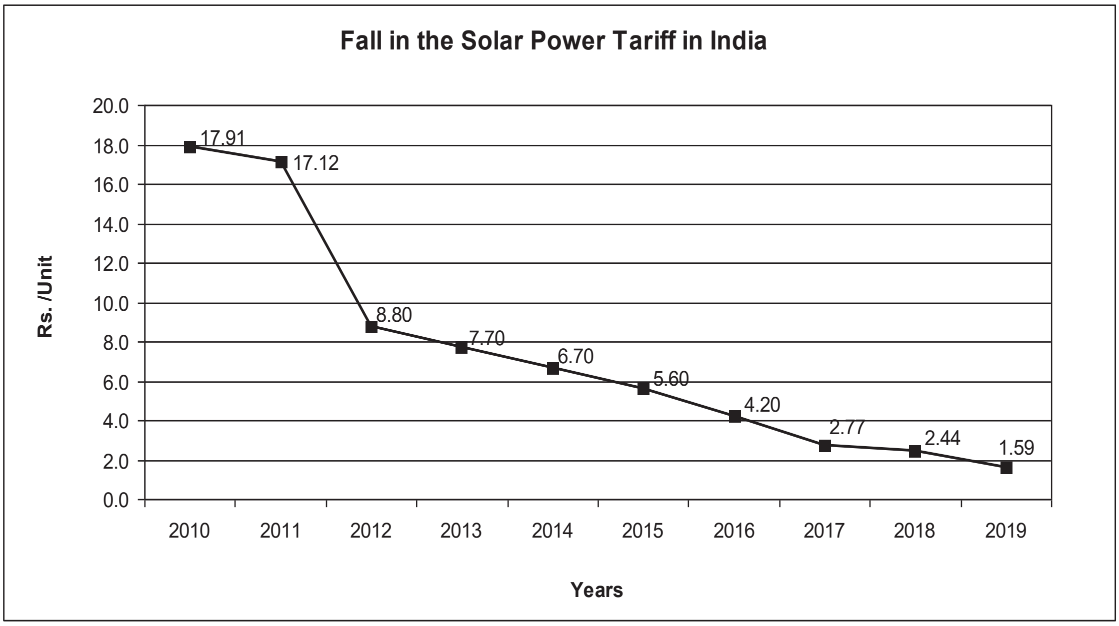

Figure 1. *Change in the tariff of solar power over last 10 years in India.*

Table 4. *Relative irradiance conversion efficiency of different systems/approaches*

#	Process	% efficiency
	Photosynthesis	4-5
	Single junction photovoltaic	20
	Single junction photovoltaic in pipe line	30
	Multi junction potentials	46
	Beyond visible spectrum	63
	Moorella thermo-aceticCD found on sea bed	80

Co-generation and agrivoltaic system

Wind and solar power generation requires 2 to 2.5 ha of land per MW and competes with the food security. Adani Group of companies has leased even very productive agriculture land for 100 MW solar plants from 220 farmers of Bathinda, Punjab @ Rs. 1,35,850 (US$ 2000) per ha per annum for 30 years with 5% annual escalation clause. This conflict of land use for energy and food security can be resolved by optimizing the use of limited land resources. Fig. 2 shows a typical agri-voltaic three tier system consisting of very high (at 120 meter) wind rotors, sloping solar panels just 2 m above the ground permitting rain water harvesting, for plants inter-cropped between panel arrays and growing shade loving plants under the panels. Solar and wind energy will share the same land, grid, and related servicing infrastructure. Solar power is generally generated during daytime and wind power during both day and night. This combination of co-generation improves grid quality. Rainwater harvested from the solar panels can be used not only for irrigating crops planted between and under the panels but also for washing the panels in the non rainy period.

Both wind mills and solar panels will provide various kinds of shelters to the shade loving crops, reduce wind erosion and shifting of sand dunes. Hand held small machinery can be used for tillage operations in this system and will provide work opportunity for the farmers and labourers. Overall, 30-40% increase in land productivity, compared to solar, wind and crops alone with Land Equivalent Ratio of 1.3 to 1.6, have been reported (Dupraj *et al.,* 2011; Poncet *et al.,* 2012; Harashvardan et al., 2016; Samra, 2017). It will earn carbon credits of more than 600 tons CO_2 ha^{-1} year^{-1} and reduce global warming and pollution.

Photo-voltaic generation alone will save 599 t of Co2/ha/year

Figure 2. *Three tiered agri-voltaic system of wind turbines, photo voltaic panels and inter crops.*

Micro-climatic and environmental externalities of agri-voltaic systems

Clearance of land for installation of solar and wind energy systems and re-succession of vegetation provide new vegetative cover with different GHG sequestration and land cover (Beaty *et al.,* 2017). Conversion of solar radiation and wind velocity into electricity reduces soil erosion and sand dune shifting, and modifies temperature, and moisture regimes, vegetative cover, biological activities and succession of flora and fauna (Castellano, 2013; Marrou *at al.,* 2013 a,b,c; Amstrong *et al.,* 2016; Daniel, 2017).

Dupraz *et al.* (2011) reported 43-71% reduction in photosynthetic radiation (PA) in an agri-voltaic system of cultivation. Better moderation of air and soil temperature, both in summer and winter, below the panels as compared to in between arrays and nearby open grass land was also recorded. A 19-29% reduction in dry weight of biomass and grain yield was observed by Dupraz *et al.* (2011), as compared to pure cropping. However, gains of co-generation of solar energy are much higher. Similar results have also been reported by Cossou *et al.* (2014) and Marrou *et al.* (2013a). Solar and wind farming also have impacts on wildlife and birds mobility due to micro-meteorological changes. Crops Wind Energy Experiments in USA have proved moderation in wind turbulence and micro-meteorology by wind towers, leading to significant alteration in micro-climate and crops/biomass productivity (Kaffine, 2018).

Bio-fuel energy

Replacement of more polluting fossil fuel by the renewable safer bio-fuel across the word is being prioritized to manage global warming and climate change. In the World, bio-methane (CNG) was produced from human excreta first time for lighting remote and isolated lepers colony in Mumbai in 1897. Technology of bio-gas production from animal dung *(Gobar Gas)* was released by the Indian Agriculture Research Institute (IARI), New Delhi, in 1939 at household level, on limited scale. It was promoted by *Khadi* Village Industrial Commission since 1962 and more than 5 million plants were put up to 2017 for domestic cooking and protecting health of women in the rural sectors. Most of these had limited acceptability, being small scale intervention.

Now there are several options of converting bio-mass into fuel brickets, bio-char, bio-diesel, ethanol and bio-gas (CNG) commercially at higher scale. Keeping in view environmental, technological and economic considerations and comparisons made by Warfield (2018), bio-CNG is financially viable biofuel from ligno-cellulosic biomass, animal dung, sewage water/sludge, and other domestic and industrial wastes under anaerobic digestion (Tables 5 and 6). Fats and slaughter house wastes have 5 to 6 times higher potential of bio CNG production as compared to vegetative biomass. Ethanol, from fermentation of sugarcane juice, press mud, starchy raw material, damaged or surplus food grains, is also a viable preposition. Confederation of Indian Industry and NITI Aayog (CII and NITI Aayog, 2018) made very detailed assessment of *in situ* and *ex situ* management of surplus biomass in India. They concluded that bio-CNG generation is the best way to convert waste into energy and wealth and cut down air pollution and GHG emissions into the environment (Table 7).

Table 5. *Specific bio-gas production potential and methane content of different substrates*

#	Substrate	Dry matter (%)	Bio-gas yield ($M^3\ t^{-1}$)	Methane content (%)
1	Wheat straw*	86.5	367	78.5*(**
2	Barley straw	84.0	380	77.7
3	Lucerne	22.5	445	77.7
4	Grass	16.0	557	84.0
5	Corn silage	34.0	108	52.0
6	Dried leaves	12.5	260	58.0
7	Beet leaves	13.5	501	84.8
8	Poultry waste	27.5	520	68.0
9	Cattle manure	14.00	270	55.0
10	Horse dung	27.5	250	66.0
11	Sheep dung	25.0	320	65.0
12	Pig manure	13.5	480	60.0
13	Rice straw	90.0	285	60.0

*Wheat straw worth Rs. 50,000 per ha @ 7.5 ton

Table 6. Bio-methane potentials of livestock in Alberta, Canada

#	Feed stock	Total solid (TS %)	Volatiles solids as% of TS	Biogas yield $M^3 t^{-1}$	Methane content (%)
1	Animal fat	89-90	90-93	801-837 (6.2)*	NA
2	Animal carcass	34-39	90-93	348-413(2.9)	NA
3	Straw	70	90	105-158(reference)	60-70
4	Municipal sludge	30-20	90	17-140(0.6)	65
5	Ethanol by-product	7	-	58(0.4)	50-56
6	Hog manure	9-11	80-85	28-46(0.3)	58
7	Poultry manure	25-27	70-80	69-96(0.6)	60
8	Dairy manure	12	80-85	25-32(0.2)	54

*Value in brackets indicates times of the straw as a reference substrate

***Table 7.** Average cost and co-benefits of various management options CO_2 (derived from CII-NITI Aayog Action Plan 2018)*

Practices	Cost (Rs. $acre^{-1}$)	Environment benefits	Co-financial Benefits
1. *In situ*	2100*	Compost** Soil health	Nil
2. *Ex situ*			
Char pellets and brickets	8696	Negative energy consumption	11,065
Bio-CNG	4559	Compost (60%)*** Soil health	15,563

*Subsidy is not included in the calculations; **Gases other than CO_2 released;

***No release of gases other than CO_2

Global warming by GHG emission also led to the production of bio-diesel by esterification of wasted oils/fats or non-edible oils, and ethanol production from sugars, starches or spoiled grains since 2009. A group of about 100 consultants of LEE Company presented a report in March 2, 2018 in Washington and advocated that bio-methane (CNG) from non-food bio-mass is the cheapest gas with least pollution potentials vehicular emissions (Warfield, 2018). Cost of CNG generation worked out by International Energy Agency, IIT Delhi and plants manufacturers (Table 8) is quite attractive with an assured feed in tariff rate of Rs. 46 kg^{-1}. Keeping in view nature of the feed stock, the cost of CNG generation varies from Rs. 16.45 to Rs. 25.16 kg^{-1}. Recalcitrant paddy straw has relatively very high contents of lignin, silica, ash, alkali metals etc. and is relatively difficult raw material. It requires baling and densification of loose material for easy handling, transport, storage and pre-treatment for efficient digestion.

***Table 8.** Cost of bio-CNG generation by Praj Industries (Tariff rate>Rs.46)*

Feed	Rs. kg^{-1} CNG
Rice Straw	25.16
Cattle Manure	23.69
Sewerage Treatment Plant	23.97
Wood Waste	22.07
Press Mud	21.97
Distillery Waste	16.45
Milk Plants waste	11.00

Even then it is cheaper than fossil CNG by Rs. 15 kg^{-1}. It has now become environmentally, financially or commercially viable business model. Government of India notified very enabling policy in the Gazette dated June 4, 2018 of harnessing Rs. one trillion economy including substitution of import of polluting fossil fuels. It is also a policy of earning income, getting revenue, creating employment and getting clean environment from wastes of agriculture, animals (dung), sewerage, municipality solids, domestic and industrial wastes. Anaerobic digestion of raw material produces methane and recovers nutrients completely into digestated as bio-manure. This technology is environmentally friendly with almost zero emissions and nearly no effluents. Significant crop responses, and improving and sustaining soil health have been demonstrated on farmers' fields. Table 9 indicates potential of this advanced bio-fuel technology for ligno-cellulosic material.

Table 9. *Receipt and revenue potentials in billion Rupees (B Rs.) of bio raw materials (million tons) in India*

#	Raw material	Bio-mass (million tons)	Bio-CNG (B Rs.)	CO_2 (B Rs.)	Slurry (B Rs.)	Manure (B Rs.)
1.	Surplus crops residue	234	1040.0	285.60	70.20	421.20
2.	Cattle dung and poultry dropping	250	960.0	264.00	75.00	450.00
3.	Sewage	22.6 MLD	27.12	7.40	0.10	1.80
4.	Municipal Solid waste	62	74.40	20.40	5.00	55.80
5.	Non-hazardous Industrial wastes	27	37.20	3.80	0. 27	48.60
	Total	*595.6*	*2138.72*	*571.20*	*150.57*	*977.40*

- Environmental benefit, C-trading etc @ 1% GDP (Rs.190 trillion)= Rs. 1.9 trillion
- Grand total = Rs. 3839.79 Billion
- GST@5% = Rs. 191.99 Billion
- Marginal crop response to bio manure @Rs. 20,000/ton = Rs. 7519.8 Billion
- Investment potentials @ Rs. 6260 million per ton = Rs. 3728 Billions
- Primary employment potentials 3.3 million people

New bio-fuel policy

India has recently announced very unique innovative and out of box new bio-fuel policy (GOI, 2018) of three trillion Rupees economy of advanced bio-fuels technology. This waste to wealth and clean India policy is based on non-food, ligno-cellulosic and surplus crop biomass, animal dung, domestic and industrial wastes for bio-CNG and bio-manure production. Shifting of policy focus to non-food, non-feed and non-fodder biomass is very sensible because of food security concerns of India. Rules 115-A and 115-B of Central Motor Vehicle Act 1989 have been amended by the Ministry of Transport and Highways for dual fuel usages of agriculture and construction vehicles on December 4, 2018. As per this amendment bio-fuels now can be used in tractors, farm machinery and combine harvesters. Keeping in view the current production cost of bio-CNG and manure it is now economically viable business model with tremendous potential. North-Western region, with highest productivity and production of biomass like in Punjab, has the highest potential of biomass and bio-wastes. Recently potentials of 25 GW of bio-CNG alone have been discovered against the targets of 10 GW from all kinds of bio-mass in India.

Distribution and marketing chain policy of October 2018

In order to transport one ton of compressed gas in cylinders one has to also transport the dead weight of 10 tons of steel cylinders and add this cost to the market price of gas. This handicap was not there with ethanol, which could be blended with gasoline and sold through the existing very intensive and extensive network of petrol pumps. This was the main reason that most of the investors preferred ethanol production. However, transporting through pipeline network is very cheap and that is why PNG (Piped natural gas) for domestic cooking is almost half of the compressed gas price distributed in cylinders.

A few months after the gazette notification of new bio-fuel policy, the GOI also announced consolidation of gas pipe lines and marketing infrastructure network with private and public investments of Rs. 750 Billion (One US$ = Rs. 65) on October 1, 2018. It includes 14 districts of Punjab with hubs at Ludhiana and Jalandher. Oil Marketing Companies also fixed minimum tariff of Rs. 46 kg^{-1} CNG plus 5% GST at its nearest sale point and EOI (Expression of Interest) advertised on October 1, 2018 by Government of India.

Table 10. *Relative feed in tariffs (FIT) of renewable energy in 2018*

Source	**Tariffs (Rs. KWh^{-1})**	**Investment (Crore* Rs. MW^{-1})**	**Life (years)**
Roof top solar	1.59	4.5	25
Solar on ground mounted	2.50	5.0	25
Wind	3.70	5.75	25
Small-hydro			
0.5-2 MW	6.12	8.00	40
> 2 MW	4.43	7.00	40
Coal	3.70	5.0	40
Bio CNG	4.0	6.0	25
Ethanol from biomass	5.70	6.0	25
Bio-mass thermal	8.00	6.5	25

* 1 Crore= 10 million

Farm machinery

Fuelling of tractors and other farm machinery with bio-fuel of CNG in Russia, USA, Australia, Canada and Nigeria has been found to be 25-40% cheaper than diesel. While kits are available to convert existing tractors and other farm machinery into CNG-operated ones, more efficient specially designed engines have been fitted into New Holland, John Deere, Mahindra and Swaraj tractors. CNG being more combustible than diesel, produces less noise pollution. Emissions from bio-CNG fuelled vehicles are much safer since they have significantly lesser concentration of polluting elements of carbon monoxide, nitrous dioxide and particulate matter. Large farms abroad are generating bio-CNG from the surplus crop and animal or dairy residues/wastes and the technique can be adapted to smallholdings in India by aggregated supply chains and franchising. Bio-CNG can replace LPG, CNG, DME and H_2 gaseous fuels at cheaper rates especially in the rural sector. Aggregation and franchising at reasonable scale with the present level of technology and marketing will avoid the recurrence of happened to the Gobar Gas plants at domestic or micro-scale in the past. It is a success story of converting burning of biomass and other polluting wastes to energy, employment, wealth and clean environment business model.

At the current level of technologies, production cost of gaseous bio-fuel is cheaper than ethanol and that too with far less carbon footprints. Now bio-CNG generation from surplus biomass and other wastes is very attractive with very good future. Renewable energy being a green field is being promoted by various kinds of incentives across the world under various conventions, treaties, agreements and voluntary mechanisms. The recent policy of India also provides incentives and a few of them are mentioned below:

- Priority sector for financial lending.
- Multi-lateral and bi-lateral funding including carbon financing.
- Joint ventures and 100% Foreign Direct Investment through automatic approval route.
- Viability gap funding subsidy in grant for bio-fuel production.
- Incentivizing the nascent advanced bio-fuel industry in the form of tax credit, waving of registration, external development (EDC), land use change (LUC) charges, environmental clearance charges, advanced depreciation in plant expenditure, differential pricing.
- Carbon credits.
- Green funding through NABARD & Public sector banks at concessional rates.

Because of the enabling policies, Indian Oil Corporation Ltd. has signed MOUs with Punjab Government to set up 400 plants, with Haryana for 100 plants, and 5000 all over India in four years. A large scale plant (33.23 t day$_{-1}$ equivalent to 6.7 MW) approved by Government of Punjab in July 2018 is being erected by a German company in village Bhutal Kalan in district Sangrur, Punjab. There is green funding of European banks as Foreign Direct Investment in automatic mode. Many other investors have also shown an interest in the bio-fuels. However, Indian investors still have some reservations about sustained supply chain of raw material, ease of doing business and bio-manure digestion related policy. In the meanwhile, it is advisable to continue with the *in situ* incorporation till production, purchase and marketing of economic goods and services is fully developed.

The same Euro standards 6 have been fixed for all kinds of bio and fossil CNG production in India. The successful CNG fuelled public and private transport in Delhi, tested over 10 years, is being extended to rest of India. The Petroleum Minister, Government of India announced on October 2018 setting up of 5000 bio-gas plants with an investment portfolio of Rs.1750 Billion in the country. Another investment of Rs. 700 Billion has also been approved to consolidate distribution and marketing infrastructure of compressed gas. This will expand compressed gas filling stations from 1,500 to 10,000 in five years. Expression of interests of investors for biogas production has also been invited by the different Oil Marketing Companies of India. While reducing emissions of GHG, it will generate employment at primary, secondary and tertiary level and stimulate overall development.

References

Armstrong. A., N.J. Ostle and J. Whitaker. 2016. Solar park microclimate and vegetation management effect on grass carbon cycling. *Environmental Research Letters* 11(7): 074016.

BP. 2018. Statistical Review of World Energy: 2-56.

Beaty, B., J. Macknick, J. McCall, G. Brans and Ner. D. Buck. 2017. Native vegetation performance under solar PV array at the National Wind Technology Centre www.nrelgov/publication.

Castellano, S. 2013. Photovoltaic greenhouses: evaluation of shading effect and its influence on agricultural performances. *Journalof Agricultural Engineering* 45: 168-175.

Chandra, R., A. Trivedi, B.V. Jha and V.K. Vijay. 2017. Energy Generation from paddy straw- Analysis of bioenergy models. *Akshay Urja* (June): 22-27.

Candia-Garcia, C., L. Delgadillo-Mirquez and M. Hernandez. 2018. Biodegradation of rice straw under anaerobic digestion. *Environmental Technology and Innovation*. 10: 215-222.

CII and NITI Aayog. 2018. Action plan forbBio-mass management. Publ. CII, Mantosh Sandhu Centre. Vol. 23, Institutional Area, Lodhi Road, New Delhi-110003, India.

Cossou, M., L. Murgia, L. Ledda, P.A. Deligios, A. Sirigu, F. Chessa, and A. Pazzona. 2014. Solar radiation distribution inside a green house with south oriented photovoltaic roof and effect on crop productivity. *Applied Energy* 133: 89-100.

Daniel, T.K. 2017. Good neighbours? Microclimate effects of wind farms on local crop yield. daniel.kaffine@ Colorado.edu.

Dupraz, C., H. Marrou, G. Talbot, L. Dufaour, A. Nogier and Y. Ferard. 2011. Combining solar, photovoltaic panels and food crops for optimizing land use: Towards new Agri voltaic schemes. *Renewable Energy* 36: 2725-2732.

Dupraz, C., G. Talbot, H. Marrou, S. Roux, F. Liagre, Y. Ferard and A. Nogier. 2016. To mix or not to mix: evidences for the unexpected high productivity of new complex agri-voltaic and agro-forestry systems. www.dupraz@supagro.inra.fr.

GOI. 2018. National Policy on Bio-fuel - Ministry of Petroleum and Natural Gas Notification in the Gazette of India Extraordinary (Part-1-Sec-1), dated 4th June 2018, New Delhi.

Harashavardhan, D. and J.M. Pearce. 2016. The potential of agri-voltaic systems. *Renewable and Sustainable Energy Reviews* 54: 299-308.

IHME. 2018. State of Global Air/2018: A Special Report on Global exposure to Air Pollution and Its Disease Burden, Boston, MA.

Kaffine, D.T. 2018. Good Neighbours? Microclimate effect of wind farms on local crop yield. Daniel Kaffine@ Colorado.edu/daka9342/windcrop.pdf.

Marrou, H., L. Dufour and J. Wery. 2013a. How does a shelter of solar panels influence water flow in a soil crop system? *European Journal of Agronomy* 50: 38-51.

Marrou, H., L. Guilione, L. Dufour, C. Dupraz and J. Wery. 2013b. Microclimate under agri-voltaic systems. Is crop growth rate affected in partial shade of solar panels? *Agriculture and Forest Meteorology* 177: 117-132.

Marrou, H., J. Werfy, L. Dufour and C. Dupraz. 2013c. Productivity and radiation use efficiency of lettuce grown in partial shade of photovoltaic panels. *European Journal of Agronomy* 44: 54-68.

MNRE. 2019. Scheme for farmers for installation of solar pumps and grid connected solar power plants: KUSUM Yojna. NO.32/645/2017-SPV Division GOI, MNRE, Block No. 14, CGO Complex, Lodhi Rd, New Delhi-110003 dated 08 March 2019.

Poncet, C., M.M. Muller, R. Brun and H. Fatnassi. 2012. Photovoltaic green houses, non-sense or a real opportunity for the Greenhouse systems? Proc. XXVIIIth.

Sakimoto, K.K., A.B. Wong and P. Yang. 2016. Self-photosensitization of non-photosynthetic bacteria for solar-to-chemical production. *Science* 351(6268): 74-77.

Samra, J.S. 2017. Agri-voltaic systems of solar farming for mitigating climate change in India. Pages 296-301 *in* Agriculture under Climate Change -Threats, strategies and policies (eds. Belavadi, V.V., Natraja Karaba, N and Gangadharappa, N.R.), Publ. Allied Publishers Pvt. Ltd.

Warfield, S. 2018. That was then, this is now or The new economics of biogas projects: *Bio fuel Digest.html*.

Solar drying of fruit and vegetables: Innovations and prospects

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Abstract

Use of solar energy for drying fruit and vegetables is a promising technology to save fuel and environment. In most of the developing countries the solar insolation is much higher than world average of 3.82 kWh m^{-2} day^{-1}. This is encouraging the solar crop drying. It is not only the economic drying method but also produces quality product when the proper design of solar dryers is used. Many solar dryers developed in past range in capacity from domestic to commercial scale use and have proved techno-economically viable. The intermittent availability of solar radiation, however, results in the discontinuity of drying. Therefore, in past decade some innovative dryers such as hybrid solar-electric dryer, hybrid photovoltaic thermal solar dryer, vacuum solar dryer and solar dryer with thermal energy storage have been developed. The greenhouse dryer has also proved effective for large scale solar drying.

Introduction

Using solar radiation for crop drying is the first and foremost techniques of food preservation. It is widely accepted as the prime food processing technology because it is ecofreindly, efficeint and techno-economically viable. Amongst all the technologies of the use of solar thermal energy, the solar crop drying is considered the most energy-efficient due to the direct application of solar radiation for drying. Most of the developing countries are situated in the climatic zones where the solar insolation is higher than the world average of 3.82 kWh m^{-2} day^{-1} (Mujumdar, 2006). The daily average solar radiation received in India is 5.8 kWh m^{-2} day^{-1} that is third highest after Papua New Guinea and Egypt (Fig. 1). Hence, the commercial scale solar drying is technically and econimically realistic. Low temperature is normally recommended for drying of the fruit and vegetables. A temperature rise of 15-20^{o}C of air from ambient is sufficient to meet the requirement of crop drying (Jain, 2007). Dehydration of fruit and vegetables through solar drying is more appropriate as these products have high free moisture content.

Working principle of solar crop drying

Solar energy for product drying is the process in which solar radiation is converted to thermal energy. The absorbed radiation heats-up the surface of product and is utilized to evaporate the moisture from the produce surface to surrounding air. Solar drying of agricultural products in enclosed structures by forced convection is an attractive way of reducing post-harvest losses and to overcome the lowering of the quality of dried products associated with traditional open sun-drying. Another application involves generating the hot air through solar air heater or solar water heater and performing a convective drying in the drying chamber.

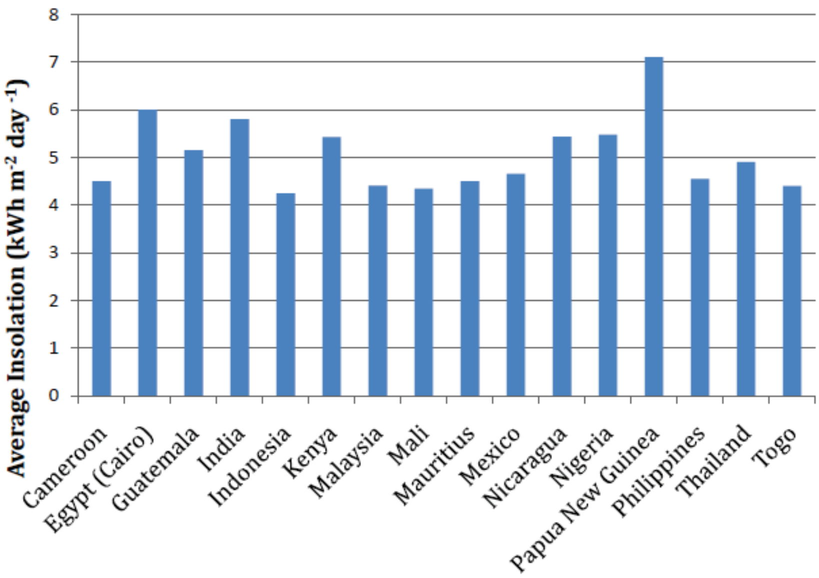

Figure 1. *Total horizontal solar insolation in some developing countries (Mujumdar, 2006).*

The duration of solar drying is limited to sunshine hours, hence for continuous drying a thermal storage can be provided with the solar air heater. A thermal storage unit integrated with the solar air heater can be charged during the peak sunshine hours and utilized (discharged) during the period when sunshine is off, for supplying the hot air to the dryer (Jain and Jain, 2005; Jain, 2007).

The large scale solar drying can be attained in greenhouse structures. The rate of evaporation depends on the vapor pressure difference between the crop and greenhouse air. Greenhouse with forced mode of drying reduces the relative humidity inside the greenhouse and increases the vapor pressure difference resulting in fast rate of moisture removal. The other factors important in solar drying are the product properties i.e. absorptivity, heat and mass transfer coefficient and diffusivity. These parameters are required to be investigated during the drying processas they are important in designing the solar dryer.

Innovations in solar dryers

***Cabinet type solar dryer*:** Cabinet and box type solar dryers, developed in the very early stages of technology development, are still in use at rural and domestic level for drying small batches of fruit and vegetables. The innovative, direct type solar dryers were then developed with a capacity ranging from 8 to 200 kg (Rao, 2014). A typical high efficiency solar dryer, having 2.23 m2 solar window, with capacity of drying 50 kg of fruits and vegetables, enabled to evaporate 15 kg moisture in a day (Fig. 2). The solar dryer was fitted with a PV system (20 W - 12 VDC) and electric backup of 4 kW for forced convection.

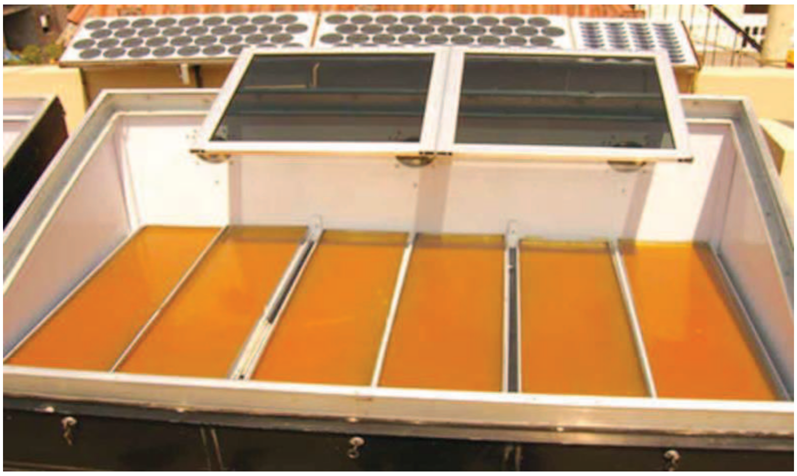

Figure 2. *Highly efficient direct cabinet solar dryer (Rao, 2014).*

Photovoltaic/thermal (PV/T) hybrid solar dryer: Recently, a photovoltaic/thermal (PV/T) hybrid solar dryer (Fig. 3) was developed (Poonia *et al*., 2018). The performance of the PV/T hybrid dryer was evaluated by drying 18 kg fruits of ber (*Zizyphus mauritiana*) and it gave the thermal efficiency of 16.7%. The economic evaluation of the hybrid PV/T solar dryer revealed a high IRR (54.5%) and low payback period (2.26 years), making the dryer cost-effective and economically viable.

Figure 3. *Photovoltaic/thermal (PV/T) hybrid solar dryer (Poonia et al., 2018).*

The solar air heaters were developed for energy saving to supply the hot air to the commercial convective dryers (Hollick, 1999). Solar panel efficiency increased and each square meter of solar panel was able to dry 4 kg of chillies a day, reducing the moisture content from 80% to 5% and fuel saving 0.5 litres of oil per square meter panel per day.

PV-ventilated solar greenhouse dryer: In the past decade, the PV-ventilated solar greenhouse dryers (Fig. 4) were developed for large scale direct drying (Janjai *et al.,* 2009). The drying time of longan and banana reduced (50%) and high quality of the products, interms of color and texture, was obtained. The payback period was around 3.36 years.

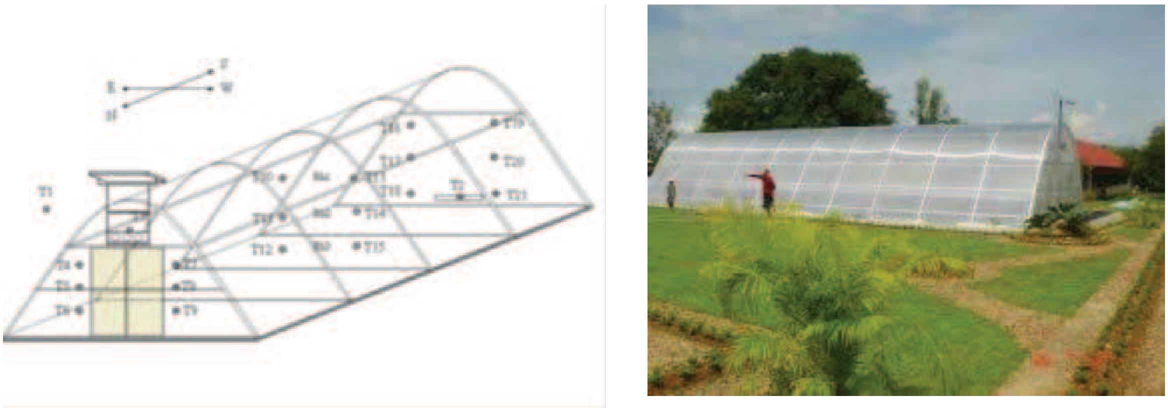

Figure 4. PV-ventilated greenhouse dryer (Janjai et al.,2009).

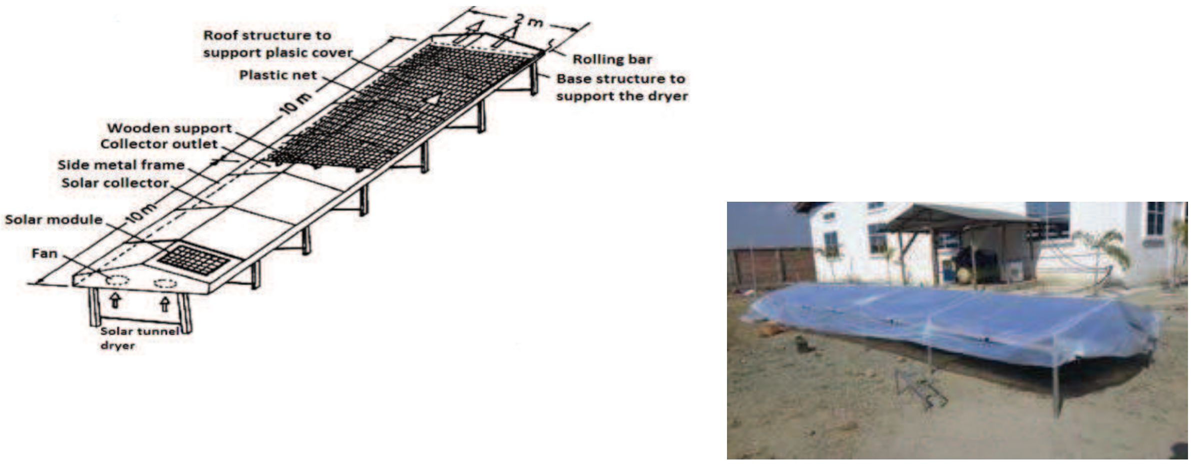

Figure 5. *Schematic diagram and photo of solar tunnel dryer (Bala and Janjai, 2009).*

***Solar tunnel dryer*:** The solar tunnel dryer was developed with a length of 20 m and a width of 1.80 m (Fig. 5). The dryer was composed of a flat plate solar air heating collector covered with plastic, a drying tunnel unit, 2 DC fans and a 40W photovoltaic module (Bala and Janjai, 2009). The dryer had the loading capacity of 80 kg of red chilli and it reduced moisture content from 2.85 to 0.05 kg kg^{-1} dry biomass in 20 h. The design of solar tunnel dryer was modified by providing the biomass heating for night operation (Amunugoda *et al.,* 2013).

***Hemi-cylindrical solar tunnel dryer*:** A walk-in type, heat protective, hemi-cylindrical solar tunnel dryer (Fig. 6) has been developed for drying grapes (Rathore and Panwar, 2010). The performance of dryer with chemically untreated seedless grapes showed that it took seven days to dry at a16% (wet basis) moisture content. The temperature gradient inside the tunnel dryer was about 10-28^{o}C during the clear sunny day.

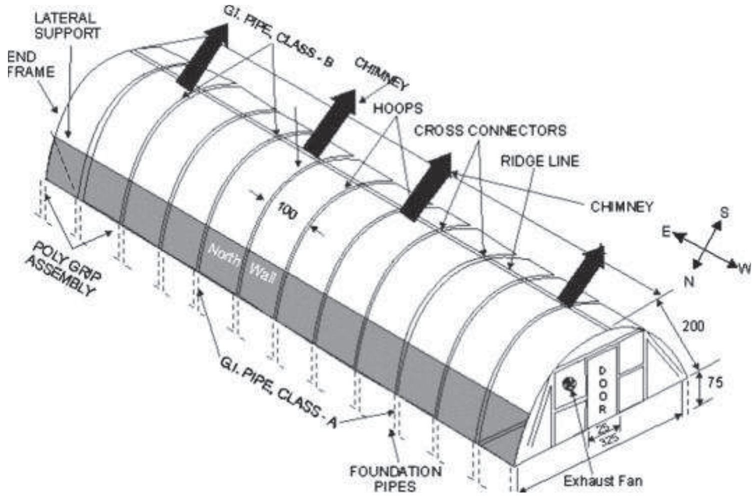

Figure 6. Walk-in type hemi-cylindrical solar tunnel dryer (Rathor and Panwar, 2010).

***Hybrid photovoltaic-thermal greenhouse dryer*:** A hybrid photovoltaic-thermal (PV/T) greenhouse dryer (Fig. 7) was developed and could dry 100 kg seedless grapes (Barnwal and Tiwari, 2008). The greenhouse dryer had a floor area 2.50 × 2.60 m^2 and centre height of 1.80 m. The roof of UV stabilized polyethylene sheet was inclined at an angle of 30°.

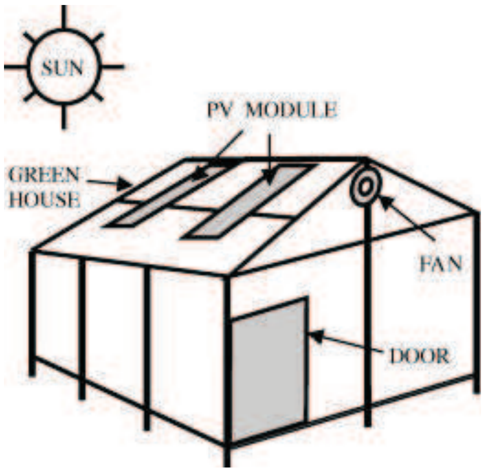

Figure 7. Hybrid photovoltaic-thermal (PV/T) integrated greenhouse dryer (Barnwal and Tiwari, 2008).

***Vacuum solar dryer*:** Vacuum solar dryer is an innovation at the research stage to dry the fruits at vacuum to evaporate the moisture at low temperature and increase the drying rate (Thigale and Patil, 2016). The vacuum drying system (Fig. 8) consisted of drying chamber, vacuum pump and solar water heater for providing heat in drying chamber. Drying of grapes under vacuum pressure of 55 mm of Hg, reduced the drying period to 91 hours for production of raisins.

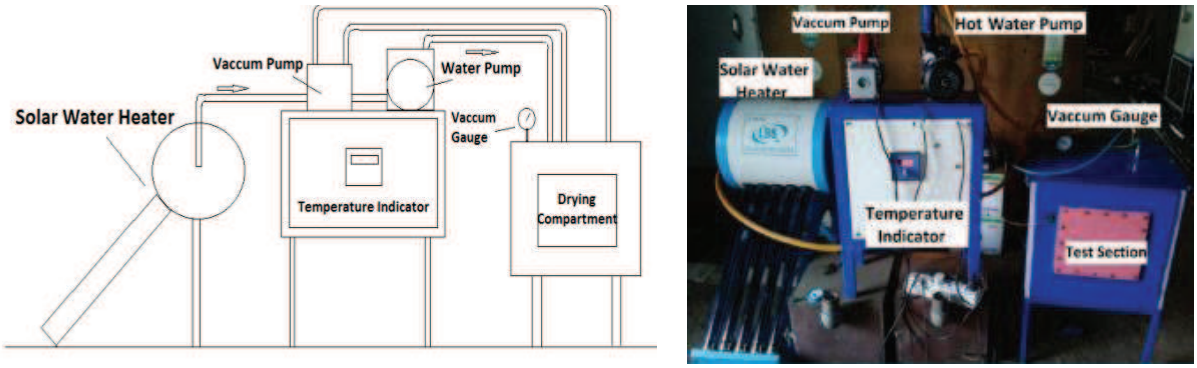

Figure 8. *Various component of vacuum solar drying system (Thigale and Patil, 2016)*

***Solar dryer with phase change material thermal energy storage*:** A natural convective through-pass solar dryer (Fig. 9) was developed with phase change material thermal energy storage (Jain and Tewari, 2015). As a result of thermal storage the temperature of drying chamber remained 4-6°C higher than ambient till mid night, leading to continued drying after sun set. The solar dryer ensured the maintenance of natural colour and flavour in the dried products. Drying 30 batch of 18 kg of each of clusterbean, carrot, *ber* and date palm, in different seasons, with their prevailing raw material cost and product cost, can give annual profit of INR 1,25,000 with a payback period of around 10 month.

Figure 9. *Solar dryer with PCM thermal energy storage (Jain and Tewari, 2015)*

In summary, solar dryers with various designs and capacity were developed to meet the requirement ranging from domestic to commercial application for fruits and vegetables. However, the selection and construction of specific solar dryer mainly depends on i) location of solar drying, ii) type of fruits & vegetables and iii) volume / amount of drying.

Prospects

Fruits and vegetables are highly perishable and their post-harvest losses in quality or complete damage is estimated to be about 25 to 30%. Losses can be minimised by producing local value-added food products through the development of rural agro-entrepreneurship.

Solar drying can play a vital role to overcome post-harvest spoilage and losses. The solar drying enables adoption of Good Manufacturing Practices (GMP) and yields export worthy processed foods, with long shelf life, meeting the standards of importers. For successful accomplishment of fruit and vegetables solar drying, the entire chain of process line has to be focused on. This will include: i) organizing cooperatives in production and solar drying area; ii) selection of suitable design and capacity of solar dryers; iii) identifying the potential and favourable month of drying in the year and the fruit and vegetables and their process parameters, iv) identification of standard quality parameters; v) selecting quality packaging materials for packing the dried fruits; and vi) awareness creation and marketing (Wakjira, 2010).

Limitation

During the rainy days the solar dryer are not effective; however on cloudy days they can be used for drying, due to diffuse solar radiation, but the drying rate is significantly reduced.

Conclusion

Solar driers are simple in construction and can be constructed using locally available materials by the local craftsman with little skill and training. The solar drier can be operated, independent of electrical grid, by a photovoltaic module. Numerous designs of solar dryers were developed to improve the drying operation, save energy and improve product quality as well as save the environment, which is a main concern.

References

Amunugoda, P.N.R.J., N.S. Senanayake, R.S. Wilson Wijeratnam and K.D.G. Kulatunga. 2013. Quality enhancement of dehydrated products through the modification of solar tunnel dryer for continuous operation in rural communities. *International Journal of Energy Engineering* 3(1): 7-14.

Bala, B.K. and Serm Janjai. 2009. Solar drying of fruits, vegetables, spices, medicinal plants and fish: Developments and potentials. Pages 1-24 *in* the proceedings of International Solar Food Processing Conference.

Barnwal, P. and G.N. Tiwari. 2008. Grape drying by using hybrid photovoltaic-thermal (PV/T) greenhouse dryer: An experimental study. *Solar Energy* 82: 1131-1144.

Hollick, J.C. 1999. Commercial scale solar drying. *Renewable Energy* 16: 714-719.

Jain, D. 2007. Modeling the performance of the reversed absorber with packed bed thermal storage natural convection solar dryer. *Journal of Food Engineering* 78: 637-647.

Jain, D. and P. Tewari. 2015. Performance of indirect through pass natural convective solar crop dryer with phase change thermal energy storage. *Renewable Energy* 80: 244-250.

Janjai, S., N. Lamlert, P. Intawee, B. Mahayothee, B.K. Bala, M. Nagle and J. Muller. 2009. Experimental and simulated performance of a PV-Ventilated Solar Greenhouse Dryer for drying of peeled longan and banana. *Solar Energy* 83: 1550-1565.

Mujumdar, A.S. 2006. Handbook of Industrial Drying. CRC Press, Boca Raton, USA.

Poonia, S., A.K. Singh and D. Jain. 2018. Design development and performance evaluation of photovoltaic/thermal (PV/T) hybrid solar dryer for drying of ber (*Zizyphus mauritiana*) fruit. *Cogent Engineering* 5: 1-18.

Rao, M. Ramakrishna. 2014. Innovative solar dryer: Food processing technology. *Akhsay Urja:* 34-36.

Rathore, N.S. and N.L. Panwar. 2010. Experimental studies on hemi cylindrical walk-in type solar tunnel dryer for grape drying. *Applied Energy* 87(8): 2764-2767.

Thigale, O.N. and A.M. Patil. 2016. Development of vacuum solar grape dryer. *International Journal of Latest Research in Engineering and Technology* 2(5): 94-99.

Wakjira, M. 2010. Solar drying of fruits and windows of opportunities in Ethiopia. *African Journal of Food Science* 4(13): 790-802.

Post-harvest interventions in millets for creation of demand

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Extended Summary

Millets are a traditional staple food of the rural poor in dry land regions of the country. In India, millets are grown on about 20 mha with annual production of 18 million tons and they contribute 10% to the country's food grain basket. *Jowar, bajra, ragi,* foxtail, *kodo,* proso, little and barnyard millets are unique with respect to high dietary fiber, phytochemical and nutraceutical properties, free radical scavengers, and source of micro and macro nutrients and slow digesting carbohydrates. Hence, they provide several health benefits.

In India total area under the millets crops declined, with CAGR of 5.4% annually, from 2010-11 to 2014-15, and the production of total millets has also declined at the rate of 4% annually. Creation of demand for millets will help the farmers in getting better price and market for their produce. Proper value addition measures can be taken up at farm level to overcome these problems. This will boost the millets cultivation nationwide and therefore will positively impact the farmers' income.

Millets are smart food crops because they have multiple useful characters:

- *Good for the consumer:* They can help overcome some of the biggest nutritional and health problems (iron, zinc, folic acid, calcium deficiency, diabetes and more) in the world;
- *Good for the planet:* They have a low water footprint, are able to survive in the hottest driest climates and will be important in coping with climate change, and more;
- *Good for the farmer:* Their yields can increase up to 3 fold, they have multiple uses (food, fodder, fuel), and are typically the last crop standing in times of drought; thus growing these crops become a good risk management strategy for farmers.

However, the direct consumption of millets as food has significantly declined over the past three decades. The major reasons for the decrease in millet consumption are that their domestic food preparation processes are cumbersome and time-consuming, there is a lack of processing technologies, there is a lack of awareness of their nutritional merits, and also there is government policy disincentive towards millets, favoring the supply of fine cereals instead at subsidized prices.

The revival of millets can be achieved through concerted efforts of research, marketing, testing and entrepreneurial training and demonstration to stimulate the processing of high quality competitive products for urban areas. Millets are traditionally used for the preparation of *roti, mudde,* fermented foods and beverages. Grains with high starch (65-72%) and low protein (8-12%) could be utilized for production of alcohol. It has become imperative to reorient the efforts on the millet crop to generate demand through value-addition of processed

foods through diversification of processing technologies, nutritional evaluation and creation of awareness backed by backward integration.

Millets are neither ready to eat nor ready to cook grains and need some kind of processing invariably for human consumption. Most commonly followed conventional processing methodologies are milling including decortication and size gradation, popping, malting, fermentation and cold extrusion. In the recent years the contemporary food processing technologies such as extrusion cooking, advanced methods of vermicelli/noodles and biscuits and bakery preparation are applied to millets also. In this regard, interventions through diversification of processing technologies related to millets are attempted to remove the inconveniences and develop, fine tune and standardize millets product technologies. For this purpose, the Indian Institute of Millets Research (IIMR), Hyderabad has installed and retrofitted 30 machineries under National Agriculture Innovation Project. Primary processing and secondary processing methods have been developed and fine-tuned using those equipments. As a result, more than 50 millet product technologies such as multi grain flour, semolina, flakes, extruded products (vermicelli and pasta), biscuits, extruded snacks, instant mixes etc. have come out.

In this regard a value chain model is needed with emphasis on value addition and development of value added products from millets. IIMR has taken a lead in this direction by developing and commercializing a variety of value added millets products namely *Jowar Atta*, J*owar* rich Multigrain *Atta*, *Jowar* Pasta, Instant *Pongal* Mix, *Jowar* Vermicelli and so on through value chain approach on pilot scale. The institute has assessed the impact of value chain model in reviving the demand for sorghum/millets in the long term through interventions in backward supply chain management, on farm value addition, processing, product development, nutritional testing, marketing, policy and awareness creation. The pilot model was scaled where backward and forward linkages are well established and the impact was visible among various stakeholders in the value chain; especially, the farmers for the first time could realize the productivity enhancement and 2 to 3 fold increase in their income.

Entrepreneurship development and capacity building efforts such as training for rural/urban entrepreneurs and women groups on processing technologies, product preparation, marketing, popularization etc. are initially required. Identification of entrepreneurs, linked with other stakeholders, publicity and awareness campaigns are important and innovative approaches of popularization are needed. Brand ambassadors can help in capturing market share (Fig. 1). Policy makers are to be sensitized on health and nutritional benefits of processed millet foods to the target populations (school children-midday meal scheme and poor social groups - PDS system).

Value addition to millets impacts different aspects; primarily it creates demand and usage of millets in the consumer's daily diet in present lifestyle. Millets have good health benefits to prevent diabetes, cardiovascular disease, blood pressure, cancer etc. Entrepreneurs are looking forward to start the millet processing units, for this they require raw material that ultimately will impact the farmers to cultivate millets to meet the demand for processing and consumption of millets. Technological intervention has been successful in creating options for consumers in millets. This has led to impact on consumers who might have been suffering from life style diseases by having access to healthy food choice and also to farmers to enhance their income.

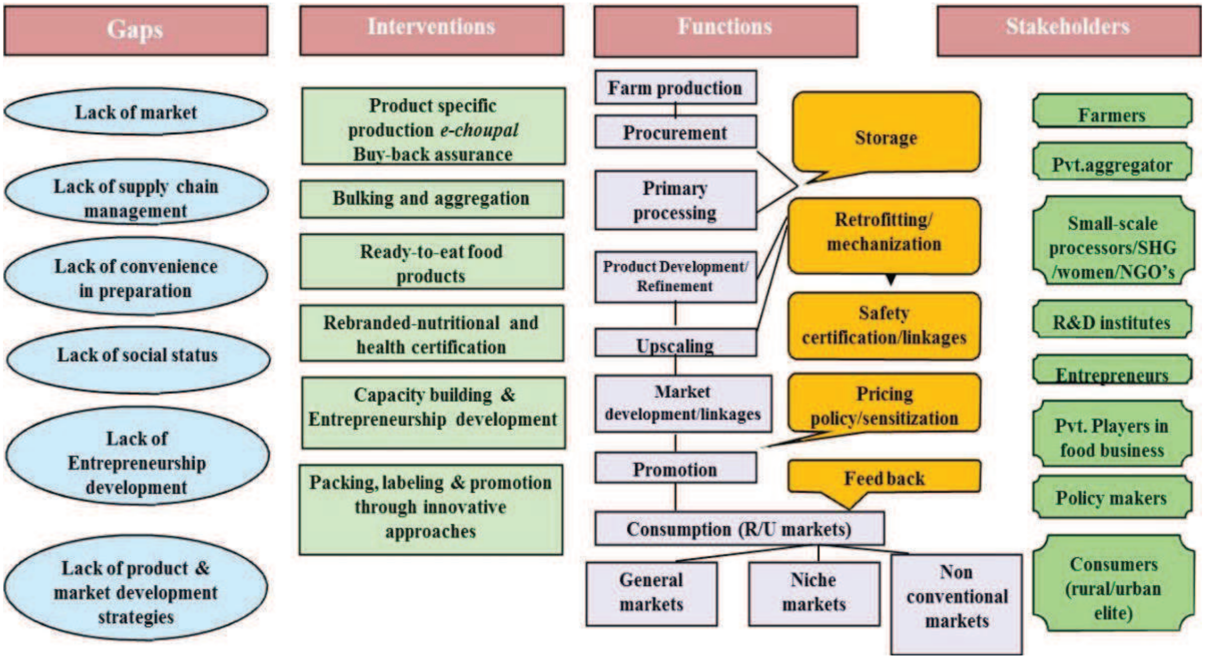

Figure 1. *Gaps, interventions and functions of value chain in millets.*

Solar PV options for farmers in arid agriculture: Agri-voltaic system and solar pumps

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Extended Summary

With growing pace in the development of societies, there is a concomitant rise in energy use by burning fossil fuels. But it has adverse effects on climate due to the greenhouse gas emissions. In this context, we need to harness and use more and more renewable forms of energy, especially solar energy that is plentiful in most part of the country. Also, at several locations harnessing wind power and utilizing biomass could be other effective alternatives.

Solar based devices may also work in an integrated manner with small wind turbines as hybrid devices. At present, about 16% of the country's installed electricity generation capacity is contributed by renewable sources e.g. wind, solar, bioenergy, hydro-electricity etc., which was 71.5 GW by the end of July 2018.

In agricultural sector, energy is directly used for pumping irrigation water, operating different mechanized farm implements/tools and processing of foods. Share of agricultural sector in total energy consumption is about 7-8% and further increase in energy use from its present value of 1.6 kW ha^{-1} to 2.5 kW ha^{-1} is expected to meet the production target of next 20 years. Off-grid national target of 2000 MW in the form of solar PV pumping system, mini-grids etc. can be achieved through interventions in agricultural farms.

Considering the potential of solar energy in future, a few technological interventions for its utilization and generation in agricultural farms are given below.

Solar PV pumping system

For sustainable production from agricultural farms, irrigating the crops at right stages is highly important. Even in rainfed situation, life-saving irrigation during long dry spell has also been found beneficial for crop survival and to obtain the targeted yield. Pressurized irrigation systems, e.g. drippers, sprinklers etc., are of great importance in meeting the 'more crop per drop' mission. However, assured power supply is essential to operate these systems. Solar PV pumping systems are quite helpful to operate the pressurized irrigation system. Specifically, solar pumps can be useful as water lifting devices in irrigation canals and also to evenly distribute water in command areas and thus reduce the wastage of water.

Solar PV pumping system mainly consists of three major units (i) Solar PV modules (ii) mounting structure and (iii) pumping unit. Solar PV pumps of 3 HP and 5 HP capacity are commonly available in markets along with either AC or DC pumping unit. These solar pumps have the capacity to drawup water from a depth of about 75 m and therefore may be beneficial in those areas where groundwater is not very deep. Solar pumps are directly operated by solar irradiance and therefore diurnal and seasonal variations in irradiance play a key role in successful use of solar PV pumps in a place. In arid western Rajasthan and Gujarat, clear sky conditions with average irradiance of 5-6 kWh m^{-2} day^{-1} are available for

>300 days in a year and thus solar PV pumps can be operated for about 6 hours a day for most of the period in a year.

Agri-voltaic system

Agri-voltaic or solar farming system is capable to produce both energy and food from the same piece of land. Apart from food and energy production, rain water can also be harvested from the top of PV modules in a solar farming system, which can be used for irrigating the crops and cleaning the deposited dusts from PV modules. In agri-voltaic system, interspace areas between two PV arrays and the area below PV module is utilized to grow suitable crops.

In western Rajasthan, maximum 500 kW capacity PV module can be installed in 1 ha area of solar farming in which about 49% and 24% of the total land area can be cultivated as interspace area and below panel area, respectively. Suitable crops for interspace area are mung bean (*Vigna radiata*), moth bean (*Vigna aconitifolia*) and clusterbean (*Cyamopsis tetragonoloba*) during *kharif* season, and cumin (*Cuminum cyminum*), isabgol (*Plantago ovata*), and chick pea (*Cicer arietinum*) during r*abi* season (Fig. 1). Apart from these arable crops, medicinal plants e.g. *gwarpatha* (*Aloe vera*), *sonamukhi* (*Cassia angustifolia*) and *sankhpuspi* (*Convolvulus pluricaulis*) can be grown in interspace area. Areas below PV modules can be used to grow vegetables and spices e.g. turmeric, cucurbitaceous crops, brinjal, leafy vegetables etc.

Figure 1. *A view of moth bean crop grown in the interspace between PV arrays in the 105 kW agri-voltaic system established at ICAR-CAZRI Jodhpur.*

The electricity generated from agri-voltaic system can be directly supplied to local grid through net metering system (Fig. 2). For optimum PV generation, regular cleaning of deposited dust from PV module surface is essential and requires about 20-40 litre water month^{-1} kW^{-1}. The rainwater harvesting system from top surface of PV modules in agri-voltaic system has the capability to provide water for cleaning purpose and to recycle it. Apart from cleaning, harvested rainwater may provide irrigation of about 40 mm during *rabi* season. Potential capacity of harvested rainwater from agri-photovoltaic system covering 1 ha area is about 3.75-4 lakh litre at Jodhpur. Approximate annual income from PV generated electricity in 1 ha at arid western Rajasthan and Gujarat is about Rs. 25-30 lakhs ha^{-1} year^{-1}.

Other solar devices for use in agriculture

Apart from the above two options there are other solar devices too in agricultural production system. Several solar PV and thermal technologies are available to perform various post-harvest operations e.g. drying, cleaning, grading, winnowing of agricultural produces etc. Inclined solar drier have been found quite useful to dry different agricultural produces along with good maintenance of quality of the produce.

Animal-feed solar cookers have been found to help in augmenting the milk production from cattle by providing them quality boiled feed. Solar water heater also has great potential in processing of agricultural produces. Solar PV winnower-cum-drier helps in cleaning of agricultural produces. Solar PV operated duster and sprayer helps in applying agricultural chemicals in fields to protect crops from pests and diseases.

Passive cool chambers are useful for on-farm short term storage and preservation of fruits and vegetables. Therefore, it is pertinent to apply these solar technologies in farmers' field to make the food production system more economic and environment friendly.

Figure 2. *Energy generation from 50 kW agri-voltaic system during winter months at Jodhpur, India.*

Small farm mechanization in Egypt

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Abstract

Agricultural mechanization in the Egyptian agricultural sector contributes to raising the efficiency of agricultural production processes and reducing losses, which results in increasing and improving the productivity and quality of different agricultural crops. It is one of the tools for reduction of costs and time of agricultural operations, reducing the waste both during production and harvesting and transport operations. The private sector plays a vital role in supporting and advancing the development of various sectors of agriculture in general and agricultural mechanization in particular. The preparation of the Agricultural Mechanization Strategy should be based on the prevailing agricultural policies, where governments develop strategies to achieve agricultural policy objectives. The agricultural machinery strategy in Egypt is one that works towards the objectives of government policy for improvement of the wellbeing of small holder farmers. Realization of the strategy of increase in the degree of mechanization by 0.5% per annum, with investments in this area of 3% to 8%, will depend on: Planning and introduction of new technologies for mechanization based on the irrigation systems developed in the area; Developing specialized training centers for agricultural mechanization; Modernization of the finance and lending structure and the establishment of the Agricultural Bank of Mechanization; Encouraging and expanding the local manufacturing for small agricultural machineries and equipment and spare parts for other equipment; Development of agricultural extension systems and activation of the media to increase specialized agricultural programs.

Introduction

Agricultural mechanization in the Egyptian agricultural sector contributes to raising the efficiency of agricultural production processes and reducing losses, which will increase and improve the productivity and quality of different agricultural crops. It is one of the tools of production contributing to the reduction in costs and time of agricultural operations as well as reducing the waste of crop during harvesting and transport operations. Table 1 shows the cultivated and reclaimed agricultural lands while Table 2 shows some indicators of the current status of Egypt's agricultural sector.

In general, the use of mechanization has many advantages. There is a problem of labor shortage during the peak periods of agricultural operations (e.g. time of wheat and rice harvest) in general, and it is particularly acute in the case of new lands where there is less population and the agricultural labor, which usually inhabits the villages and areas of the old valley, is not available. Mechanization reduces the need for manual labor. Mechanization reduces the time required for agricultural operations, reduces expenses on the cost of human labor, especially in new lands in remote areas. Mechanization of agricultural operations to improves the performance of agricultural operations. It provides many work opportunities for the machine operation, maintenance and management.

Table 1. *Cultivated and reclaimed agricultural lands (million hectares)*

Type of land	M ha
Total cultivated area (4.03% of total area of Egypt)	4.03
Area of the Nile Valley & Delta (surface irrigated lands)	2.73
Area of the newly reclaimed land (pressurized irrigated lands)	1.30
Cropping area	7.14
Area of reclaimed land by 2017	0.63
Expected area of reclaimed land by 2030	1.05

Table 2. *Some indicators of the current status of Egypt's agricultural sector*

Indicator	Estimated average (2017)
Agricultural Water Use (Billion Cubic Meter) (85% of Egypt's annual water use)	60
Percentage of small holdings (less than 2 ha or 5 Acre)	47.22
Per capita cultivated land (Acre)	0.10
Per capita water availability (m^3 $year^{-1}$). (This is below the water poverty line and it expected to fall to less than 500 cubic meters per capita before the year 2030).	600/1001
On-farm irrigation water application efficiency	50%

Local manufacturing of agricultural equipment in Egypt

SWOT analysis of agricultural mechanization in Egypt:

Strengths

- High quality research and development institutes (AEnRI, Extension service)
- High trust of farmers in the governmental stations of farm mechanizations
- The growing market of agricultural mechanization

Weakness

- The number of the machines is lesser than the needs
- Poor maintenance level
- Lack of spare parts
- Small size of the holdings
- Low technical level of operators and technical staff.

Opportunities

- Labor force deficiency
- Low contribution of the private sector to cover the needed mechanization services
- The expected good return from the investments in the agricultural mechanization
- The strong need for small-farms mechanization
- The agricultural development strategies favor mechanization
- Development of on-farm irrigation systems in old lands (2 million ha)

Threats

- The changes in crop patterns may change the mechanization requirements
- The gap between needed and the presented specifications of machines
- The lack of investments in agricultural machines sector (3-5% of the total agricultural investments)
- The growing increase in the costs of the other production inputs.
- The dominance of small holdings in the holding structure of Egyptian agriculture due to fragmentation of holdings tenure to 1.8 acres (Table 3).

Table 3. *Number and area of agricultural holdings in Egypt*

Class of land holders	Total holdings				Mean size of tenure (acre)
	Number of persons	%	Area (acre)	%	
Landless	823,893	18.13	---		
Less than one acre	1,615,590	35.57	72,310	8.09	0.45
1 acre - less than 5 acres	1,744,506	38.41	3493660	39.13	2.00
5 acres - less than 10 acres	234,426	5.16	1441642	16.14	6.15
10 acres - less than 20 acres	81,558	1.80	1049554	11.75	12.86
20 acres - less than 50 acres	33,571	0.74	923186	10.34	27.5
50 acres - less than 100 acres	5,654	0.12	357119	4.00	63.16
100 acres and more	2,686	0.06	941056	10.55	350.35
Total	4,541,884	100	8928527	100	1.86

Current situation for agricultural mechanization in Egypt

Fig. 1 to 7 show different agricultural equipment used in Egypt. Agricultural equipment are currently manufactured in the local market as follows**:**

- Local workshops: At the level of villages centers in different provinces.
- Specialized workshops: Some equipment are manufactured according to the specifications with mark of quality specified.
- Factories of agricultural equipment: Different commercial models and designs for such as rotational and agricultural machinery for harvesting potatoes and grain harvesters.

The obstacles to local manufacturing of agricultural equipment in Egypt are:

- Lack of the necessary information for local manufacturers to know the size and type of demand for equipment and agricultural machinery
- Lack of marketing experience necessary for local, Arab and international markets.
- Open door policy to import wide agricultural equipment without controls of the age of manufacturing and specifications
- Lack of funding that would enable manufacturers to work on developing and modernizing production lines for factories.

- Continued adherence to the method of assembly and not to expand the depth of manufacturing.
- Lack of good coordination among the various engineering projects to activate the industries feeding agricultural equipment.
- Non-reliance of local manufacturing on the engineering studies and raw materials of quality required.
- Shortage of after-sales service of equipment.

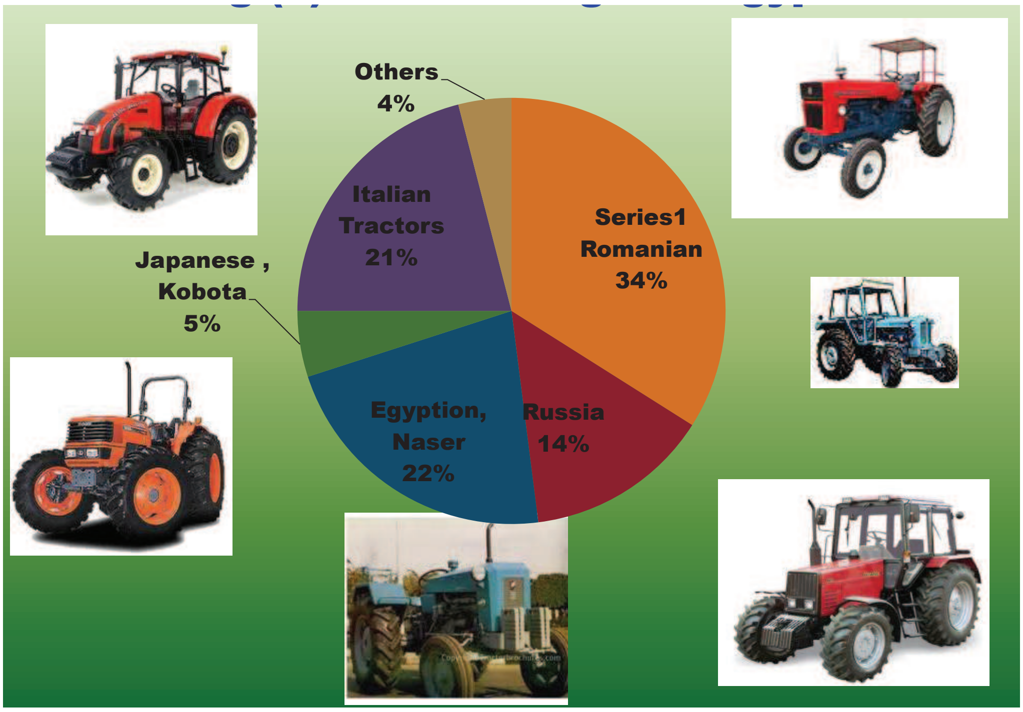

Figure 1. *Different types of tractors used in Egypt, based on place of manufacture.*

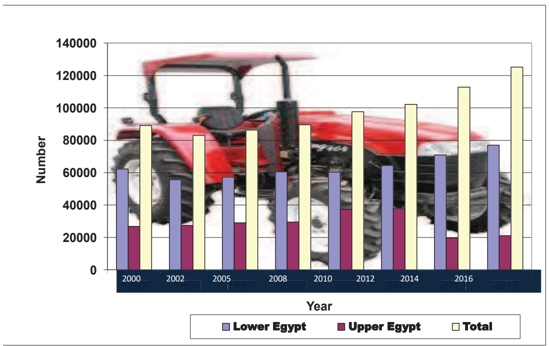

Figure 2. *Number of tractors used in Egypt since 2000.*

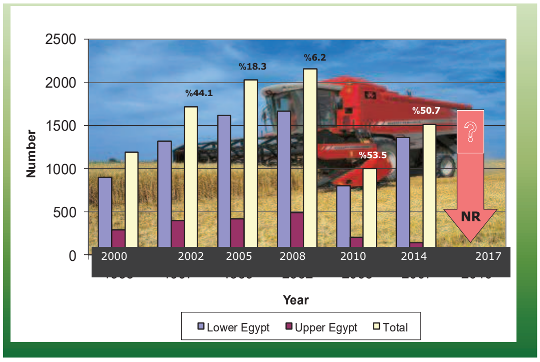

Figure 3. *Number of combines used since 2000 for harvesting in Egypt.*

Figure 4. *Number of on-farm irrigation pumps used in Egypt since 2000.*

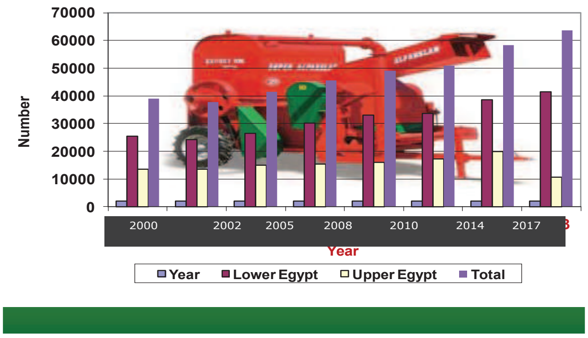

Figure 5. *Number of thrashers used in Egypt since 2000.*

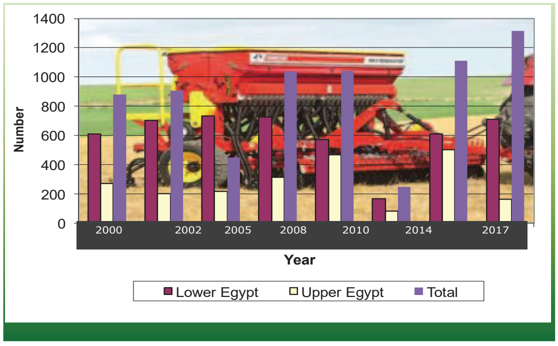

Figure 6. *Number of seed drills used in Egypt since 2000.*

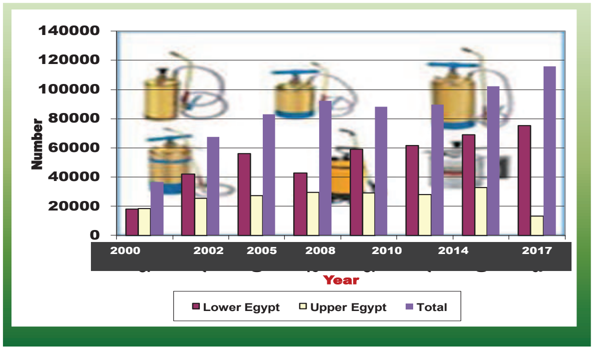

Figure 7. *Number of tsprayers used in Egypt since 2000.*

Development of the degree of mechanization

Development of the degree of mechanization during the first ten years of the '*Sustainable Agricultural Development Strategy Towards 2030'* by 0.5% per annum will depend on planning to introduce new technologies for mechanization based on the irrigation systems developed in the delta and valley areas (5 million acres). This will involve:

- Developing specialized training centers for agricultural mechanization.
- Modernization of the finance and lending structure and systems and the establishment of the Agricultural Bank of Mechanization.
- Development of agricultural extension systems.
- Activation of the media to increase specialized agriculture.
- Providing crop assemblies for the small agricultural tenure to follow the policy of agricultural cycle liberalization.
- Encouraging the productive role of the village, especially for rural women and rural industrialization.

- Developing replacement of current conventional irrigation systems that hinders the use of agricultural mechanization
- Correcting infrastructure bottleneck such as narrow roads that are not suitable for equipment movement.
- Control on random high pressure lines of electricity with agricultural crops and roads.
- Control on open waterways for irrigation and drainage channels.

The economic feasibility of the manufacture and assembly of agricultural mechanization equipment locally, based on the concepts of economic efficiency, can be encouraged by:

- Using available capacities in Egypt of specialized factories and workshops and technicians specialized in agricultural engineering.
- Reducing investment costs and maintaining the exchange rate.
- Reducing the costs of producing the main crops.
- Linking and fitting the production of equipment to the Egyptian conditions and markets that meet the basic needs.
- Production at a lower cost and within the concepts of economic calculations, especially simple equipment and easy installation.

Small agricultural machinery and equipment in Egypt

The institution and bodies that support the widespread use of agricultural mechanization in Egypt include the following:

- Agricultural Engineering Research Institute (AEnRI), ARC, Ministry of Agriculture.
- Mechanization service stations for renting the agricultural machinery and equipment at reasonable prices.
- Businessmen Association for the Development of Agricultural Mechanization.
- Agricultural Workers Syndicate.
- Development and Agricultural Credit Bank.
- Industrial Associations.
- The Civil Associations.
- General Assembly of Livestock.
- General Assembly of Agricultural Machinery.
- Agricultural Credit

- Directed media.
- General Association of Agricultural Mechanization.
- General Union of Producers and Exporters of Horticultural Crops.
- National Associations.

Following activities offer opportunity for expanding farm mechanization in the old lands and newly reclaimed areas:

- Mechanization of beet harvest and for harvesting other crops to expand the reclaimed lands.
- Mechanization of rice planting and harvesting operations in areas designated for crop cultivation.
- Technology for the production of green silage to feed the livestock.
- Technology for production of compost from plant residues and production of bio-fuels from secondary plant products.
- Mobile feed mixing units to encourage and expand animal production.
- Laser-leveling equipment to improve surface irrigation efficiency.
- Mechanization of sugarcane crop production - harvesting, loading and transport to factories.
- Technology for drying date products and medicinal and aromatic plants in Upper Egypt villages to increase the quality of the product for export.
- Construction of cooling stations to maintain the quality of the product for export and local consumption.
- Establishment of storage silos to reduce the losses of agricultural crops, which may reach about 10%.
- Develop grain transport methods to reduce waste

Focus has to be on the use of integrated mechanization methods for major field crops (corn, soybean, rice, wheat, barley, Bulgarian beans, peanuts and other oil crops, cotton, fodder crops), olive trees and other garden crops.

Investments for agricultural equipment

The investment in the annual replacement and the introduction of new technologies for an area of 6.5 million acres in the old land (Delta and Nile Valley) is given in Table 4.

Table 4. *The total Investments in agricultural equipment for the old land*

Item	Investments ($ Million)
Tractors	
Tractors 75 HP	17
Tractors from 25 - 75 HP	72
Tractors <25 HP	10
Equipment	24
Soil preparation machinery for Cultivation	20
Cultivation machinery and crop service	10
Drills and drills	24
Harvesting machinery and equipment	
Post harvest equipment to reduce crop losses	72
Modern transportation	240
Silos storage	
Sub-Total	489
Horticultural equipment	
Trimming equipment	1.0
Harvesting equipment	1.0
Grading and filling equipment	1.5
Cold stores	2.5
Refrigerated transport	4.0
Sub-Total	10.0
Animal production equipment	
Farmer Service Equipment	1.5
Mobile cases (less than 10 animals)	1.0
Dairy collection and cooling units (feed units)	1.5
(Jerash / Mixing / Silage)	2.0
Poultry Equipment	0.5
Sub-Total	6.5
Total	505.5

References

Central Agency for Public Mobilization and Statistics. 2013. Bulletin of Agricultural Machinery for the Year 2013. Reference No. 72-22129 / 2013.

Ministry of Agriculture and Land Reclamation. Publications and studies of the economic affairs sector.

Ministry of Agriculture and Land Reclamation. 2009. *Sustainable Agricultural Development Strategy Towards 2030.*

Ministry of Agriculture and Land Reclamation. 2014. Business plan 2014-2018. *Sustainable Agricultural Development Strategy Towards 2030.*

Theme 9: Role of Policies, Institutions and Markets in Improving Livelihood Security and Resilience of Dryland Communities

Lead Presentations

An integrative approach for facing climate change challenges

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Abstract

The world is awakened now to the fact that the continuation of the old pattern of thinking in dealing with nature would speed the annihilation of life on earth. The pace of scientific research in different fields has therefore increasing to find solutions to minimize the harm that humans has been caused in the last few centuries. The contribution of science is undeniable - the scientific achievements in agriculture helped to save the life of millions in past decades. However, the need to integrate science with politics and spiritual world views is urgently needed to make the scientific findings more effective. The path from science to people takes different directions. First, policy makers should use scientific findings in building their sustainable development strategies. Those findings require political will, and holistic views of how to serve each nation's interests in relation to the wellbeing of our planet. Second, social sciences should serve the scientific findings, by integrating them with local communities' knowledge. The already existing indigenous knowledge in different parts of the world is relevant to the world concern about sustainability, and should be respected, and made use of. International organizations use participatory approaches to realize this goal. The scientists can enrich indigenous knowledge, and add to it in order to improve the communities' livelihood. Third, education is an important tool to connect different scientific disciplines in an integrative way, elucidating eco-system's involvement in every aspect of our life. Obviously, environment has an impact on our health, level of energy, economy, resource management, and other aspects in our lives. Within this context, a need for radical cultural change, regarding our relationship with nature seems to be urgent.

Introduction

As much as we need scientific advancement to save our planet from a fateful annihilation, the world needs a global cultural perspective that depends on the grassroots' awareness of how to preserve natural resources, and care for nature (earth, water and air). This awareness is about a holistic vision that explains the interrelationship between humans and nature, indicating that life is manifested in every natural component. Therefore, we should appreciate nature's bounty and kindness. This vision is more than a relatively valuable cultural perspective; it is scientifically proven that the natural phenomena are interconnected and that human survival is conditioned by the stability of the eco-system. Appreciation and gratitude toward nature should overwhelm our emotions and impact our behavior and inspire us with new idea to improve our life condition without harming the eco-system. People can create pressure on their governments to take major decisions to respond to the scientific findings in practice, not rhetorically.

In tracing the roots of our current malaise, it is obvious that the worldview that emphasizes that everything in the world was created to serve human interests, engraves pride and superiority within human soul. Exploiting natural resources to serve humans has been common attitude. Accordingly, we have been depleting our natural resources, and polluting our environment. Continuation of the same worldview threatens our survival as a human race on this planet. This tragic end is ignored by some nations whose leadership has come to represent ignorance of our common destiny. Without the spirit of compassion toward nature and towards each other, the aspirations, which we have as scientists and people who are concerned about development, will be aborted. Empowering compassionate style of leadership may bring us together to collaborate to save life on our planet. The suggestions introduced here are in harmony with the United Nations Sustainable Development Goals (SDGs).

Eco-system and processes of global political will

'Big problems need big solution', this is how a folkloric proverb goes. It expresses the current situation in relation to challenges that the world is facing. As a result of the repercussions of the climate change, we read in the literature: "*Four billion people living on less than $2 a day, over one billion people without access to clean water, and millions of people dying every year from preventable diseases or famine. Soil erosion, loss of biodiversity, global warming have become phenomenal*" (UNEP, 2007). Or "*Climate change, with an increase in temperature and the rise in sea water level, will have an adverse impact on the livelihood of seven billion people that inhabit our globe now, and the situation will worsen if the projected rise of the population to 9 billion in 2050 were to come true. This will greatly disturb the coping capacity of our planet, and lead to severe ecological disaster. The approach to integrated natural resources management has to be customized to different ecosystems to meet the needs of communities that depend on them. Such approach would require developing intensive knowledge and understanding of the coping mechanisms to deal with drought risk, managing and restoring ecological functions, sustainably harvesting biodiversity, and diversifying production system and livelihoods, and this technological understanding has to be shared globally, regionally and nationally*" (El-Beltagy, 2017).

Scientific research and innovations come up as top priority in our efforts to face the challenges of climate change. Shared scientific knowledge to face the challenges is part of a wider needed spectrum where political will should back these findings. All these efforts target human livelihoods as an end goal, and it is here where social sciences and education come to bring the world to a safe shore. Over and above, we need a radical shift of consciousness, to redefine who we are, and how we are interconnected physically and spiritually to the whole.

No doubt that in the near past the concern of the environment has been attracting policy makers. Without the rise of the political systems' interest in the eco-system, international conferences would not have taken place. On the other hand, the awareness of the relationship between human behavior and the environment brought sociological and anthropological studies at the forefront with the scientific innovation to meet the repercussions of the depletion of natural resources and environmental pollution. Sustainable development is part and parcel of the holistic approach to save our and other species' lives.

Global political will is represented through a series of international conferences, which took place in the last century, starting as early as 1972 in Stockholm. The 1972 conference was more concerned about the human condition in polluted atmosphere due to poverty. It was not until Rio Conference in 1992 that the world paid attention to the depletion of the natural resources as a universal ecological problem. The idea of global economy emerged to address the problem of environmental degradation collectively. Following the First Earth Summit in Rio, the United Nations Framework Convention of Climate Change (UNFCCC) came into effect in 1994.

The Second Earth Summit took place in Johannesburg in 2002 that recognized the necessity of changing consumption and production patterns to manage the natural resource base for economic and social development. The concept of development includes access to energy for people who lack modern energy services. Biodiversity conservation and effective ecosystem management are necessary to reverse the processes that have destroyed the world's tropical rainforest. In this Earth Summit, heads of the States and governments assumed a collective responsibility to advance and strengthen the interdependent and mutually reinforcing pillars of sustainable development, social development and environmental protection - at the local, national, regional and global levels. It was clear for the attendees that partnership would speed the process of reaching the agreed upon targets.

The third phase took place early on before the Second Earth Summit under the Third Conference of Party (COP3) in December 1997 in Kyoto, Japan. It adopted what has been known as Kyoto Protocol, which outlined the greenhouse gas (GHG) emissions reduction obligation. The Protocol acknowledged that individual countries have different capabilities in combating climate change and put the obligation to reduce emissions on developed countries on the basis that they are responsible for the high level of GHG emission. GHG emission came in the focus from then on.

The Protocol entered into force in February 2005, three year later after The Second Earth Summit. In its scientific dimension, the protocol provided several means for countries to reduce gas emission. One dimension is to clean the atmosphere from the gas through increasing the planted areas. Clean Development Mechanism (CDM) is a program that encourages developed countries to invest in technology and infrastructure in developing country. It would encourage finding alternative sources of energy through new technology and offer them to those who need them most.

At COP 18, held in Qatar in 2012, delegates agreed to extend Kyoto Protocol until 2020. They also affirmed the necessity to a new comprehensive, legally binding climate treaty by 2015 that would require major GHG producing countries to limit and reduce their emission. COP 21 became another milestone and became known as the 2015 Paris Agreement where close to 200 nations agreed to keep global warming below 2°C above pre-industrial levels, and to pursue efforts to keep warming below 1.5°C. But no binding measures were put in place to meet these goals. This means that Kyoto protocol did not reach its goals.

The United Nations adopted wide range of projects through its different organizations, especially the UN Environment Program (UNEP) and the Intergovernmental Panel on Climate Change (IPCC) to bring the world to work seriously in a collaborative manner for keeping with the latest innovations that lessen GHG emission and enforce policies for cleaning our environment.

A study in 'Nature Climate Change Journal' warns that the amount of carbon we can release into the atmosphere before we exceed climate change targets might be a lot less than we thought. For the current state, the world must reduce emissions by up to 40% more than planned. "If we really want the targets defined relative to a pre-industrial baseline then it is likely that we may need tougher mitigation than we previously thought".[1] Secretary General Antonio Guterres warned that "the world risks is crossing the point of no return on climate change, with disastrous consequences for people across the planet and the natural systems that sustains them." In its first report commissioned by UN, under the 2015 Paris Agreement, IPCC indicated that emissions must be cut by almost 50% by 2030. The report advised that the world economy would have to be transformed at a speed and scale that has "no documented historic precedent". Paris agreement charts a new course in global climate effort. "The Paris Agreement requires all Parties to put forward their best efforts through nationally determined contributions (NDCs) and to strengthen these efforts in the years ahead. This includes requirements that all Parties report regularly on their emissions and on their implementation efforts".[2]

Since Paris accord in 2015, the supreme decision-making body of the Convention (COP) gathers yearly in different places around the globe to review the implementation of the Convention and other legal instruments that the COP adopts and takes decisions necessary to promote the effective implementation of the Convention, including institutional and administrative arrangements.

The UN Environmental Program (UNEP) became the agent responsible for assisting developing countries in implementing environmentally sound policies and practices. UNEP's activities cover a wide range of environmental issues and concerns about green economy. It works in promoting environmental science, paying attention to the way scientific finding can be implemented. It has been expanding its activities to work with national governments, regional institutions in conjunction with environmental and non - governmental institutions (NGOs).

The 2018 Emissions Gap Report sent strong signals to national governments and to the political part of the Tanaloa Dialogue at the Cop 24, held in Poland[3]. States, regions, cities, companies, investors and citizens are asked to stepup action in six key areas: energy

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[1] https://www.dw.com/en/have-we-already-blown-our-carbon-budget/a-39878925
[2] https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement
[3] https://img1.wsimg.com/blobby/go/9fc76f74-a749-4eec-9a06-5907e013dbc9/downloads/1cue9k5fb_255610.pdf

transition, climate finance and carbon pricing, industry transition, nature-based solutions, cities and local action, and resilience.[4]

Despite all these world efforts, the president of the United States negates to repercussions of climate change. His famous slogan America First seems to appeal to the majority of the United States' citizens. This is an indicator of radical cultural change in the US political value system. His predecessor, president Barak Obama, had a holistic vision where he understood clearly that the interests of the citizens of the world that they share as human beings are far more powerful than the forces that drive them apart. In one of his speeches he said: "For human history has often been a record of nations and tribes subjugating one another to serve their own interests. Yet in this new age, such attitudes are self-defeating. Given our interdependence, any world order that elevates one nation or group of people over another will inevitably fail".[5]This is the kind of vision which we need around the world. Major agreements were signed in 2015, UN Sustainable Development Goals' (SDG's), the 'Paris Agreement' to coordinate efforts to tackle climate change, and the 'Sendai Framework for Disaster Risk Reduction'.

People around the world are awakened to the threats that we are facing. More than four million people have taken part in an unprecedented wave of climate protests across the world in the most powerful message to governments to take serious action during the Climate Change Summit meeting in New York in 2019.[6] Secretary General António Guterres raises ambition and encourages increased climate action: "The race is on. It is a race we can win. It is a race we must win."

Cognizing nature: Mindset and climate change

Having discussed the sequential phases of the international concerns about environment, this paper - in its integrative approach - is interested in searching for the underlying mind-set, which leads the world to the current status, and opts to search for possible shift of consciousness to build on.

Our modern era has witnessed wide scale dividedness, conflicts of interests, isolations, and racing for power, and domination. These are symptoms for social, spiritual and psychological illness. According to in depth analytical psychology, we export our inner conflicts to our human and natural environments (Jung, 1933). Healing the consequence of the situation, which we collectively have created, requires collective change in cognizing our relationship with nature. Let us examine the past and current worldview.

The mechanistic view of the natural world: In dealing with the environmental issues, the world efforts targeted the human wellbeing and considered nature as subservient. Reifying nature has become a common approach within the common world cultures. Accordingly,

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[4]http://wedocs.unep.org/bitstream/handle/20.500.11822/26896/EGR-KEYMESSAGES_2018.pdf?sequence=1&isAllowed=y

[5] Barak Obama Speech in Cairo, Egypt, June 4/2009, published in New York Times June 6/2009

[6]https://www.climatechangenews.com/2019/09/20/three-million-join-students-global-strike-climate-action/ reached on 9/23/2019.

economic policies and practices have been based on exploitation of the natural resources for short term consumption and have overlooked the damage done to the earth, water, and air.

The simple fact that we humans have come to existence through long process of evolution is completely ignored. For one reason or another, humans think that they can master the universe, control it, and use it for their own interests. They have lost the awareness and consciousness that they are part of the comprehensive whole. Newtonian physics envisaged the world as a big machine, void of life. This view encouraged the growth of technological invention and industrial plundering. The achievements of the scientific achievements cannot be denied. On the social level capitalism, through the formation of modern commercial corporations, prevailed and exploitation of natural resources became the norm. Globalization and free trade through trans-continent and trans-state companies reinforced the consumptive behavior at the expense of the limited natural resources. The Industrial Revolution accompanied by scientific contributions brought humans to unprecedented phase of their history, and the technological advancements have been progressing to reach Information Revolution. Alas, we have lost our connection with nature, and were not aware of the harm that we have been doing to our environment, by polluting the atmosphere. It seemed that humans were trapped in the tragedy of the commons according to Hardin hypothesis. Hardin (1968) explained that humans tend to overuse resources when there are rules to organize their uses, and they do not feel guilty if they exceed their limits.

During the last two centuries, and as a result of the increasing use of fossil fuel for all sort of human activities, emission of gases continues to rise and harm the ozone layer in the atmosphere, and the climate has started to change. Global citizens have become more alienated from their mother nature and psychologically separated from one another, forgetting that they were rooted and created from the womb of this ancient mother. This underlying mindset directs human behavior on the individual and national levels for limited self - interests.

Short-sighted political visions: Despite the great efforts done by scientific research, and the creation of several UN organizations and affiliates, the world has not reached the anticipated targets. Short- sighted vision drives political leaders to retreat or slow the progress of the agreed upon international policies. The position of the current US President is a good representation of this limited vision. He openly denies that the world is facing a serious threat as a result of climate change: "President Donald Trump has falsely called climate change a 'hoax' invented by China, incorrectly suggested that wind turbines cause cancer and dismissed a landmark scientific report produced by the federal government's own scientists. His Administration has sought to roll back key climate regulations at every turn"[7].

Moreover, there seems to be a paradox between the Earth well-being, and the countries' economic interests. Countries who depend economically on fossil fuel are not likely to make decisions that affect their economy. Countries like Venezuela, Saudi Arabia, Iraq, Russia, the United States, United Arab Emirates, Kuwait, and Iran have huge portions of their annual gross domestic product (GDP) dependent upon producing and/or exporting fossil fuels. A

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[7] https://time.com/5622374/donald-trump-climate-change-hoax-event/ retrieved 9/25/2019

significant mandated reduction in use of global fossil fuel could plunge those countries into rapid economic decline and in some cases, possibly even social and political unrest or collapse.[8]

In the 2019 UN Summit for Climate Change, the Secretary General firmly asserted that there is no time to discuss or negotiate climate change, it is time to act: "This is not a climate talk summit. We have had enough talk," he added. "This is not a climate negotiation summit. You don't negotiate with nature. This is a climate action summit".[9]

On the Climate Change Summit in 2019, expressing the youth fury, Swedish teen activist Greta Thunberg criticized world leaders for not taking action regarding climate change. "People are suffering. People are dying. Entire ecosystems are collapsing. We are at the beginning of a mass extinction and all you can talk about is money and fairy tales of eternal economic growth - how dare you?" said Thunberg accusing world leaders of ignoring the scientific warnings behind the climate crisis.[10]

Climate change and the lust of power and warfare: War is an old phenomenon, caused partly by the drive of survival. In case of scarcity of resources, tribes fought to own these resources. This tribal spirit is still prevalent in our contemporary world with more greed. If the old tribes were fighting for survival, today's nations fight for power. Motivations for power vary in nature. European countries raced to occupy lands in Asia and Africa because of their rich natural resources. France and Britain were rivals, racing to expand their territories overseas in the nineteenth century to gain economic and military power. As a result of the Industrial Revolution, fossil fuels became essential in promoting industrial machinery. Middle Eastern countries' wealth created competitions between Super- Powers in the 20th century (The United States and the Soviet Union) to control the economy of those countries, and to made them follow their economic policies and hence exploit their wealth. Even after the end of the cold war between the United States and The Soviet Union, the world still suffers from the dividedness spirit, and rivalry. The president of the United States does not hide this tendency to overrule and control the world for the interest of his country.

The Rio declaration mentioned warfare as inherently destructive of sustainable development, and environment. It acknowledged that the state of peace was important for environmental protection. Rio recommendation went in vain with the eruption of wars in the Middle East between Iran and Iraq, followed by Iraq invasion to Kuwait and the interference of US and UK coalition to liberate Kuwait. In 2003, the US invaded Iraq to end Saddam Hussein regime. The impact of these wars on the environment was catastrophic.

During wars, people who kill each other, kill at the same time their mother earth, and pollute water and air as essential sources of life. With the continuation of this sort of mindset, where some people think they are superior, and have the right to defeat and control other people, our

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8 http://www.joboneforhumanity.org/why_35_years_of_reduction_failure?utm_campaign=the_five_most_important_facts&utm_medium=email&utm_source=factnet, retrieved July 5, 2019

9 https://news.un.org/en/story/2019/09/1047052, retrieved 9/23/2019

10 https://ww.dailynewssegypt.com/2019/09/25/how-dare-you-greta-thunberg-attacks-world-leaders-at-un-climate-summit/

environment will suffer regardless of the great efforts of scientific research, innovation of new technology and the efforts of international organizations and the United Nations.

Climate change and sustainable development goals (SDGs)

Integrating science, politics with respect to local communities and their knowledge of how to deal with natural resource, is the core of development. Sustainable development goals harmonize with eco-system preservation, which is the mission of the United Nation Environmental Program (UNEP). The UN Executive Director for UNEP says: "Crucially, the Sustainable Development Goals integrate environmental sustainability and social equity with economic progress. Such integration - the idea that environmental sustainability is not an impediment to, but a driver of, development and human well-being - has been a key focus of UNEP's work. The Economics of Ecosystems and Biodiversity (TEEB) continues to demonstrate that recognizing the tangible economic benefits of ecosystems is central to creating inclusive green economies and lifting millions of people out of poverty" (UNEP (2015).

The need for shift in consciousness

From the above review of how the interest in the environment has emerged internationally, it has become obvious that discussion on climate change is more than a political, scientific and economic debate. It is an accumulative outcome of how humankind envision who they are and depict their relationship to the natural world.

Commodification of the earth natural resource serve human beings' spirit of consumerism, and politicians' lust for exploiting the fossil resources for their own interests. Climate change as such is a reflection of the spiritual and moral blindness and ignorance. In the last few centuries, humans ignored their interconnectedness, and the so-called developed countries have been racing to dominate the rest of the world. The 20th centuries witnessed two world wars and the killing of millions of people. The same mentality still directs the policies of some of the most influential countries.

In this time of climate change crisis, we should learn from physics and in-depth psychology and change our perception to ourselves and to nature. We are in a time of paradigm shift where we may entirely redefine who we are in relation to the whole. We learn that we are not any more separated from the cosmos, and we are also interconnected to consciousness that is greater than our individual selves.

Physical science teaches that living organism are open systems and exchange matter and energy from their environment. The peculiarity of open systems is that they interact with other systems outside of themselves. When we look more closely at the environment of a system, we see that it too consists of systems interacting with their environments. If we now consider the collection of such systems that interact with each other, that collection could again be seen as a system. If these parts did not interact, the whole would not be more than the sum of its components. But because they interact, something more is added. With respect to the whole the parts are seen as subsystems. With respect to the parts, the whole is seen as a supersystem. That is how we are interconnected with the Earth, and the Earth is interconnected with other cosmological systems, and it goes on and on (von Bertalanffy, 1950). To put it in different wording: "The organism is the archetypal metaphor of all deeply interconnected and interrelated systems. It is firstly a holistic entity, -a system within which all constitutive entities exist in meaningful relationship to all other entities. The entities comprising an organism carry nested self-similarity, and fractal properties, which is to say that observation at multiple scales reveals information about the larger self-organizing system" (Nelson, 2019).

Perceiving the cosmos as interrelated and interconnected systems *ad infinitum* removes the delusion of separateness, everything is connected to everything else in mysterious order, which is far beyond being controlled by materialistic mechanical laws. It is magnificent to realize that humans have the capability to apprehend this interconnectedness. This is only possible because human consciousness is an extension of the universe's consciousness. Our realization of who we are shifts from being nothing in the expansive universe to be manifests of its existence. "In the organismic frame our identity moves from that of a single finite human, to an expression of a developing principle of consciousness being variously expressed in the world" (Nelson, 2019).

This paradigm shift challenges the long taken-for-granted notion that everything follows a mechanical order, even our bodies. This long-standing metaphor of the universe as a great machine has been associated with the development of science. However, we are in the edge of new science with other postulates. Bringing the organismic approach to our consciousness means that we perceive the universe as an alive entity, with a self - generating process.

This approach to the universe and nature was known to the indigenous people in different parts of the world. Our ancestors were aware of the interconnectedness between humans and their natural environment; they respected nature, believing that everything has soul, even stones and mountains. The animistic approach known to these people has been considered superstitious beliefs, due to lack of knowledge. It is amazing that the indigenous knowledge, which had no scientific base, is coming back under scientific umbrella.

Acknowledging that the universe is alive and has self-generating drives and consciousness, came awareness to quantum scientists once more and they have started to speculate on this hypothesis. In another seemingly remote scientific discipline, in depth analytical psychology offers to evolution theory a perspective that coincides with quantum mechanics theory. We are in a stage of transition. Stapp says, "…today the great machine metaphor no longer serves to further our understanding as it once did, and there are nowtelling signs that the modern mind is in the midst of a transition; toward an *organismic* lens on reality - apprehended as an evolving, self-generating, and ultimately living process" (Stapp, 2001).

Out of his observation and mathematical studies, Von Neumann introduced a theory that provides a quantum framework for cosmological and biological evolution. This theory is formulated as an indeterministic theory. Freedom of choice "on the part of both the human participant and Nature herself, lead to a picture of reality that gradually unfolds in response to choices that are not necessarily fixed by the prior physical part of reality alone (Stapp, 2001). Von Neumann reformulated Quantum Theory as theory of an evolving objective universe interaction with human consciousness. This theory brings the objective physical state of system in line with a subjectively felt psychical reality. The physical state is thereby converted from a material substance to an informational and dispositional substrate. In other words, physical theory became converted from a theory about 'physical reality', as it had formerly been understood, into a theory about human knowledge (Stapp, 2001).

In depth psychology expressed this relationship between both the psychic and physical realms through, what the Swiss psychologist C.J. Jung (1875-1961) called, archetypes. Jung connotes this term to denote shared symbols that are produced by the collective unconsciousness. From his own practices, Jung realized that humans are connected unconsciously to collectivity that exceeds their personal consciousness or unconsciousness, and that they share certain symbolic expressions through their dreams and their active imagination that transcends personal experiences. Within this contexts, collective unconsciousness represents objective existence, yet it sends messages to individuals, revealed to them through dreams, or unexpected knowledge. Sometimes these symbols became source of unfolding knowledge. According to Jung, who analyzed Wolfgang Pauli's dreams, mandalas (archetypes of wholeness) played a crucial role in Pauli's dreamlife to compensate for the disruptive impact of quantum physics on established worldviews. By analyzing and visualizing his dreams, a process of working-through, Pauli managed to visualize and master archetypal influences, thus maintaining his creativity as a physicist (Zwart, 2019).). Jung gave a perspective that integrates the archetypal insight into scientific thinking. "To achieve this, … the researcher should first of all become consciously aware of the power of the archetypal content and come to terms with it: A process which Jung refers to as individuation. In other words, the first law of thermodynamics is a *coniunctio oppositorum*, a 'marriage' if you like, of modern scientific thinking and an archetypal insight, a disruptive collision at first, which eventually allows science to reach a higher level of comprehension. In other words, for Jung, research practices (from alchemy up to quantum physics) are practices of the self: exercises in self-formation or individuation (Zwart, 2019).

From a Jungian perspective, scientific findings come as a result of a union between rational and imaginative, or receiving from the unconscious images (archetypes) and gave a time to become meaningful on the conscious level. For Jung scientific knowledge unfolds in the human mind through creative imaginative processes, supported by meaningful coincidences (synchronicity). Here is where synchronicity came on the core of interest for both Jung and Nobel Prize Winner Wolfgang Pauli. Pauli, who sought Jung psychological help, became a friend. Together, they collaborated to interwind psychology and physics. Synchronicity or meaningful coincidences became a framework for understanding an order that does not follow the simple mental relation of cause and effect. The acausal phenomena as appear in synchronicity are explained in the light of a sort of interconnectedness beyond the apparent observable and recognizable elements. *Unus Mundus* is the term that denotes to the world that time and space are one whole. It is an underlying unified reality from which everything emerges and to which everything returns without being transcendental. This unity is spiritually/psychologically experienced beyond description, and synchronicity would be appreciated from this perspective. This outcome is explained through quantum physics from another point of view. Both quantum theory and in-depth analytical psychology have a meeting point, emphasizing the interconnectedness between human and unknown dimension of reality which unfolds itself to human mind in what we call 'knowledge'.

Conclusion

The revolution in consciousness as revealed by new scientific approach may bring us to another phase of evolution where humankind come together as one family, facing the challenges of the climate change with new perception of the unity of life, and our oneness as human beings. This awareness would move from its philosophical framework to living practices of everyday life, and a guideline for world politics, and international relationship. We can survive if we let the universe inspire us how to connect to its wisdom and open ourselves to receive its guidance. We have the choice to be modest and humble, yet hopeful and active, or to remain in the illusion that we have the power to dominate and control nature. This new approach means to be more in harmony with the discovery of science that reveals before our eyes that we are more than body and matter; we are spirits and souls. It is a realization of who we are as human beings. If spiritual wisdom in our history came to bring this reality to our consciousness, scientific approaches have made the spiritual wisdom a reality in our life.

References

El Beltagy, A.S. 2017. Achieving Sustainable Development Goals (SDG) in the dry areas - A myth or a realty**.** Proceedings, 12th International Conference on Dryland Development, IDDC, 2017.

Hardin, Garrett .1968. The tragedy of the commons. Science 162: 1243-1248.

Huntington, Samuel. 1997. *The Clash of Civilization: The Remaking of the World Order,* Touchstone, USA, New York, 1997.

Jung, C.J. (translated by W.S, Dell and Cary F. Baynes). 1933. *Modern Man in Search for a Soul,* Routledge.

Karen, Armstrong. 2000. *Battle for God: Fundamentalism in Judaism, Christianity and Islam.* Knopf/Harper Collins.

Kimmerer, Robin Wall. 2005. *Braiding Sweetgrass: Indigenous Wisdom, Scientific Knowledge and the Teachings of Plants.* Milkweed Editions, Canada.

Mijares, Sharon, Aliaa Rafea *et al.* 2007. *The Root of All Evil: Exposition of Prejudice, Fundamentalism and Gender Bias.*

Nelson, Adrian David. 2019. *The Living Universe: Cosmos Organism.* California Institute of Integral Studies.

Scherrer, A.P. *et al.* 2017. Importance of the pre-industrial baseline for likelihood of exceeding Paris Goals. *Nature Climate Change*, July 24/2017.

Stapp, H.P. 2001. Quantum Theory and the Role of Mind in Nature. Foundations of Physics, Vol 31 No. 10, October 2001, p. 147

UNEP (United Nations Environmental Program). 2007. Our Planet, Connected Dreams, The Magazine of the United Nations Environment Program, February 2007, 3 p.

UNEP (United Nations Environmental Program). 2015. Untied Nation Environmental Programme Annual Report 2015, 6 p.

von Bertalanffy, Ludwig. 1950. The theory of open system in physics and biology. *Science* III: 23 -29.

Zwart, H.A.E. 2019. Archetypes of Knowledge: The relevance of Jung's psychology of scientific discovery for understanding contemporary techno-science. *International Journal of Jungian Studies* 2019: 1-21.

Policy, institutions and markets for sustainable livelihood opportunities in arid agriculture

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Extended Summary

The government is focusing on farmers' welfare and is envisioning to double the farmers' income by 2022. Different central and state level programs have been floated to execute and monitor the outreach of technologies, soil health, farm credit and market to the farmers. Price supports are triggered for many of the crops; entrepreneurship is inculcated to the farming community.

Technology still provides a promising scope to increase income at farm level. The estimates portray that yield gap vary from one-fourth to one-third within the paddy farms. If the yield gaps are addressed through proper scientific and management interventions, there can be significant gain in output. Research and development organizations need to make concerted efforts to bridge such gaps. The non-traditional areas for cultivation can provide a remunerative solution for further enhancing the farmers' income. These may include shifting orientation from cereal dominance to high value commodities like horticulture and livestock. The diversification strategy requires strong emphasis on regional crop planning and preparation of optimum crop plans for identification of competitive crops, which ensure reasonable income and nutrition along with sustainability to particular agro-climatic conditions.

The current market architecture does not provide farmers with a choice of markets but imposes constraints to their selling options. India has a meagre 8,900 markets regulated through various government agencies for selling of farmers' produces. Lack of access to adequate number of market hubs means farmers do not get to bargain for their produces thus affecting their viable livelihoods. In India, poor marketing linkages and infrastructure constraints have led to high and fluctuating consumer prices, resulting in only a small share of consumer rupee being transferred to the farmer. In addition to this, the issues of poor produce handling, loss of produce and lack of scientific grading and storage facilities have also affected the efficiency of agricultural marketing in India.

There has been large gap in the development of the storage infrastructure, transportation, mechanization, grading standards, export promotion, processing industry support and market intelligence in India that requires upgradation. Market intelligence or the dissemination of information on market demand and availability is an important area which could play a significant role in farmers' decision making regarding the production and marketing of agricultural commodities. As more marketed surpluses are generated, farmers will need to know which market to transfer their produce, what price to expect, availability of marketing infrastructure and status of competing supply.

Food processing has huge potential to dramatically improve rural livelihoods by raising farm incomes through value addition in agricultural produce. The major strategy to follow is to encourage processing by the household sector. Against the corporate sector, which contributes about 7%, household sector contributes around 13% of the output of food processing sector. Fruits and vegetables, and livestock processing especially provide high scope. This would turn to reality under optimal skill delivery to the farm households. Special schemes could be introduced that cater processing by the farmers and simultaneously link the processed food to the urban market. Equally, encouraging Farmer Producer Organizations and other private sector to invest more in processing would complement the effort. If concerns related with upgradation of food processing technologies, cold storage infrastructure, transport of processed products and food quality grades are addressed properly, this will strengthen the linkage between agriculture and manufacturing sector and will ensure to address ever-growing concern related with rural livelihood security.

Role of agricultural credit is extremely important in meeting the crop cultivation, animal rearing and other sub-sectors' requirements in agriculture. The Government of India has initiated several policy reforms to ensure the timely and required availability of credit to the farmers with the purpose to have progressive institutionalization with an inclusive approach. A notable reform initiated recently is Kisan Credit Card Scheme to enable the farmers to purchase agricultural inputs and draw cash to meet their consumption needs. Most of the farmers in the country lie in the marginal and small category with very small holding size that makes the diffusion of advanced technologies difficult. The holdings are tiny and scattered particularly in the hilly areas. Studies have established that the inequality in land ownership has been impacting the status of livelihood security for a long time. Thus, land consolidation coupled with other suitable land reforms need to be effectively implemented. Further, the climatic risks are resulting in decline in productivity and creating distorting impact on prices. Thus, risk management is an essential component to be studied in detail to identify viable solutions for sustainable livelihood of the farming communities.

Empowering small-scale farmers and women by enhancing food security in the marginalized environments of the Aral Sea Basin

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Abstract

Living conditions of people inhabiting the Aral Sea Basin (ASB) countries have been adversely affected by a combination of climate change and land degradation, mostly by soil salinization. Desert rangelands productivity has declined and biodiversity is being lost at an alarming rate because of soil salinization, rising water table and increasing mineralization of groundwater. Utilization of marginal water for growing non-conventional crops on salt affected lands, desert pastures and hayfields is emerging as a potential option for a better livelihood of poor resources desert communities. This spaper focuses on strengthening advocacy and awareness of small-scale farmers and woman entrepreneurs on managing risks and enhancing productivity of saline lands and water resources through application of alternative innovative biosaline agricultural technologies.

Introduction

Living conditions of the remote and hard-to-access market rural communities of some 4.9 million people inhabiting the Aral Sea Basin (ASB) countries have been adversely affected by a combination of climate change and land degradation, mostly by soil salinization. Desert rangelands productivity has been declining by 50% and biodiversity is being lost at an alarming rate due to intensive soil salinity, rising water table and increasing mineralization of groundwater. The situation has become worse recently in borderline of these territories because of intensive irrigated agriculture and overgrazed pastures due to lack of good quality forage alternatives for livestock, and remote markets. As living conditions deteriorate, people (mainly male workers) are forced to migrate elsewhere in search of a better income/welfare.

Utilization of marginal water for growing non-conventional crops on salt affected lands, desert pastures and hayfields can help support food chain supply for rural communities and livestock productivity, and is emerging as a potential option for a better livelihood of poor resources desert communities.

This study focuses on strengthening advocacy and awareness of small-scale farmers and woman entrepreneurs on managing risks and enhancing productivity of saline lands and water resources through application of alternative innovative biosaline agricultural technologies.

Methodology

Socio-analyzing systems (SAS) of rural small-scale farmers survey and participatory gender rapid assessment (RGA) were adopted to identify the perceptions and management practices of farmers with regards to saline environments problems, the level of readiness and acceptability of innovative biosaline technologies by the vulnerable rural population with special focus on women groups. In total 250 small-scale farmers and households living in 3 Village Citizen Councils named Karabuga, Shortanbay and Koybak, located in the delta of Amudarya River in Uzbekistan were randomly selected and interviewed.

Results

The findings showed that local communities recognized the existing environmental risks and high necessity to reverse increasing trend and to restore the marginal underutilized resources, which represent about of 25% of low quality water and 44% of abandoned and saline lands (Fig. 1 and 2).

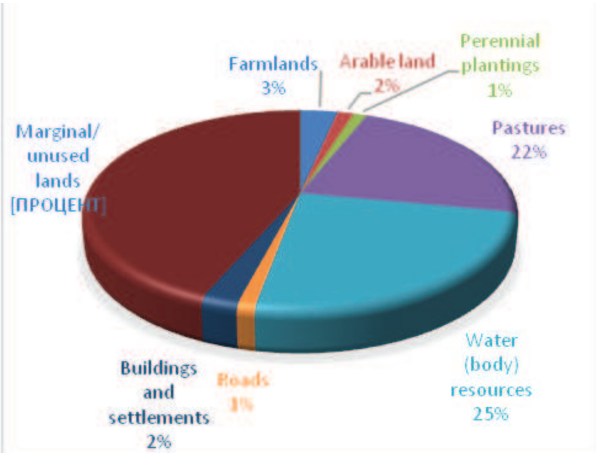

Figure 1. *Land use in the Aral Sea Basin (ASB).*

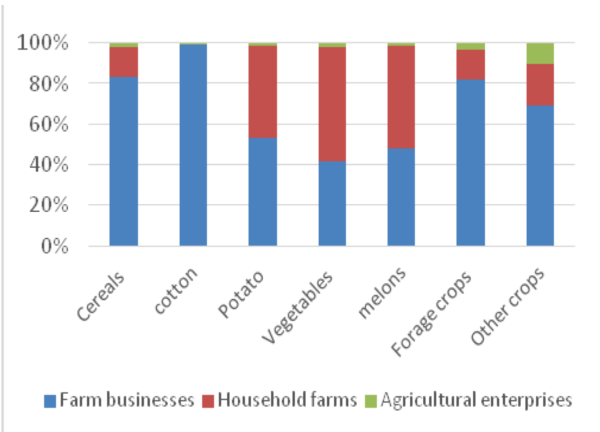

Figure 2. *Most cultivated crops in irrigated land of Aral Sea Basin.*

Gender-disaggregated data sets have captured the spatial variation in livelihoods in Aral Sea Basin (ASB) areas and used to identify interventions along with insights in institutional and policy reforms to improve livelihoods. Gender Rapid Assessment (GRA) analysis revealed that despite women's prominent role in agricultural production, agriculture also exhibits the gender imbalances observed in other sectors, particularly in control over productive resources. Although women comprised more than half of those engaged (as household farms) in the agriculture sector (52.6%) in 2008, only 17,000 (7.2%) of 235,000 registered farms were headed by women.

It also appears that, after restructuring and merging of cooperative (*shirkat*) farms into individual farms, the number of female-headed farms was reduced further, to 12,084 (5.5%). These reforms also caused change in the land use, where strategic crops (cotton and cereals) were replaced with more intensified crops, including vegetables, melons and forage crops (Fig. 2). On the other hand, the transformation of *shirkat* farms into single-farmer enterprises has resulted in job losses in the agriculture sector and increasing short-term agricultural migration of poor, low-skilled female workers. According to a report, 32.0% of all working women and 26.4% of working men were employed in agriculture in 2015 as compared to 28.5% of women and 25.5% of men in 2010. Table 1 shows such trends apparently, where male workers have decreased (by out migrating) sufficiently for the last decades. However, women occupy only 4.2% of managerial low-paid positions in agriculture. Furthermore, women's salaries are only 82% of men's salaries in the agriculture sector. Women have benefited substantially less than men from privatization of agricultural production and land allocation schemes because of the state inaction in ensuring women's rights to property, which has meant that "it is largely men who are in a position to acquire rights to land during privatization, a process that is facilitating the resurgence of patriarchal land rights" (Table 1).

Table 1. *Gender-related aspects of work in rural households*

Years	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Men	13967	14321	14587	14965	14442	13863	13851	13834	13690	13546	13402
%	35,2	32,8	32,6	33	33,4	29	29,8	29,2	28,5	27,7	27

One of the gaps - forage options from marginal/unused saline lands in Aral Sea Basin - was addressed through local initiatives that included Rural Women Learning Alliances. Solutions include the growing of winter feed by livestock keepers, using non-conventional crops. Identified farmers (152 from 9 villages at Karauzyak district), agro pastoralists (65 smallholder pasture users from Koybak cooperative and Ermak livestock farm) and women groups (45 women in 2 groups from 9 villages of Karauzyak district) of interest raised commitment to adopt mixed farming, improved forage production and agro pastoral production systems, and trained in postharvest practices on seed multiplication and storage. The Seed Growers Network was established and options for double cropping (suitable crops and their seeds such as *Triticale*, fodder beet, sorghum, pearl millet, mung bean, Sudan grass, forage pea, *Jerusalem artichokes*, *Atriplex*, kochia, *Indigofera*, *Amaranthus*, sweet clover, sainfoin, quinoa) were introduced. The seed material produced was pooled for bulk-scale supply to forage farmers located in their neighborhood through a 'farmer to farmer' seed delivery system, indicating that there is sustainability and demand for these diverse crops and their introduction into current production systems. This result led to diversified farmers' income by ⅓ compared to their former traditional seed production.

Conclusion

Villagers found out that the cultivation of non-conventional crops for multiple purposes results in effective utilization of water resources, while simultaneously supporting ecosystem functions and increasing economic benefits for local households. Further, such crops help desalinize the soil by drawing salt up into their aboveground biomass, which allows less salt-tolerant crops to grow. The cultivation of halophytes in combination with forage biomass or remains of traditional crops after harvesting represents a critical innovation in the cattle feeding system. Women farmers, female agricultural scientists and researchers, and women-led food NGOs strengthen empowerment of women in businesses initiatives in biosaline agriculture development. Rural Women Learning Alliance under supervision of international and regional research teams could become a strong unit in enhancing productivity of salt affected lands, improve livestock feeding system and increase the income of rural poor communities.

Community-based landscape management for sustainable livelihoods in drylands

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Extended Summary

Green Revolution while contributing to increased food production and enhanced food security of the country is inadvertently fostering a perfect storm. Unsustainable agricultural practices are reducing ecosystem services across India and resulting in loss of agricultural biodiversity. Additionally, overgrazing by livestock is reducing available habitat for wild species and increasing the rates of desertification and land degradation. Agriculture also places enormous stress on the country's limited water resources, particularly groundwater aquifers. Moreover, climate change is an emerging threat that will accelerate the loss of agricultural productivity and have adverse ecological impacts. Consequently, intensive agricultural practices are often incompatible with the long-term conservation objectives of high ecological landscapes.

About 82% of the country's farmers are small and marginal. Some 60% of agricultural land is primarily rainfed. Considering that majority of the farmers in drylands are resource poor, efforts to increase food production must happen within the framework for sustainable management of natural resources and improved access to food for all. India's agriculture sector needs to fully integrate environmental concerns in its policies, plans and programmes to ensure that the sector's negative environmental impacts are mitigated and positive contributions are enhanced. Environmental mainstreaming is important for the agriculture sector's own long-term sustainability, especially under the context of a changing climate. Issues such as sustainable land and water management, pollution abatement, maintenance of agrobiodiversity and pollinators are as much concerns for sustainable agriculture as they are environmental issues. Further, integration of environmental concerns will ensure that financial investments by the government into other sectors, especially in the environmental sector, are not directly undermined. Also, the good health and wellbeing of local people will not be sustained unless the negative environmental impacts of agriculture are mitigated.

Mainstreaming environmental concerns into the agriculture sector requires a multi-sectoral approach within a given landscape. Landscape is defined as 'a large tract of land constituted by a mosaic of interacting land uses with people and the impacts of their activities as the cornerstone of its management'. The landscape approach deals with large-scale processes in an integrated and multidisciplinary manner, combining natural resource management with environmental and livelihood considerations. It also factors in human activities and their institutions, viewing them as an integral part of the system rather than as external agents. This approach recognizes that the root cause of problems may not be site-specific and that a development agenda requires multi-stakeholder interventions to negotiate and implement actions. Thus, landscape approaches facilitate convergence between sustainable use of natural

resources-land, water, and biodiversity and developmental outcomes for sustainable livelihoods.

The Food and Agriculture Organization of the United Nations (FAO) administered the Andhra Pradesh Farmer Managed Groundwater Systems (APFAMGS) project. This project demonstrated with replicated results that dryland farmers working collectively in Farmer Water School (FWS) groups at landscape level could reduce overuse of groundwater by reducing water demand. This was achieved by farmers collecting and sharing practical data on groundwater recharge and water requirement for ensuing dry season crops. Following which, farmers engaged in a community dialogue on crop-plans and crop-water management for the upcoming season. Likewise, the Strategic Pilot on Adaptation to Climate Change (SPACC) project showed the benefits of smallholders working cooperatively to improve ground water management by applying innovative tools such as community operated weather stations, crop water budgeting, soil monitoring, crop monitoring, and better cropping patterns to achieve water conservation goals.

More specifically, FAO and its local partners implemented the APFAMGS and SPACC projects in seven drought prone districts of Andhra Pradesh (Anantapur, Chittoor, Kadapa, Kurnool, and Prakasam) and Telangana (Mahabubnagar and Nalagonda). The projects developed a participatory hydrological monitoring programme to build farmers' capacities with the requisite knowledge, data and skills to understand the hydrology of groundwater resources. Additionally, they also built farmers' capacities to adapt to climate change and variability under the Sustainable Land and Ecosystem Programme (SLEM) of the Government of India, under the Ministry of Environment, Forest and Climate Change (MoEFCC).

The projects facilitated the formation of Groundwater Monitoring Committees (GMCs) - 638 farmer committees at the village-level that monitored groundwater resources in particular villages. These committees were then federated into 63 Hydrological Unit Networks (HUNs) at the hydrological unit level. The GMCs and HUNs in each hydrological unit estimated the total groundwater resource available and worked out appropriate cropping systems that are climate resilient and matched with water availability. These farmer institutions then disseminated the information to the entire farming community within each hydrological unit and acted as pressure groups. These efforts encouraged appropriate water saving and harvesting projects, promoted low investment organic agriculture and helped formulate rules that would ensure inter-annual sustainability of limited groundwater resources. In a majority of the pilot project area (638 villages across seven districts), the results have been very positive, as witnessed by a substantial reduction in groundwater abstraction through crop diversification and irrigation, water-saving techniques and improving profitability. The APFAMGS approach is acknowledged by the Government of India (Anonymous, 2011) as an effective model for groundwater management and adaptation to climate change in rain-fed areas of the country.

The Green Agriculture Project will draw upon these experiences to harmonize agricultural and environmental priorities and investments, in select dryland areas, without compromising

India's ability to meet its food and nutrition needs and strengthen rural livelihoods. The project will be implemented in five landscapes across five states - Madhya Pradesh, Mizoram, Odisha, Rajasthan, and Uttarakhand. Each of these landscapes represent a unique set of dryland ecosystems and associated conservation and livelihood challenges. The diversity of landscapes will facilitate the development of self-sustainable and replicable models for promoting conservation, productivity, and sustainable livelihoods. In these landscapes, Government, GEF and other investments will be aligned to promote and incentivize maintenance and/or adoption of new agro-ecological practices to reverse negative impacts of current unsustainable agriculture and land use to maximize multiple global environmental benefits (protect biodiversity, sustainable land management, greenhouse gas emission reduction, and maintenance of high conservation value forests).

Reference

Anonymous. 2011. Twelfth Five Year Plan Approach Document: Faster, Sustainable and More Inclusive Growth. (http://planningcommission.gov.in/plans/planrel/12appdrft/appraoch_12plan.pdf)

Recommendations emerging from the 13th International Conference on Development of Drylands

The Conference was attended by 379 participants from 80 international and national organizations representing 39 countries from six continents.

The Conference structure included plenary sessions including evening lectures, concurrent technical sessions, satellite symposia, panel discussions and poster sessions. It covered following themes:

- Impact of climate change in drylands
- Managing land degradation & desertification
- Soil health management, carbon sequestration and conservation agriculture
- Water harvesting and improving water productivity
- Conservation and use of agro-biodiversity; developing adapted cultivars
- Sustainable intensification and diversification (Arid horticulture, aquaculture, protected agriculture)
- Livestock, rangeland and agroforestry management
- Post-harvest management, value chain, and use of renewable energy
- Policies, institutions and markets for improved livelihood security.

The detailed program is given in Appendix 1.

In the intensive deliberations of the participants over a period of three days involving 16 plenary presentations, two highly informative evening lectures, 53 lead presentations in 11 technical sessions and several rapid voluntary presentations in these sessions, lead presentations and panel discussion in five satellite symposia, and a policy-dialogue panel discussion several important recommendations emerged that also formed the basis for the '*Jodhpur Declaration*' (Appendix 2).

Theme-wise major recommendations are given below:

1. Impact of Climate Change in Drylands

Global warming, climate variability, drought, rising population and nutritional security are major emerging issues in dryland agro-ecosystem and these issues need to be addressed in a collaborative mode involving different countries and international institutions.

Climate change is occurring faster than predicted by various models and anthropogenic factors are responsible for that. A rise in global temperature by 3-4.5ºC by the end of Century would lead to severe reduction in food security through reduced agricultural productivity in dry areas because of water shortage, heat stress, weather aberrations and catastrophic events, and agricultural land degradation by salinization, loss of soil fertility and soil erosion. Climate change will alter weather conditions in arid regions in such a way that agriculture will become more difficult and land degradation will increase in the coming decades. The impact of the ensuing extreme weather conditions will cause displacement of some 65 million people from Africa in the near future.

It is therefore essential that public awareness is enhanced about the implications of climate change so that the required political pressure on the politicians and the policy makers is generated to take required measures and implement agreements.

For assessment of climate variability the prediction models should be strengthened with data from regional and local assessment, seasonal forecasting, ENSO phase analysis, etc. Knowledge emerging from innovative research, for more precise assessment of impact on regional and local level, should be freely shared and capacity building done through funds available/committed in the international agreements. Any complacency in implementing international agreements such as Paris Accord, Kyoto Protocol, Sandai Agreement, and Sustainable Development Goals will have severe negative effect on ecosystem health, food security and social tranquility.

Good weather data are a prerequisite for any initiative related to climate change adaptation as inadequate data hampers planning and risk management. Green climate fund and other global funds as well as national adaptation funds should support a robust weather data management and retrieval system in the concerned organizations.

For coping with the adverse impacts of climate change, a global thinking with local action will be required. Use of new science and innovation will permit development of precision agriculture, more efficient use and saving on resource inputs (pesticides, fertilizers, energy and water), increased productivity and improved environment.

Research outcomes for climate smart technologies should be expeditiously incorporated in the development programs and up- and out-scaled. Climate smart technologies and practices are context specific. Hence they cannot be applied uniformly in all conditions, and should be tested for each specific agro-ecological situation for effective implementation. The issue of resilient agriculture can be addressed holistically by imparting knowledge – not information – to farming community, attract attention of policy makers towards the benefits of newer technologies, and strengthened extension networks for lab to land sharing of knowledge.

Establishment of Regional Action on Climate Change (RACC) knowledge hubs in different parts of the dry areas will facilitate identification of knowledge gaps and developing mechanisms to bridge these gaps. This will be crucial for enhancing resilience of the dryland communities. Hence such hubs be established on priority basis and their knowledge output be used for local and regional disaster management planning and action.

2. Managing Land Degradation & Desertification

Drylands are spread over nearly 70 million squire kilometers, representing nearly 41% of Earth surface. Due to climate change the dryland area is increasing and is likely to cover nearly 50% of the surface area of Earth by 2100. The drylands are highly vulnerable to desertification and the degradation has been increasing because of anthropological reasons. For example, in China, 80% aeolian desertification was due to human activity and had to be combatted through human participation.

Climate change studies suggest that a gradual increase in wind speed is occurring in the arid areas, particularly *Thar* area of Indian subcontinent, and its interaction with sandy landscape should be reduced using suitable conservation techniques. Traditional conservation techniques and creation of wind breaks in dry areas and soil mulching in the irrigated areas, specially during the peak of summer are best measures to cope with the problem.

Combating desertification by sand dune stabilization and shelterbelt plantation, using wind breaks of different kinds and live mulch, has received much attention in the desertified areas of China and India and efforts have met with success in spite of several operational problems. The efforts have to be supported by suitable policy decisions, as has been the case in China with the "Grain for Green Program" operating since 1997 resulting in a decrease of 2.54% in the aeolian desertification in the period from 2000 to 2010.

Preventing land degradation requires the use of Sustainable Land Management (SLM) practices. In the studies conducted in Ethiopia, SLM practices reduced soil erosion by water to the tune of 11-68% and soil loss up to 38-94%. The techniques include terracing, mulching, minimum soil disturbance in field operations, and integrating mixed crop-livestock-bioenrgy (biogas) system with traditional SLM practices. Integrated farming systems based on tree-crop-grass-livestock has potential of preventing land degradation in arid areas. Incorporating stress-tolerant horticultural crops, field and fodder crop cultivars, and watershed management principle would further improve the performance of these systems.

Restoring degraded lands is a leading global agenda, and vast areas of degraded lands have been restored using simple, cost-effective practices. The initiative AFR 100, launched by African Union, targets to restore 112 million ha of degraded and desertified lands in 28 countries in Africa. The global alliance provides the platform for incorporation of trees and shrubs into cropping systems, as the trees buffer the crops from climatic stresses, besides providing other benefits.

The complexity and uncertainty in dryland farming systems demand the use of multi and inter-disciplinary R & D and scaling methods. The synergy among the traditional practices and modern innovative technologies has to be harnessed to achieve prevention of land degradation and desertification.

3. Soil Health Management, Carbon Sequestration and Conservation Agriculture

Management of soil health is key to sustainable soil productivity. Critical indicators of soil health – soil biodiversity, soil organic carbon, labile soil carbon, soil respiration, enzymes like β glycosidase – need to be included in the routine soil health assessment.

The soil organic carbon stocks in drylands have been depleted because of climate change, soil degradation and improper land use. The anticipated climate change will lead to drier deeper layers of the soil, which will exacerbate the problem of soil degradation, and cause further decline of soil carbon. Maintaining soil organic carbon is essential to maintain soil functions.

The emission of CO_2 and its sequestration depends on region and climatic conditions. Some of the practices to encourage faster carbon sequestration are afforestation, tree plantation in areas where the vegetation is sparse, sustainable forest management, reducing wild fires and tree cutting, and production and addition of biochar. Carbon stocks of different land use systems should be mapped so that planning for enhance carbon sequestration could be done.

Amongst various strategies to enhance soil stocks of organic carbon and improving soil health in dry areas, adequate addition of organic material and adopting Conservation Agricultural (CA) practices, such as keeping soil covered with crop residues, low or no-tillage, diversification of cropping system through incorporation of legumes in the rotation, using customized microbes and microsymbionts, and other SLM practices, are of paramount importance. Thus, Conservation Agriculture has emerged as a key practice for converting the drylands from grey to green and needs strong public-policy support for its wide adoption.

4. Water Harvesting and Improving Water Productivity

Enhancing water-conserving and water-saving technologies for dryland agriculture and improving returns per drop of water, energy and carbon footprint is crucial for dry areas as their expanse is likely to increase by nearly 7% in coming decades because of climate change.

Promoting groundwater recharge and its judicious use is essential for sustained increase in productivity, equity and sustainability of water. The groundwater governance regime will however have to be evolved based on the unique set of ecological, socio-economic, and political contingencies of each region. Policies will have to be formulated to curb depletion of this resource to critical limits.

Water scarcity coupled with climate change has compounded the resilience of dry areas manifold. Therefore, building a natural resilient resource base with water as a focal point is an imperative for sustainable production and livelihood support system on the dry areas. Rainwater harvesting and its appropriate management, with adoption of efficient soil and crop management practices (including use of drought and heat tolerant cultivars and such innovations as drought-tolerance inducing endophytes) will be an important strategy for sustainable dryland agriculture.

Rainwater harvesting and its sustainable use has to be taken up in a mission mode for adaptation to climate change in the rainfed areas. By reviving traditional water harvesting systems and adoption of on-farm water harvesting and recycling technologies and using the harvested water with different micro-irrigation systems, solar power energized wherever possible, rainfed agriculture production can be stabilized and insulated against drought events becoming frequent with changing climate. Life-saving supplemental and deficit irrigation practices, at critical stages of growth, have given excellent results with different oilseed and pulse crops that are traditionally grown rainfed in different agro-ecological conditions in dry areas and exposed to varying degrees of soil moisture stress.

Use of advanced monitoring and sensing platforms, and decision support systems (e.g. CropSyst) can play a vital role in water-smart agriculture, particularly needed in the dry areas.

Waste water recycling and reuse, linked to appropriate policy framework, and conjunctive use of brackish water can help in coping with water shortage and enhance the productivity of blue water used for irrigation.

5. Conservation and use of Agro-Biodiversity; Developing Adapted Cultivars

Drylands are rich in unique agro-biodiversity whose deployment in developing stress tolerant cultivars of field and horticultural crops and medicinal plants, and stress tolerant livestock species offers opportunity for enhancing the resilience and sustaining livelihoods of dryland communities. Taking stock of existing diversity, its characterization and evaluation, conservation and utilization deserve high priority, particularly in the face of changing climate. Agro-biodiversity indexing of dryland areas with differing agro-ecological and environmental conditions should be given priority.

Genetic dissection and molecular characterization of the climate change responsive traits (e.g. root growth, heat tolerance, resistance to newly emerging biotic stresses), identification of genes of interest as per specific breeding objectives, making them usable through molecular biology and genetic engineering techniques, and ensuring their accessibility for varietal improvement wok is essential. Identification of germplasm suitable for stressful conditions would necessitate development of low-cost screening techniques. Using such techniques for precision phenotyping, core sets of germplasm for tolerance to drought, heat and other abiotic stresses as well as biotic stresses should be developed. Use of imagery tools, like red edge or NDRE imagery and thermal imagery, in screening of germplasm would facilitate rapid phenotyping.

While the genetic diversity available in wild types and wild relatives from the stressed environments is of great value for developing climate smart crop cultivars, the diversity available in commercial cultivars should also be deployed. Modern tools offer opportunities for introgression of traits from hither-to-fore unthinkable sources and these tools should be deployed for developing cultivars adapted to harsh conditions of drylands. In addition to the traits for stress tolerance, the crop improvement should also emphasize improvement of the nutritional value of the produce.

Conventional breeding techniques will have to be coupled with modern tools of biotechnology and genomics in achieving better adaptation and productivity enhancement of traditional and new crops. Phenotypic and genotypic data integration should be used not only for genomic selection but also for prediction model breeding programs. Decision support system should also be strengthened for molecular breeding programs. Gene editing is going to be a powerful tool in breeding, but its social acceptance and adoption should be carefully looked into.

Improvement of crops that are specifically adapted to the harsh environments of dry areas and that have remained generally neglected so far should be given priority as their importance is going to increase with global climate change.

Public-private partnership is essential for scaling up varietal improvement. In this regard, it is also important that the access of private sector to genetic resources in the public institutions has to be enhanced. Role of small seed companies in the replacement of quality seed can be very important and this should be encouraged.

Drought and heat tolerant genotypes of crops should be incorporated in the Conservation Agriculture to enhance sustainability of production and the resilience of farming community in the dry areas.

6. Sustainable Intensification and Diversification (Arid Horticulture, Aquaculture, Protected Agriculture)

Sustainable agricultural intensification and diversification of dryland agriculture through integration of horticulture, agroforestry, silvi-pasture, aquaculture, etc. with crop production should be promoted.

Arid horticulture can enhance the resilience of dryland farming communities in the periods when field crops fail to provide economic returns because of harsh weather conditions.

Species and varieties of arid horticulture crops that attain the productive period early should be developed.

Traditional silvi-pastoral systems should be evaluated and modern science-based changes should be incorporated to improve their efficacy. Integrating cropping with solar farms should be promoted by developing crop cultivars that can grow in between rows of solar panels and make good use of the harvested water from the panels.

Increased emphasis on R&D on crops suitable for mixed and intercropping systems to enhance cropping intensity, low volume high value crops and commodities (e.g. spices, medicinal and aromatic plants, etc.) which are specially adapted to dryland agriculture, would help in generating higher income and ensure better livelihood opportunities.

Adopting technologies of protected cultivation of vegetables, fruits and flowers, using different substrates as well as hydroponics and aeroponics can help in the intensification of dryland agriculture and improve land, water and nutrient use efficiency while avoiding environmental pollution. The system can also increase the availability of nutritious vegetables and fruits for longer period of time as compared to the open agriculture. While there has been much sophistication in the designing and operation of green houses for protected agriculture, the system can also be devised using locally available construction material, as has been done in several parts of Yemen and Afghanistan and other developing countries. Providing appropriate training to young entrepreneurs will go a long way in promoting this system of intensification of dryland agriculture.

Aquaculture also offers great scope for enhancing the rural income in dry areas if it is integrated with protected agriculture and mixed-farming. Successful example of use of scarce water in a conjunctive use in this system is available from Egypt that can be up-scaled in other dry areas.

7. Livestock, Rangeland and Agroforestry Management

Mixed farming, incorporating livestock, field and forage crops and grasses adapted to harsh environmental conditions of arid regions, has long provided resilience to dryland communities and assured their livelihoods. Research and development for each component of mixed farming needs to be strengthened to make it more efficient. Integration of bioenergy component in the system, by using animal waste for biogas production and much needed organic manure, hold promise as revealed by studies in the arid areas of India and South Africa and deserves up-scaling in these and other dry areas.

Optimum management of grasslands in arid areas is very challenging because of complex animal production system and soil-plant-animal interactions. The sustainability of grasslands can be increased by introduction of native legumes, reseeding with suitable grass species, using innovative methods of seed pelleting, and adoption of soil and water conservation measures.

Adoption of area-specific scientifically designed agro-forestry systems can help in meeting the challenge of uncertain agriculture in the dry areas. The farmers have to be provided policy support and insurance facilities for planted trees to harness the full potential of agroforestry.

Alternative feed sources need to be identified. A good potential candidate is spineless cactus (*Opuntia ficus-indicus*) because of its ability to produce nutritious fodder under low rainfall situation and because of its drought and heat tolerance.

Temperature-humidity index (THI) has proved useful in identification of climate resilient management practice for cattle. Balanced nutrition should go hand in hand with improvement of breed for adaptation to the harsh environments. Camel has been a well adapted animal for arid areas, put traditionally to various uses in arid agriculture. With increasing mechanization this utility is declining. Hence, it can be harnessed as a milch animal in the arid areas because of medicinal value of its milk, which can be accordingly branded, and thus additionally contribute to rural economy.

8. Post-harvest Management, Value Chain, use of Renewable Energy, Farm Mechanization

The post-harvest losses of dried foodstuff, grains, fruits and vegetables because of fungal and insect pest infestation can be considerably reduced by adopting the 'dry chain' concept, wherein drying is achieved to a desired level and the produce maintained at that level in sealed storage containers. Low technology options are available for small holder farmers for drying such as chimney and pellet driers and simple, low cost tools for monitoring humidity during the storage in the form of 'dry card' and moisture absorbing beads, developed by the University of California, USA. These can be promoted amongst small-holder farmers in the developing countries.

Solar dryers with forced convection, photovoltaic (PV) operated dryers with forced convection, PV operated ventilated green house dryers and solar tunnel dryers designed and developed in ICAR institutions in India have wide scope for use in the rural areas and their use improves drying process and quality of products and saves environment.

Value addition to the produce at the village level can enhance economic returns to farmers. Good initiative has been taken in India to develop several primary and secondary processing machines for millets. Their use should be promoted through demonstration and encouraging millet processing startups. Crop improvement scientists should pay attention in developing cultivars for specific end products.

Use of wind and solar energy in the dry areas for generating electricity can prevent CO_2 emission to the tune of 600 tons per ha per year as compared to coal-powered generation. Combination of wind mills and solar panels for electricity generation in the arid environments offers scope for protecting the land from wind erosion and shifting of sand dunes, and can even permit growing shade loving plants in the shelter provided by panels. In addition, the system can earn carbon credit.

Agri-voltaic or solar farming should be promoted for best utilization of land and rainwater in low rainfall areas, as it will augment farmer income from generation of electricity and the crops grown in between the panels with rainwater harvested from the panels.

Small holder farmers need mechanization of their field operations. Innovative implements have been developed in several countries that enhance operational efficiency, reduce costs and save energy. Even PV-energized devices have been developed. Access to such equipment should be facilitated through institutional support. Private sector can play an important role in this by promoting village level custom services.

9. Policies, Institutions and Markets for Improved Livelihood Security

Developing countries would have to at least double their investments in agricultural research and innovation for development (ARI4D) to address future challenges and to ensure food, nutritional and environmental security of the dryland eco-systems. Public-private sector partnership synergies will have to be fully harnessed in this regard.

There is a need for greater allocation of funds targeted for sustainable development of dryland agriculture, as there has been inadequate attention paid to this sector in the past. Community involvement and empowerment, particularly that of the rural women, in planning and implementations of measures for enhancing the resilience of farming systems and improving the sustainability of the natural resource base in the dry areas.

Scientific research findings and innovations to mitigate climate change should be integrated with social, cultural and environmental conditions of the dryland dwellers. Traditional practices should be re-examined for their relevance and efforts made to make them more effective by integrating them with the results of modern scientific innovations.

Packaging of technology for each ecosystem, synergistic policy support with regard to water harvesting (farm ponds, recharging groundwater and wells), fertilizer use (neem coated urea, vermi-compost production using biogas plant sediments and other farm waste), marketing and pricing (linking farmers to the market, strengthening value chain, realistic minimum support price and assured off-take of produce), with continuous support for policy implementation are essential for sustainable development of rainfed farming systems and enhancing the livelihoods of the dryland communities.

Integrated farming system approach with participatory land scape management is essential for sustaining the natural resource base of dryland areas. Farmers living in these areas are expected to provide ecosystem services for sustaining the natural resource base. Incentives should be provided for these services.

It is critical that technology dissemination is accelerated and quality extension services are provided, for example by promoting a self-employed cadre of 'Technology Agents' and the use of new information technology tools. Thrust is needed on vocational training of rural youth and farm graduates, and linking their services to farmers on consultancy basis through bankable projects. Development of appropriate information technology tools for effective dissemination of customized information has made much progress but equality is missing. Policy and institutional support would be needed for up and out-scaling these innovations to enhance the resilience of dryland farmers in the face of changing climate.

Farmer Producer Organizations (FPOs), micro enterprises, agri-clinics and custom-hiring centers for farm machinery, with necessary legal and policy framework, need to be encouraged. Provision of 'Pledged Storage' or warehouse receipt system around agri-markets, and linking farmers with markets through farmers' cooperatives around activities related to post-harvest processing and value addition would go a long way to avoid distress sale.

Importance of international cooperation, sharing of knowledge on proven technologies and relevant scientific methodologies, based on isoclimatic and social considerations, and South – South collaboration will increase as the sustainability of agriculture and rural livelihoods in the dry areas will be increasingly challenged by climate change.

Annexure I

13th International Conference on Development of Drylands
Converting Dryland Areas from Grey into Green

Technical Program

Day 1: 11 Feb 2019 (Monday)

Venue: Hotel Indana Palace, Jodhpur

09:00-11:00 Inaugural Session

Chairs:	Prof. Dr. Adel El-Beltagy, Chair, International Dryland Development Commission (IDDC), Cairo, Egypt
Chief Guest:	Sh. Gajendera Singh Shekhawat, Minister of State for Agriculture and Farmers' Welfare, Government of India
Welcome: Address:	Dr. O.P. Yadav, Chairman, AZRAI and Director, ICAR-CAZRI, Jodhpur, India
Guest of Honour:	Mr. Aly Abousabaa, Director General, ICARDA, Beirut, Lebanon
Guest of Honour:	Dr. Peter Carberry, Director General, ICRISAT, Patancheru, India
Guest of Honour:	Dr. Martin Kropff, Director General, CIMMYT, Texcoco, Mexico
Guest of Honour:	Dr. Claudia Sadoff, Director General, IWMI, Colombo, Sri Lanka
Guest of Honour:	Dr. R.S. Paroda, Chairman, TAAS, New Delhi, India
Guest of Honour:	Dr. Panjab Singh, President, NAAS, New Delhi, India
Guest of Honour:	Prof. Dr. Adel El-Beltagy, Chair, International Dryland Development Commission
Chief Guest:	Sh. Gajendera Singh Shekhawat, Minister of State for Agriculture and Farmers' Welfare, Government of India
Vote of Thanks :	Dr. R.S. Tripathi, Convener, National Advisory Committee & National Coordinator, CAZRI, Jodhpur, India

11:00- 11:30 Group Photo & Tea

11:30-13:00 Plenary Session 1

Co-Chairs:	A.K. Singh, Secretary, NAAS, New Delhi, India Mr. Aly Abousabaa, Director General, ICARDA, Beirut, Lebanon
Plenary Lecture 1:	Prof. Dr. Adel El-Beltagy, Chair, IDDC, Cairo, Egypt (Navigating through uncertainties: Agro-ecosystems affected by dynamic impact of climate change)
Plenary Lecture 2:	Dr. Martin Kropff, Director General, CIMMYT, Texcoco, Mexico (Maize and wheat science for alleviating the pressure on natural resources in drylands)
Plenary Lecture 3:	Dr. Peter Carberry, Director General, ICRISAT, Hyderabad (Risk mitigation in dryland agriculture: Prospects and realities)

13:00-14:00 Lunch

14:00-16:30 Plenary Session 2

Co-chairs:	Dr. Raj Paroda, Chairman, TAAS, New Delhi, India Dr. Martin Kropff, Director General, CIMMYT, Texcoco, Mexico
Plenary Lecture 4:	Mr. Aly Abousabaa, Director General, ICARDA, Beirut, Lebanon (Role of traditional knowledge combined with new innovative technologies in achieving livelihood resilience in dry areas in the face of changing climate)
Plenary Lecture 5:	Dr. Magdy Madkour, Professor, ALARI, Cairo, Egypt (Gene editing for adaptation of dryland crops to changing climate)
Plenary Lecture 6:	Prof. Ayman F. Abou Hadid, Professor, ALARI, Cairo, Egypt (Sustainable intensification and diversification in drylands: Role of protected agriculture and arid horticulture)
Plenary Lecture 7:	Ms. Maria Beatix Giraudo, Senior Advisor to Govt. of Argentina (No till-based sustainable production systems for converting dryland areas from grey into green: The experience of AAPRESID)
Plenary Lecture 8:	Dr. John M. Dixon, Former Principal Adviser- Research/ Manager, Cropping Systems and Economics Program, ACIAR, Australia (Conservation agriculture for sustainable intensification for dry areas)

16:30-17.00 Tea

17:00-18:30 Poster Session (Themes 1, 2, 3 and 4)

18:30-19:30 Cultural Program

20:00 Reception Dinner

Day 2: 12 Feb 2019 (Tuesday)

09:00-10:30 Plenary Session 3

Co-chairs:	Dr. Panjab Singh, President, NAAS, New Delhi, India Dr. Peter Carberry, Director General, ICRISAT, Hyderabad, India
Plenary Lecture 9:	Dr. Claudia Sadoff, Director General, IWMI, Colombo, Sri Lanka (Water security and sustainable growth in drylands)
Plenary Lecture 10:	Prof. Hisashi Tsujimoto, Professor, Tottori University, Tottori, Japan (Development of innovative germplasm for wheat breeding for dry and heat-prone agro-environment of Sub-Saharan Africa)
Plenary Lecture 11:	Mr. Richard China, Director, Strategic Partnerships and External Engagement, Bioversity International, Rome, Italy (The agrobiodiversity index: How is agrobiodiversity faring in drylands?)

10:30-10:45 Tea

10:45-13:00 Technical Sessions 1, 2, 3 and 4 (Concurrent)

Technical Session 1: Impact of Climate Change in Drylands (Theme 1)

Co-chairs:	Dr. B. Venkateswarlu, Former Vice-chancellor, VNMKV, Parbhani Dr. Winston Yu, Principal Researcher and Senior Advisor, IWMI, Washington DC
Lead Lecture 1:	Prof. P.K. Aggarwal, Director, South Asia, CGIAR-CCAFS, New Delhi, India (Managing Increasing climatic risks in agriculture: Opportunities and constraints)
Lead Lecture 2:	Prof. Guram Aleksidze, President, GAAS, Georgia (Climate change and the strategy of decreasing its harmful influence on agriculture in Central Asia and South Caucasus Countries)
Lead Lecture 3:	Dr. K. Sami Reddy, ICAR-CRIDA, Hyderabad (Climate resilient agriculture in rainfed areas: Adaptation strategies in Indian context)
Lead Lecture 4:	Dr. S. Bhaskar, ADG (AAF&CC), ICAR, New Delhi, India (Resilience to changing climate in dryland agriculture: Experiences from India)
Rapid Presentations:	4 presentations of 5-7 minutes each

Technical Session 2: Managing Land Degradation & Desertification (Theme 2)

Co-chairs:	Dr. Ch. Srinivasa Rao, Director, ICAR-NAARM, Hyderabad, India Prof. Atsushi Tsunekawa, Professor, Tottori University, Tottori, Japan
Lead Lecture 1:	Prof. Mitsuru Tsubo, Professor, ALRC, Tottori University, Japan (A crop-livestock-bioenergy system for rural farmers in South Africa)
Lead Lecture 2:	Dr. Amal Kar, Ex-Head, NRE, ICAR-CAZRI, Jodhpur, India (Measuring land degradation: A quantitative approach for better understanding of the problem in Thar desert)
Lead Lecture 3:	Dr. P.C. Sharma, Director, ICAR-CSSRI, Karnal, India (Managing dryland salinity for food and environmental security: Issues and options)
Lead Lecture 4:	Dr. R.P. Dhir, Former Director, ICAR-CAZRI, Jodhpur (Desertification perspectives and interventional effort)
Rapid Presentations:	4 presentations of 5-7 minutes each

Technical Session 3: Soil Health Management, Carbon Sequestration and Conservation Agriculture (Theme 3)

Co-chairs:	Dr. Gurbachan Singh, Former Chairman, ASRB, New Delhi, India Dr. Alok K. Sikka, IWMI, New Delhi, India
Lead Lecture 1:	Dr. S.K. Choudhary, ADG (S&WM), ICAR, New Delhi, India (Soil management for sustainable agriculture in India)
Lead Lecture 2:	Dr. A.K. Patra, Director, ICAR-IISS, Bhopal, India (Conservation agriculture for soil health and climate change mitigation)

Lead Lecture 3: Dr. D.L.N. Rao, ICAR-Emeritus Scientist, ICAR-IISS, Bhopal, India
(Soil organic matter, soil health and sustainability)

Lead Lecture 4: Dr. M.L. Jat, Cropping Systems Agronomist, CIMMYT, New Delhi, India
(Conservation agriculture vis-a-vis climate smart agriculture: What can be learnt from South Asia?)

Lead Lecture 5: Dr. Praveen Kumar, Head of Division, ICAR-CAZRI, Jodhpur, India
(Concept of negative emission of CO2: Role of agriculture and forestry)

Rapid Presentations: 5 presentations of 5-7 minutes each

Technical Session 4: Conservation & use of Agrobiodiversity; Developing Adapted Cultivars (Theme 5)

Co-chairs: Dr. Raj Paroda, Chairman, TAAS, New Delhi, India

Prof. Magdy Madkour, ALARI, Cairo, Egypt

Lead Lecture 1: Dr. Michael Baum, Director BIGM, ICARDA, Beirut, Lebanon
(Field crops breeding for resistance to biotic and abiotic stresses at ICARDA: Achievements and prospects)

Lead Lecture 2: Dr. Rajeev Varshney, Director, Genetic Gain, ICRISAT, Hyderabad, India
(Translational genomics for improving dryland crops)

Lead Lecture 3: Dr. Usha Barwale Zehr, Director & CTO, MAHYCO, Jalna, India
(Agriculture innovation - Climate ready crops)

Lead Lecture 4: Dr. Kuldeep Singh, Director, ICAR-NBPGR, New Delhi, India
(Conservation and use of plant genetic resources: Developing adapted cultivars)

Lead Lecture 5: Dr. J. Rane, ICAR-NIASM, Baramati, India
(Abiotic stress management interventions to convert naturally less into sustainably more in dryland)

Rapid Presentations: 4 presentations of 5-7 minutes each

13:00-14:00 Lunch

14:00-16:30 Satellite Symposium (2 parallel sessions)

1. **Crop Improvement for Sustainable Production in Marginal Regions – ALRC, Tottori, Japan & ICARDA, Beirut, Lebanon**

Satellite Symposium 1

Chair: Prof. Dr. Mohan Saxena
Executive Secretary
International Dryland Development Commission

Rapporteur: Dr. Vinay Nangia
Senior Hydrologist, ICARDA
Specially Appointed Associated Professor
IPDRE, Tottori University

Program

Time	Title	Speakers
14:00-14:10	Opening remarks	Prof. Hisashi Tsujimoto
14:10-14:25	Water-saving wheat: Tuning water use efficiency and drought tolerance using ABA receptors	Dr. Ryosuke Mega
14:25-14:40	Durum wheat ideotype for the drylands of tomorrow	Dr. Filippo Bassi and Dr. Michael Baum
14:40-14:55	Manipulation of centromere specific histone H3 (CENH3) in crop plants for haploid breeding: Towards sustainable food production in dryland	Dr. Takayoshi Ishii
14:55-15:10	Pulses for harvesting 'More from Less' in dry areas	Dr. Shiv Kumar Agrawal
15:25-15:40	How to find effective root symbiotic microbes for crops? -Toward the use of customized microbes for sustainable agriculture in an object area	Dr. Takeshi Taniguchi
15:40-15:55	Barley improvement for marginal lands	Dr. Ramesh Verma
15:55-16:15	Discussion	
16:15-16:20	Crop improvement for the dry areas/ Conclusions and closing remarks	Dr. Michael Baum

2. Big Data Analysis in Dryland Agriculture – ICRISAT, Hyderabad, India

Satellite Symposium 2

Chair: Dr. Peter Carberry, DG, ICRISAT, Hyderabad, India

Co-Chair: Dr. Brian King, CIAT, Cali, Colombia

Rapporteur: Dr. M. Govindaraj, ICRISAT, Hyderabad, India
Dr. Henry Fred Ojulong, ICRISAT, Nairobi, Kenya

Program

Time	Title	Speakers
14:00-14:05	Welcome remarks by Chair	Dr. Peter Carberry
14:05-14:10	Introduction of speakers	Co-Chair
14:10-14:25	Big data and informatics platforms at ICRISAT and future strategies	Dr. Abhishek Rathore
14:25-14:40	The CGIAR platform for big data in agriculture: Towards big-data enabling agriculture development	Dr. Brian King
14:40-14:55	GOBii, a scalable genomics data management system with rapid data extract times and integration with downstream genomic selection analysis pipelines	Dr. Elizabeth Jones
14:55-15:10	Big data and digital augmentation for accelerating agroecological intensification	Dr. Chandrashekhar Biradar
15:10-15:25	Seeing is believing: Using crop pictures in personalized advisory services	Dr. Berber Kramer
15:25-15:40	Big data in Indian agricultural research and development	Dr. Rajendra Parsad
15:40-15:55	Breeding modernization at ICRISAT: Implementing industry principles in the public sector	Dr. Jan Debaene
15:55-16:25	Discussion	
16:25-16:30	Concluding Remarks	Co-Chair

16:30-16:45 Tea

16:45-18:30 Discussion on Climate Change (Climate change in the region and the possible measures needed for adaptation to them, The RACC framework) **10 participants (Participation only by invitation): Working Lunch Session**

16:45-18:30 Poster Session (Themes 5, 6, 7, 8 and 9)

18:30-19:30 Evening Lecture 1

Dr. Ismail Serageldin, Founder President, Bibliotheca Alexandrina, Egypt

(Climate change as a trigger to poverty and outmigration in the dry areas)

Co-chairs: Dr. Adel El-Beltagy, Chair, ICDD, Cairo, Egypt

Dr. Raj Paroda, Chairman, TAAS, New Delhi, India

<u>**Day 3: 13 Feb 2019 (Wednesday)**</u>

09:00-10:30 Plenary Session 4

Co-chairs: Dr. J.S. Samra, Ex-CEO, NRAA, New Delhi, India
Dr. Ayman F. Abou Hadid, Professor, ALARI, Cairo, Egypt

Plenary Lecture 12: Dr. Dennis Garrity, Dryland Ambassador for UNCCD, Nairobi, Kenya
(How can we restore hundreds of millions of hectares of degraded land – and get the biggest bang for the buck?)

Plenary Lecture 13: Prof. Dr. Atsushi Tsunekawa, ALRC, Tottori University, Tottori, Japan
(Sustainable land management to convert areas from grey to green)

Plenary Lecture 14: Prof. Dr. Wang Tao, President Lanzhou Branch of CAS, Lanzhou, China
(Science and policy interacted for combating desertification in China)

10:30-10:45 Tea

10:45-13:00 Technical Sessions 5, 6, 7 and 8 (Concurrent)

Technical Session 5: Water Harvesting & Improving Water Productivity (Theme 4)

Co-chairs: Dr. A.K. Singh, Secretary, NAAS, New Delhi, India
Prof. Abd Elghany El-Gindi, Coordinator, On-Farm Irrigation Management Program, Egypt

Lead Lecture 1: Dr. Tushaar Shah, IWMI, Anand, India
(Groundwater governance and irrigated agriculture: Global review and lessons for South Asia)

Lead Lecture 2: Dr. Alok K. Sikka, IWMI Representative, New Delhi, India
(More Crop per Drop in Drylands: Technologies, Policy Imperatives and Institutional Arrangements)

Lead Lecture 3: Dr. B. Venkateswarlu, Former Vice-chancellor, VNMKV, Parbhani, India
(Water harvesting: A key strategy for climate change adaptation in rainfed agriculture)

Lead Lecture 4: Dr. S.K. Ambast, Director, ICAR-IIWR, Bhubaneswar, India
(Improving water productivity through rainwater harvesting)

Lead Lecture 5: Dr. Vinay Nangia, Agricultural hydrologist, ICARDA, Rabat, Morocco
(Improving agricultural water productivity in the Indira Gandhi Nahar Pariyojana)

Rapid Presentations: 6 presentations of 5-7 minutes each

Technical Session 6: Conservation & use of Agrobiodiversity, Developing Adapted Cultivars (Theme 5)

Co-chairs:	Dr. Rajeev Varshney, Director, Genetic Gain, ICRISAT, Hyderabad, India Dr. R.K. Tyagi, APCoAB Coordinator, APAARI, Thailand
Lead Lecture 1:	Prof. Dr. Rodomiro Ortiz, Swedish University of Ag. Sciences, Uppsala, Sweden (Improvement strategies for developing climate smart crop cultivars for drylands)
Lead Lecture 2:	Dr. P. Anand, Corteva Agriscience, Hyderabad, India (Phenotypic strategies for developing adapted cultivars to stress tolerance in dryland ecosystems)
Lead Lecture 3:	Dr. B.M. Prasanna, CIMMYT, Nairobi, Kenya (Climate resilient maize for drought- and heat-prone environments)
Lead Lecture 4:	Dr. Tara Sathyvathi, PC, AICRP on Pearl millet, Jodhpur, India (Indian pearl millet breeding for resilience to changing climate)
Lead Lecture 5:	Dr. R.K. Bhatt, ICAR-CAZRI, Jodhpur, India (Diversity, conservation and uses of pasture grasses of hot arid region of India)
Rapid Presentations:	5 presentations of 5-7 minutes each

Technical Session 7: Sustainable Intensification & Diversification (Arid Horticulture, Aquaculture, Protected Agriculture) (Theme 6)

Co-chair:	Dr. S.K. Malhotra, Commissioner (Agriculture), Govt. of India, New Delhi, India
Lead Lecture 1:	Dr. Balraj Singh, VC, AU, Jodhpur, India (Prospects of protected horticulture in arid and semi-arid regions of India)
Lead Lecture 2:	Dr. P.L. Saroj, Director, CIAH, Bikaner, India (Horticulture based diversification: An option for enhancing farmers' income in drylands)
Lead Lecture 3:	Dr. Gopal Lal, Director ICAR-NRCSS, Ajmer, India (Climate resilient technologies for sustainable production of seed spices)
Lead Lecture 4:	Prof. Mohamed Fathy Osman, Emeritus Prof., Ain Shams University, Cairo, Egypt (Fish farming in Egypt)
Lead Lecture 5:	Dr. Ravinder Chary, Director, ICAR-CRIDA, Hyderabad (Sustainable rainfed agriculture in India: Strategies and policy framework)
Lead Lecture 6:	Dr. Ashutosh Sarker, Coordinator, ICARDA's Regional Program for South Asia and China, New Delhi, India (Intensification and diversification of dryland production systems with winter pulses in South Asia)
Rapid Presentations:	4 presentations of 5-7 minutes each

Technical Session 8: Livestock, Rangeland and Agroforestry Management (Theme 7)

Co-chairs:	Dr. A.K. Gehlot, Former VC, RAJUVAS, Bikaner, India Dr. Ravi Prabhu, DDG-Research, ICRAF, Nairobi, Kenya
Lead Lecture 1:	Dr. Gurbachan Singh, Former Chair ASRB, New Delhi, India (Edible cactus for food, nutrition and environmental security in dry areas)
Lead Lecture 2:	Dr. P.K. Ghosh, Ex. Director, ICAR-IGFRI, Jhansi, India (Sustainable grassland management, livestock production and ecosystem services in arid and semi arid tropics)
Lead Lecture 3:	Dr. A.K. Tomar, Director ICAR-CSWRI, Avikanagar, India (Small ruminant production in dryland India: Status, challenges and opportunities)
Lead Lecture 4:	Dr. J. Rizvi, Regional Director, South Asia Region, ICRAF, New Delhi, India (Agroforestry for development of dry areas)
Lead Lecture 5:	Dr. N.V. Patil, Director, NRC Camel, Bikaner, India (Therapeutic utility of desert Camel in using milk as Functional food and using camelid Nanobody in Immunotherapy)
Rapid Presentations:	4 presentations of 5-7 minutes each

13:00-14:00 Lunch

14:00-16:30 Satellite Symposium (2 parallel sessions)

3. Dryland Agrobiodiversity for Adaptation to Climate Change – ISPGR/Bioversity International/APAARI

Satellite Symposium 3

Chair:	R.S. Paroda, Chairman, Trust for Advancement of Agricultural Sciences (TAAS), New Delhi
Co Chair:	Ashok Dalwai, Chief Executive Officer, NRAA, New Delhi
Convenor:	Anuradha Agrawal, General Secretary, ISPGR, New Delhi
Co-Convenor:	Kuldeep Singh, Director, ICAR-NBPGR, New Delhi
Rapporteurs:	Rakesh Singh, Joint Secretary, ISPGR; S. Rajkumar, Principal Scientist, NBPGR

Time	Title	Speakers
Keynote Lecture		
14.00-14.20	Current threats to dryland agrobiodiversity and strategies for adaptation to climate change	R.S. Paroda TAAS and ISPGR, India
Invited Lectures		
14.20-14.35	Managing agrobiodiversity of Indian drylands for climate adaptation	O.P. Yadav CAZRI, India
14.35-14.50	Efficient conservation and use of genetic resources of cereals and legumes	Ahmed Amri ICARDA, Morocco

14.50 -15.05	Agrobiodiversity of fruits and nuts to adapt to climate change in Central Asia	Muhabbat Turdieva Bioversity International, Uzbekistan
15.05-15.20	Dryland agrobiodiversity for adaptation to climate change: Role of regional organizations	R.K. Tyagi APAARI, Thailand
15.20-15.35	Mainstreaming the agrobiodiversity of drylands - Role of Bioversity International	J.C. Rana Bioversity International, India

Panel Discussion : Issues and way forward for agrobiodiversity for adaptation to climate change

	Crop Group	**Panelist**
15.35-16.35	Millets	S.K. Gupta, ICRISAT, India
	Arid legumes	D. Kumar, Ex CAZRI, Jodhpur
	Arid oilseeds	D.K. Yadava, ICAR, Delhi
	Arid horticultural crops	P.L. Saroj, ICAR-CIAH, Bikaner
	Seed spices	Gopal Lal, ICAR-NRCSS, Ajmer
	Forages	R.K. Bhatt, ICAR-CAZRI, Jodhpur
	Underutilized and medicinal plants	Suresh Kumar, Ex CAZRI, Jodhpur
	Dryland PGR	Omvir Singh, NBPGR, Jodhpur
16.35-16.55	General Discussion on Way Forward	
16.55-17.00	Concluding Remarks	Chair and Co-Chair

4. Mainstreaming Water Productivity in Drylands – IWMI & ICAR

Satellite Symposium 4

Chair: Dr. J. S. Samra
Executive Officer
National Rainfed Area Authority (NRAA), New Delhi, India

Co-Chair: Dr. A.K. Singh
Secretary
NAAS, New Delhi, India

Mainstreaming Water Productivity in Drylands

Time	Title	Speakers
14:00-14:10	Opening remarks	Dr. J. S. Samra
14:10-14:25	Water accounting and water productivity : An overview	Dr. Winston Yu
14:25-14:40	Improving water productivity trough on-farm water management and modelling	Dr. Alok Sikka
14:40-14:55	Water management-based agricultural diversification model for water productivity enhancement in dryland/rainfed areas	Dr. S. K. Ambast
14:55-15:10	Deficit irrigation in drylands: Prospects and retrospect	Dr. N. D. Yadav

Panellist views: Challenges and way forward for enhancing water productivity in drylands (8 minutes each)		
15:10-15:18	Harnessing solar energy as remunerative crop in drylands	Dr. Tushaar Shah
15:18-15:26	Integrated watershed management for enhancing water productivity in drylands	Dr. P. R. Ojasvi
15:26-15:34	Mainstreaming climate-resilient practices for improving rainwater productivity in drylands	Dr. R. Chari
15:34-15:42	Building resilience through water-related risk monitoring and insurance in the drylands of South Asia	Dr. Giriraj Amarnath
15:42-15:50	Managed aqifer recharge for building resilience in drylands	Dr. Faiz Alam
15:50-16:20	Discussion for way forward	All participants
16:20-16:30	Closing remarks	Co-chair

16:30-16:45 Tea

17:00-18:30 CAZRI Visit

18:30-19:30 Evening Lecture 2

Prof. Rattan Lal, Director, Carbon Management & Seqn. Center, OSU, Ohio
(Re-carbonizing soils of global drylands)

Co-chairs: Dr. Ismail Serageldin, Founder President, Bibliotheca Alexandrina, Alexandria, Egypt

Dr. John M. Dixon, Former Principal Adviser- Research/ Manager, ACIAR, Australia

19:30-20:20 M.S. Swaminathan Award Function - organized by TAAS

20:20-21:00 Honorary Fellowship Award Function – organized by AZRAI

Day 4: 14 Feb 2019 (Thrusday)

09:00-10:30 Plenary Session 5

Co-chairs: Prof. Mohan C. Saxena, Executive Secretary, IDDC

Dr. Gurbachan Singh, Former Chair, ASRB, New Delhi, India

Plenary Lecture 15: Prof. Dr. Michael Reid, Emeritus Professor, Dept. of Plant Sci., UC Davis, CA, USA
(Post-harvest processing, storage and marketing of dried products: Tools for the dry chain)

Plenary Lecture 16: Dr. O.P. Yadav, Director, ICAR- CAZRI, Jodhpur, India
(Enhancing resilience of arid lands: Indian experience)

Plenary Lecture 17: Dr. Ch. Srinivasa Rao, Director, ICAR-NAARM, Hyderabad, India
(Synergy of research-technology-policy implementation for resilient rainfed-Dryland production systems)

10:30-10:45 Tea

10:45-13:00 Technical Sessions 9, 10, 11 and Symposium 5 (Concurrent)

Technical Session 9: Conservation & use of Agrobiodiversity, Developing Adapted Cultivars (Theme 5)

Co-chairs:	Dr. K.V. Prabhu, Chairman, PPVFRA, New Delhi, India
	Dr. B.M. Prasanna, CIMMYT, Nairobi, Kenya
Lead Lecture 1:	Dr. P.H. Zaidi, CIMMYT, Hyderabad, India (Climate-resilient maize for stress-prone dryland system - chasing the moving target)
Lead Lecture 2:	Dr. S.K. Gupta, ICRISAT, Hyderabad, India (Enhancing genetic gains and resilience to climatic stresses in pearl millet)
Lead Lecture 3:	Dr. N.P. Singh, Director, ICAR-IIPR, Kanpur, India (Conservation and use of agrobiodiversity: Developing adapted cultivars in arid legumes)
Lead Lecture 4:	Dr. Balram Sharma, IARI, New Delhi, India (Plant biotechnology has potential to turn grey areas into green – evergreen)
Rapid Presentations:	7 presentations of 5-7 minutes each

Technical Session 10: Post Harvest Management, Value Chain, Renewable Energy, Farm Mechanization and Automation (Theme 8)

Co-chairs:	Dr. K. Alagusundaram, DDG (Ag. Eng.), ICAR, New Delhi, India
	Prof. Dr. Michael Reid, Emeritus Professor, Dept. of Plant Sci., UC Davis, CA, USA
Lead Lecture 1:	Dr. J.S. Samra, Former DDG (NRM) and Former Chairman, NRAA, New Delhi, India (Renewable energy programme and policies of India)
Lead Lecture 2:	Dr. Dilip Jain, Head, Division of AE & RE, ICAR-CAZRI, Jodhpur, India (Solar drying of fruit and vegetables: Innovations and prospects)
Lead Lecture 3:	Dr. Dayakar Rao B., PS, ICAR-IIMR, Hyderabad, India (Post-harvest interventions in millets for creation of demand)
Lead Lecture 4:	Dr. P. Santra, Principal Scientist, ICAR-CAZRI, Jodhpur, India (Solar PV options for farmers in arid agriculture: Agri-voltaic system and solar pumps)
Lead Lecture 5:	Prof. Abd Elghany El-Gindy, Emeritus Professor, ALARI, Cairo, Egypt (Small farm mechanization in Egypt)
Rapid Presentations:	2 presentations of 5-7 minutes each

Technical Session 11: Policies, Institutions & Markets to Improved Livelihood Security (Theme 9)

Co-chair:	Prof. Mohan C. Saxena, Executive Secretary, IDDC
Lead Lecture 1:	Dr. Aliaa Refea, Professor Women's College, Chair & Founder, The Human Foundation, Cairo, Egypt (An Integrative Approach for Facing Climate Change Challenges)

Lead Lecture 2: Dr. P.K. Joshi, Director South Asia, IFPRI, New Delhi, India
(Agricultural markets and smallholder farming in dryland areas: Key policy and institutional challenges)

Lead Lecture 3: Dr. Suresh Pal, Director, ICAR-NCAP, New Delhi, India
(Policy, institutions and markets for sustainable livelihood opportunities in arid agriculture)

Lead Lecture 4: Prof. Kristina Toderich, ALRC, Tottori University, Tottori, Japan
(Empowering small-scale farmers and women by enhancing food security in the marginalized Environments of the Aral Sea Basin)

Lead Lecture 5: Mr. Konda Reddy Chavaa, Asst. FAO Representative India, FAO, New Delhi, India
(Community-based Landscape management for sustainable livelihoods in drylands)

Rapid Presentations: 3 presentations of 5-7 minutes each

10:45-13:00 Satellite Symposium 5:

Arid Agro-ecosystems: Challenges and Opportunities – AZRAI & Kirk House Trust

Co-chair: Dr. Prof. Ed Southern, Kirk House Trust
Dr. J. Rizvi, Director, ICRAF Regional Program for South Asia, New Delhi, India

Convenor: Dr. R.K. Kaul

Rapporteur: Dr. D.V. Singh; Dr. P.K. Roy

Title	Duration	Speaker/Panellist
Inaugural Remarks	10 min	Co-chairs
Lead Speaker – 1	15 min	Dr. Praveen Kumar, ICAR-CAZRI, Jodhpur: Enduring splendour of arid region: What will it take to green it?
Lead Speaker – 2	15 min	Dr. P.N. Mathur, Kirkhouse Trust – STOL programme, its initiatives and significance
Lead Speaker – 3	15 min	Dr. Serge Felicien ZIDA, Burkina Faso : Achievements so far under STOL based on experimentation in Burkina Faso and Tanzania
Lead Speaker - 4	15 min	Dr. J.R. Sharma, Former GM, NRSC/RRSC, Jodhpur : Role of space technology in energy, food and water security in arid ecosystem
Panelist views: Status, key issues and way forward for resilience in arid agroecosystems in climate change scenario for food and livelihood security		
Panellist view	50 min	• Dr. R.P. Dhir, Former Director, ICAR-CAZRI, Jodhpur : Thar arid zone: A blend of desertification and development • Dr. Amal Kar, Former Head, Div. Of NRE, ICAR-CAZRI, Jodhpur : Natural resource vulnerability under climate change scenario in arid situations • Dr. Suresh Kumar, Former Head, Div. of IFS, ICAR-CAZRI, Jodhpur : Revisiting grazing policy for arid lands • Dr. A.K. Gahlot, Former VC, RAJUVAS, Bikaner : Livestock based systems for enhancing resilience to changing climate • Dr. S.M.K. Naqvi, Former Director, ICAR-CSWRI, Avikanagar : Small ruminants for livelihood security in arid regions

		• Dr. O.P. Pareek, Former Director, ICAR-CIAH, Bikaner : Scope and opportunities of arid horticulture • Dr. O.P. Yadav, Director, ICAR-CAZRI, Jodhpur : What's next for future generation in arid agroecosytem
Discussion	10 min	
Closing Remarks	5 min	Co-chairs

13:00-14:00 Lunch

14:00-16:00 Policy Dialogue- Converting Dryland Areas from Grey into Green

Co-chair: Prof. Dr. Adel El-Beltagy, Chair, International Dryland Development Commission, Former Minister of Agriculture and Land Reclamation, Cairo, Egypt

Dr. Raj Paroda, Chairman, TAAS, New Delhi, India

Panelist

1. Sh. Pawan Kumar Goyal, Additional Chief Secretary - Agriculture, Rajasthan, India
2. Dr. Aly Abousabaa, Director General, ICARDA, Beirut, Labenon
3. Ms. Maria Beatix Giraudo, Former President, AAPRESID, Senior Advisor to Govt. of Argentina
4. Prof. Wang Tao, President, Lanzhou Branch of CAS, China
5. Prof. Atsushi Tsunekawa, Professor, ALRC, Tottori University, Tottori, Japan
6. Prof. Academician Guram Aleksidze, President, GAAS, Georgia
7. Dr. S.K. Malhotra, Commissioner (Agriculture), Govt. of India, New Delhi, India
8. Prof. Mohamed F. Osman, Former Chair, General Authority for Fish resources Development (GAFRD), Egypt

16:00-16:30 Tea

17:00-19:30 Valedictory Function

Co-chairs:	Dr. R.S. Paroda, Chairman, TAAS, New Delhi, India
	Prof. Dr. Adel el-Beltagy, Chair, IDDC, Cairo, Egypt
Opening Remarks	Co-chairs
Presentation of Recommendations	Prof. Mohan C. Saxena, IDDC
Adoption of Jodhpur Declaration	Dr. O.P. Yadav
Vote of Thanks	Dr. Anurag Saxena, Organizing Secretary

Annexure II

13th International Conference on Development of Drylands "Converting Dryland Areas from Grey into Green"

Jodhpur, India; 11-14 February 2019

Jodhpur Declaration

Preamble

Drylands cover about 41% of earth's land area and are home to 38% of world's human and almost half of livestock population. They are endowed with ample solar and wind energy, vast mineral resources, rich useful biodiversity including stress tolerant plants and animals, crops, fruits, trees, grasses, spices, medicinal and aromatic plants; and rich cultural heritage. Dryland dwellers have accumulated vast indigenous knowledge that enables them to be resilient in the harsh environments. These endowments of drylands underpin their global importance. However, achieving food security in drylands has been a great challenge due to low crop and livestock productivity and fragile natural resource base. Water scarcity, land degradation and loss of biodiversity are increasing due to excessive anthropogenic pressure and unabated climate change. The livelihood of more than 2 billion people who live in dryland areas is, therefore, at considerable risk and these areas need special attention from the research, development and policy-making communities to achieve the sustainable development goals (SDGs).

Thirteenth ICDD 2019

In order to discuss the challenges of dryland areas in the face of changing climate, and to explore their solutions, 'The Thirteenth International Conference on Development of Drylands: Converting Dryland Areas from Grey into Green' was organized by the International Dryland Development Commission (IDDC) and the Arid Zone Research Association of India (AZRAI), in collaboration with the Department of Agricultural Research and Education (DARE) of Government of India, Indian Council of Agricultural Research (ICAR), National Academy of Agricultural Sciences (NAAS) and the Trust for Advancement in Agricultural Sciences (TAAS), at the ICAR-Central Arid Zone Research Institute (CAZRI), Jodhpur, India during 11-14 February 2019. The Conference was attended by 379 participants from 80 international and national organizations representing 39 countries from six continents.

Road Map

As a result of in-depth deliberations in the conference, we the participants unanimously endorse the following action points for urgent attention of all stakeholders, including the policy makers, for implementation:

1. Drylands are most vulnerable to climate change but their vulnerability would vary from place to place because of spatial diversity in resources, farming systems and policy settings. Development of appropriate adaptive and mitigation strategies would, therefore, need precise assessment of impact of climate change on local rather than global or regional scale. International agreements that have laid out framework for transfer of knowledge and capacity building to enable developing countries to do local impact assessment and develop adaptive strategies should be sincerely implemented. Any complacency in implementing Paris Agreement, Kyoto Protocol, the Sendai Framework for Disaster Risk Reduction, and Sustainable Development Goals (SDGs) can result in a catastrophic situation leading to social upheaval and destruction of ecosystem security.
2. Scarcity of water for dryland agriculture is going to increase in future with changing climate, urbanization and growing demand from other sectors. Several agro-climatic region specific technologies have been developed which are being implemented to some extent. Appropriate irrigation practices need to be promoted, with greater focus on micro-irrigation (especially sprinkler and drip irrigation), even in canal command areas, to enhance water productivity. Technologies for efficient use of brackish water need to be developed, including conjunctive use for irrigation, fishery, etc. On-farm water conservation must be encouraged. Good watershed management practices, including traditional water harvesting-based cultivation, need to be promoted through community involvement and by forming water-users associations. Public awareness campaign to promote prudent water use needs to be taken up on massive scale.
3. Sustainable use of natural resources and their conservation and management need to be accorded high priority. Scientific land use planning, along with sustainable farming practices, should therefore be promoted. Concerted efforts have to be made for out-scaling innovations that save soil, water, nutrients, biodiversity, energy, labour, etc. In this context, Conservation Agriculture based Sustainable Intensification (CASI) should be given high priority and technological, socio-economic and policy bottlenecks that hamper its rapid adoption should be expeditiously removed. Use of solar energy for farm operations should be promoted by developing user-friendly technologies and making them accessible to small holder farmers. There are several success stories emanating from dedicated efforts of individuals and communities that have improved economic well-being of dryland communities while strengthening ecosystem health and services. These include, amongst others, the African Forest Landscape Restoration Initiative (AFR 100), Sustainable Land Management (SLM) practices and 'Grain for Green' initiative and should be out-scaled. The 'Dry Arc Initiative' by the CGIAR Centres, with similar objectives, should be supported that would contribute to sustainable development of dry areas.
4. Sustainable agricultural diversification through horticulture, agroforestry, silvi-pasture, aquaculture, etc. should be promoted. Increased emphasis on R&D on crops suitable for mixed and intercropping systems to enhance cropping intensity, low volume high value crops and commodities (e.g. spices, medicinal and aromatic plants, etc.) which are specially adapted to dryland agriculture, would help generate higher income and ensure better livelihood opportunities. Appropriate techniques for value addition and reduction of postharvest losses should be developed and promoted. Use of protected agriculture for more efficient use of soil, water and nutrients, prolonging

the period for crop production and ensuring high economic returns under harsh dry environments should be promoted.

5. Exploiting the genetic biodiversity available in the dryland areas for developing high-yielding and stress-resistant genotypes, using conventional breeding techniques as well as the state of the art molecular biology and biotechnological tools, will have to be given high priority as the past improvement efforts have mostly neglected the dry areas in this regard.
6. In order to provide livelihood security and enhance resilience of farmers in dryland areas, policy support and enabling environment, including enhanced investment and compensation/support to farmers for much needed environmental services, environment friendly agriculture and good agronomic practices, should be ensured rather than providing input subsidies. Availability of easy credit at low interest rates, crop and livestock insurance, and access to timely and accurate knowledge about weather, successful farming practices, inputs and markets, would enhance resilience of dryland farming communities to weather aberrations and secure their livelihood.
7. Farmer Producer Organizations (FPOs), micro enterprises, agri-clinics and custom-hiring centers for farm machinery, with necessary legal and policy framework, need to be encouraged. Provision of 'Pledged Storage' or warehouse receipt system around agri-markets, and linking farmers with markets through farmers' cooperatives around activities related to post-harvest processing and value addition would go a long way to avoid distress sale.
8. It is critical that technology dissemination is accelerated and quality extension services are provided, for example by promoting a self-employed cadre of 'Technology Agents' and the use of new information technology tools. Thrust is needed on vocational training of rural youth and farm graduates, and linking their services to farmers on consultancy basis through bankable projects.
9. Developing countries would have to at least double their investments in Agricultural Research and Innovation for Development (ARI4D) to address future challenges and to ensure food, nutritional and environmental security of the dryland eco-systems. Public - private sector partnership synergies will have to be fully harnessed in this regard.
10. Finally, agriculture in the dry regions must be liberated from the scourge of hunger, poverty and malnutrition. Accelerated science and innovation-led agricultural growth, therefore, must be inclusive and should address needs and aspirations of resource-poor smallholders including women farmers. In future, the gains in agricultural production would largely depend on a paradigm shift from the 'Integrated Germplasm Improvement' to 'Integrated Natural Resource Management' with focus on location specific and farm typology specific portfolios of Climate Smart Agriculture Practices (CSAPs), services (specially for weather and market intelligence, capacity development and knowledge sharing) and enabling policies for converting dryland areas from grey into green.

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