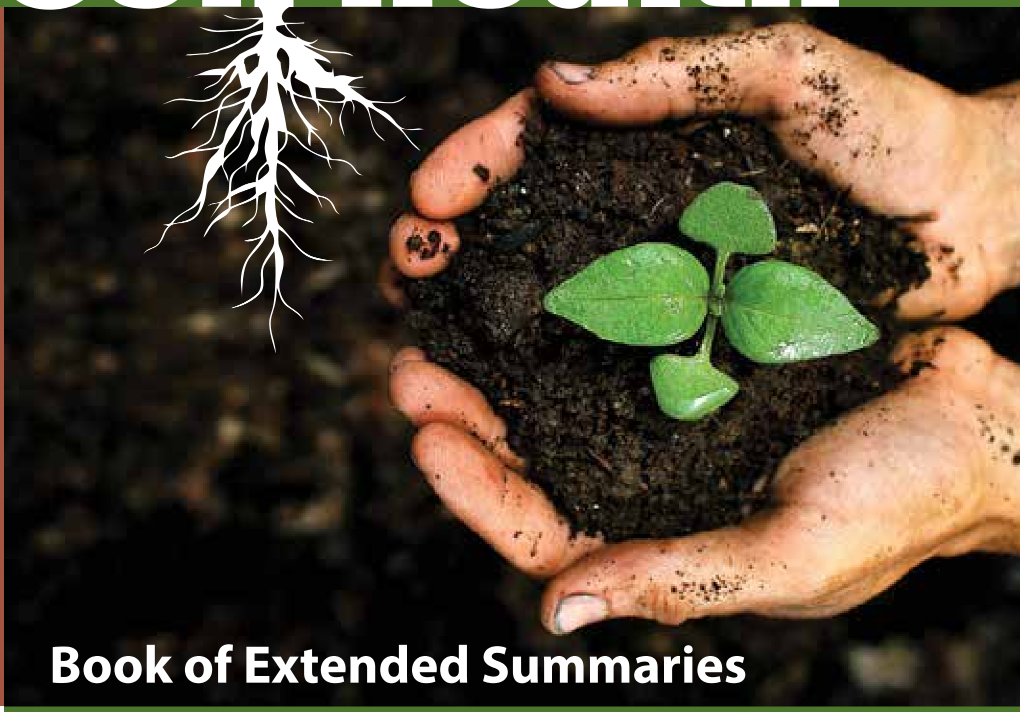
2015 International Year of Soils
healthy soils for a healthy life

National Dialogue on Efficient Nutrient Management for Improving Soil Health



September
28-29, 2015
IARI
New Delhi
India

Book of Extended Summaries

Editors:
ML Jat, Kaushik Majumdar, Andrew McDonald
Alok K Sikka and RS Paroda

Organizers:
Trust for Advancement of Agricultural Sciences
Indian Council of Agricultural Research
International Maize and Wheat Improvement Center
International Plant Nutrition Institute
Cereal Systems Initiative for South Asia
The Fertiliser Association of India

taas Progress Through Science
भाकृअनुप ICAR
CIMMYT International Maize and Wheat Improvement Center
25 years IPNI South Asia
CSISA
FAI Ensuring Food Security

Citation: Jat, M.L.; Majumdar, K.; McDonald, A.; Sikka, A.K. and Paroda, R.S. 2015. Book of extended summaries. National Dialogue on Efficient Nutrient Management for Improving Soil Health, September 28-29, 2015, New Delhi, India, TAAS, ICAR, CIMMYT, IPNI, CSISA, FAI, p. 56.

The Organizers

TAAS (Trust for Advancement of Agricultural Sciences): The Trust for Advancement of Agricultural Sciences (TAAS) was established on 17th October 2002 based on the decision of National Organizing Committee of 88th Session of the Indian Science Congress held at the Indian Agricultural Research Institute (IARI), New Delhi in January 2001 for harnessing the agricultural sciences for the welfare of the people. Its mission is to promote growth and advancement of agriculture through scientific interactions and partnerships. The major objectives are (i) to act as think tank on key policy issues relating to agricultural research for development (ARD), (ii) organizing seminars and special lectures on emerging issues and new development in agriculture sciences in different regions of India, (iii) instituting national awards for the outstanding contributions to Indian agriculture by the scientists of Indian origin, and (iv) facilitating partnerships with non-resident Indian agricultural scientists. The main activities include organizing foundation day lectures, special lectures, brain storming sessions/symposia/seminars/workshops on important themes, developing strategy papers on key policy matters, promoting farmers' innovations and conferring Dr. M.S. Swaminathan Award for Leadership in Agriculture. For more detail please visit: www.taas.in

ICAR (Indian Council of Agricultural Research): The Indian Council of Agricultural Research (ICAR) is an autonomous organization under the Department of Agricultural Research and Education (DARE), Ministry of Agriculture, Government of India. Formerly known as Imperial Council of Agricultural Research, it was established on 16th July 1929 as a registered society under the Societies Registration Act, 1860 in pursuance of the report of the Royal Commission on Agriculture. The ICAR has its headquarters at New Delhi. The Council is the apex body for coordinating, guiding and managing research and education in agriculture including horticulture, fisheries and animal sciences in the entire country. With 110 ICAR institutes and 73 agricultural universities spread across the country, this is one of the largest national agricultural systems in the world. The ICAR has played a pioneering role in ushering Green Revolution and subsequent developments in agriculture in India through its research and technology development that has enabled the country to increase the production of food grains by 4 times, horticultural crops by 6 times, fish by 9 times (marine 5 times and inland 17 times), milk 6 times and eggs 27 times since 1950-51, thus making a visible impact on the national food and nutritional security. It has played a major role in promoting excellence in higher education in agriculture. It is engaged in cutting edge areas of science and technology development and its scientists are internationally acknowledged in their fields. For details, please visit: www.icar.org.in

CIMMYT (International Maize and Wheat Improvement Centre): Headquartered in Mexico, the International Maize and Wheat Improvement Center (known by its Spanish acronym, CIMMYT) is a not-for-profit agriculture research and training organization. The Center works to improve food security and livelihoods by sustainably increasing the productivity of maize and wheat systems in the developing world. CIMMYT maintains the world's largest maize and wheat seed bank and is best known for initiating the Green Revolution, which saved millions of lives across Asia and for which CIMMYT's Dr. Norman Borlaug was awarded the Nobel Peace Prize. CIMMYT is a member of the CGIAR Consortium and receives support from national governments, foundations, development banks and other public and private agencies. For more information, please visit: www.cimmyt.org

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The Fertiliser Association of India

The Organizers (Contd...)

IPNI (International Plant Nutrition Institute): International Plant Nutrition Institute (IPNI) is a not-for-profit, science-based research and extension organization, dedicated to the responsible management of plant nutrition for the benefit of the human family. IPNI research and extension activities support nutrient best management practices (BMPs) that encourage applying the right nutrient source, at the right rate, at the right time, and in the right place – to increase crop productivity and economic return in an environmentally sustainable manner. There is widespread concern for issues such as food security and the relationship of crop production to the environment and ecosystems. As a global organization, IPNI understand these affairs and try to address these challenges with its strengths in agronomic research, education, demonstrations, training, and other endeavors through developing partnership with different organizations. IPNI South Asia Program works closely with international research and extension organizations, ICAR Research Institutes, State Agricultural Universities and Fertilizer Industry on plant nutrient management to develop and disseminate appropriate nutrient management strategies for crops and cropping systems. IPNI has active programs in Africa, Australia/New Zealand, Brazil, China, Eastern Europe/Central Asia and Middle East, Latin America-Southern Cone, Mexico and Central America, Northern Latin America, North America (Canada and U.S.A.), South Asia, and Southeast Asia. For further details visit us at http://www.ipni.net; "International Plant Nutrition Institute" @ Facebook; Twitter: @PlantNutrition.

CSISA (Cereal Systems Initiative for South Asia): The Cereal Systems Initiative for South Asia (CSISA) works to reduce hunger and increase food and income security of resource-poor farm families in Bangladesh, India and Nepal through the accelerated development and inclusive adoption of new cereal varieties, sustainable agricultural management technologies and policies. Established in 2009 as a research-for-development partnership, CSISA is implemented jointly by five CGIAR institutions – the International Maize and Wheat Improvement Center (CIMMYT), International Food Policy Research Institute (IFPRI), International Livestock Research Institute (ILRI), International Rice Research Institute (IRRI) and World Fish – in close partnership with public and private sector organizations across South Asia. It is funded by the U.S. Agency for International Development (USAID) and the Bill & Melinda Gates Foundation (BMGF). To know more, visit www.CSISA.org

FAI (The Fertiliser Association of India): The Fertiliser Association of India (FAI), established in 1955, is the national representative body of all fertilizer manufacturers in India comprising public, private, joint and cooperative sectors. It is a non-profit, non-trading organization of fertilizer manufacturers distributors, technologists, plant/equipment manufacturers, research institutes and others interested in fertilizers. The main objectives of FAI is to bring together all concerned with the production, marketing and use of fertilizers with a view to promoting solution of industry problems, assist the industry in improving its operative efficiency and to promote the most productive use of balanced fertilizers for raising agricultural productivity and ensuring food security. For more information, please visit: www.faidelhi.org

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Progress Through Science

Foreword

It is well said that health is wealth and a healthy life is not possible without healthy soils. Good soils are the foundation for meeting our basic needs for food, fuel, fibre and medicine. Soil health is critical to ecosystem functioning, since it plays a key role in the carbon cycle, storing and filtering water, and adaptation to and mitigation of climate change. In the face of mounting challenge of feeding a projected population of 9.6 billion by 2050 under the growing threat of climate change induced extreme weather events, soil health becomes quite critical for our future survival. Despite this, unfortunately we are oblivious of our soil's health status.

Considering the important role of soil, the United Nations (UN) have declared 2015 as an International Year of Soils for the global attention to ensure collective action by the global community to conserve and sustain this precious natural resource.

Currently, 33 per cent of our global soil resource is under some kind of threat and would require urgent attention to arrest further degradation due to excessive human pressure. On the contrary, the challenge of feeding the world on shrinking land resource requires us to re-think about exploitative food production strategies. Maintaining the soil's capacity to "function and perform", under projected scenario of intensive agriculture, will need a paradigm shift in existing agricultural practices, services and policies.

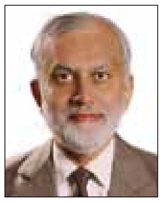
Nutrient management is one of the common denominators for maintaining healthy soils. Application of nutrient best management practices in diverse ecologies and production systems is thus critical to enhance food production, improve farm profitability and resource efficiency, beside reducing environmental footprints. Efficient nutrient management in the diverse soil and production systems would, therefore, need to integrate acquired knowledge with that of traditional practices being adopted by millions of our smallholder farmers. Also the dimension of the challenges would require a holistic alliance of policy-makers, agricultural scientists, extension specialists, and the community of practitioners to facilitate efficient nutrient management towards improving the soil health.

It is indeed my pleasure to welcome the leading scientists, policy planners and the extension specialists from the national and international public and private institutions, the fertilizer industry and the farmers to the proposed National Dialogue on "Efficient Nutrient Management for Improving Soil Health". My compliments to the organisers for bringing together the best experts in the field to attend this event. I am sure the dialogue will enable us to frame a 'Roadmap' for the best nutrient management practices in order to improve soil health for the present and future generations.

(R.S. Paroda)
Former Secretary, DARE & DG, ICAR
Chairman, TAAS

सत्यमेव जयते

डा. एस. अय्यप्पन
सचिव एवं महानिदेशक
Dr. S. AYYAPPAN
SECRETARY & DIRECTOR GENERAL



भारत सरकार
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Message

The survival of humanity is dependent on continuous functioning of mother land. In India, most of the agriculturally suitable land is already under use with no scope for further horizontal expansion except with those of rejuvenation of degraded land. Therefore, the pressure on land will increase to produce more from the same area under cultivation. Sustainably increasing food production to meet future food and nutrition needs while maintaining a healthy soil resource is complex particularly in the predominantly smallholder production systems of the country. Therefore, a healthy soil ensures its continued capacity to function as a vital living ecosystem that sustains plants, animals, and humans. To raise awareness among civil society and decision makers about the crucial role soil health plays in food security, climate change adaptation and mitigation, essential ecosystem services, poverty alleviation and sustainable development, the 68th UN General Assembly declared 2015 as the International Year of Soils.

Maintaining soil health while accommodating the increasing demand for food production is a growing challenge for agricultural scientists, farmers, development agencies and policy planners in India. Accordingly, the Government of India has taken special policy decisions, for example, National Mission on Soil Health, National Mission on Sustainable Agriculture etc., to promote sustainable soil management activities to develop and maintain healthy soils for different land users and population groups for the sustainable management and protection of soil resources, at village, district, state and national level.

I am pleased to learn that in the series of celebrations of the 'International Years of Soils-2015', the Trust for Advancement of Agricultural Sciences (TAAS), Indian Council of Agricultural Research (ICAR), International Maize and Wheat Improvement Centre (CIMMYT), International Plant Nutrition Institute (IPNI), Cereal Systems Initiative for South Asia (CSISA) and The Fertiliser Association of India (FAI) are jointly organizing a National Dialogue on "Efficient Nutrient Management for Improving Soil Health" at Prestigious IARI campus, New Delhi. Such occasions are unique in many ways for which I congratulate the organizers and look forward for fruitful deliberations and a roadmap for improving Soil Health.

(S. Ayyappan)

Dated the 10th September, 2015
New Delhi

CIMMYT
Centro Internacional de Mejoramiento de Maíz y Trigo

Martin Kropff
Director General

Message

To feed the projected 9.6 billion people in 2050, the global annual demand for maize, wheat and rice is expected to be 500 million tonnes more than 2014's record combined harvest. Much of this predicted need of cereal grain production to meet future food security needs is associated with the rapidly growing meat consumption of an expanding middle class population in Asia and has to come from existing farmland. In South Asia, the most populous regions of the world, the pressure on land is alarming wherein the availability of arable land for those dependent on agriculture has declined from over 1 hectare per person at the beginning of the 20th century to less than 0.1 ha today. Moreover, nearly 94% of the agriculturally suitable land is already under cultivation with limited scope for further horizontal expansion. Hence the pressure on land will further increase to produce more from the same or even less land with inferior quality due to competitive uses.

In Indian sub-continent, during past half century of post-green revolution period, the main shift in agriculture from 'traditional animal based subsistence' to 'intensive chemical and machinery based' agriculture has led to deterioration in soil health that multiplied problems associated with sustainability of natural resources. Also, the nutrient use in India has increased by 1573% whereas the average yield increase of total food grains was only 125% during past five decades which has led to declining efficiency and soil nutrient imbalances. The climate change will further have far-reaching consequences for agriculture and natural resources in the region; demanding a response that integrates food security with conserving and sustaining natural resources particularly soil health.

International Maize and Wheat Improvement Centre (CIMMYT) aimed to sustainably increase the productivity of maize and wheat systems to ensure global food security and reduce poverty has just responded to address the challenges of these multiple issues through establishing "Sustainable Intensification Program" having strong elements to improve soil health under current and future climates. To complement NARS and other public and private sector stakeholders in India, the sustainable Intensification Program of CIMMYT works closely with them to develop and deploy the sustainable intensification technologies to conserve natural resources, reduce environmental footprints and contribute to Government of India's National Soil Health Mission as well as adapting Agriculture to climate change.

I am pleased to note that to celebrate the 'International Years of Soils', the Trust for Advancement of Agricultural Sciences (TAAS), Indian Council of Agricultural Research (ICAR), International Maize and Wheat Improvement Centre (CIMMYT), International Plant Nutrition Institute (IPNI), Cereal Systems Initiative for South Asia (CSISA) and The Fertiliser Association of India (FAI) are jointly organising a National Dialogue on "Efficient Nutrient Management for Improving Soil Health". Such events are unique in many ways and I congratulate the organisers and look forward for exciting deliberations.

Martin Kropff

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Message

The mission of the International Plant Nutrition Institute (IPNI) is to promote responsible management of plant nutrition for the benefit of the human family. Soil health is intrinsically linked to our mission and the responsible management of plant nutrients is intrinsically linked to soil health.

Soil health refers to the ability of the soil to sustain plant and animal life, to maintain or enhance water and air quality, and to support human health. Fertile and healthy soils support life and the soil's ability to contribute to and sustain food security. A reduction or loss in the soil's productive capacity or ability to function as it was intended is a reflection of poor soil health. Such a reduction in productive capacity is land degradation; it affects almost a quarter of the Earth's surface and is one of the great environmental challenges we face, especially in smallholder production systems. This is why the Food and Agriculture Organization of the United Nations declared 2015 the International Year of Soils… to draw attention to the importance of protecting this valuable resource.

The energy, proteins, fats, vitamins, and minerals we derive from the food we eat and a crop's ability to produce nutritious foods depends directly on the health of soil. Soil fertility is a critical component of a healthy and productive soil. It integrates the physical, biological, and chemical processes in supplying essential nutrients to plants. A productive soil is always a fertile soil. Maintaining soil fertility requires adequate and balanced fertilization and science based-nutrition management. IPNI has adopted and promotes the 4R (Right Source, Right Rate, Right Time, and Right Place) approach to efficient nutrient management as the ideal for encompassing fertilizer best management practices. 4R principles guide sustainable nutrient management decisions that support good soil health.

IPNI is please to support and partner with the Trust for Advancement of Agricultural Sciences, the International Maize and Water Improvement Center, the Indian Council of Agricultural Research, the Cereal Systems Initiative for South Asia, and the Fertiliser Association of India in organizing this National Dialogue on "Efficient Nutrient Management for Improving Soil Health". Such a dialogue is long overdue. We are committed to the educational opportunities this National Dialogue will provide and look forward to the speakers and their messages on nutrient management for smallholder producers.

Terry L. Roberts, Ph.D.
President, IPNI

SATISH CHANDER
Director General

THE FERTILISER ASSOCIATION OF INDIA

9th September, 2015

Message

The Fertiliser Association of India is happy to associate with National Dialogue on **"Efficient Nutrient Management for Improving Soil Health"** being held at the Indian Agricultural Research Institute (IARI), New Delhi during September 28 – 29, 2015. The event assumes significance because it is being organised to mark the celebrations of International Year of Soils 2015.

Soil is a non-renewable resource and is vital to food security and economic development. Increasing population and intensification of agriculture have put immense pressure on the soil resource. The over exploitation and mismanagement are manifested in the form of wide spread land degradation, deterioration in soil health and contamination of soil and water resources.

Maintaining soil health through efficient nutrient management is essential to meet the humanity's increasing demand for food, feed, fuel and fibre. National policy is very important aspect which needs to be considered to maintain soil resource of the country. FAI with its member companies is committed to the cause of soil health enhancement by promoting balanced and efficient use of fertilisers through 4Rs nutrient stewardship.

I am sure, the presentations and discussions at the National Dialogue will lead to the recommendations that would be helpful in fine tuning policies for improving soil health and ensuring food security & environmental quality.

I wish great success for the event.

(Satish Chander)

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Acknowledgements

Improving soil health is a national mission and deliberating on such a topical issues through national dialogue is a collective wisdom of the organizers. Our sincere appreciations to the senior management of the organizing institutions; TAAS, ICAR, CIMMYT, IPNI, CSISA and FAI for their unconditional financial and technical support to organize such an event at the time when global community is celebrating "International Year of Soils". We are more than confident that such a national dialogue will create awareness among large number of researchers, land users, civil society and policy planners about the soil health and help in developing an 'actionable road map' to contribute to the national mission on soil health. We thankfully acknowledge the overwhelming response and commitment of all the distinguished chairs, co-chairs, panelists, speakers and facilitators of various sessions whose intellectual power will make the difference in meeting the objectives of the dialogue. Our heartfelt thanks to the Chair, co-chair and members of the organizing committee and technical committee of the event for their dedicated efforts in organizing this national event. We sincerely acknowledge the support of Director IARI, secretary ICAR and Secretary DARE & Director General ICAR for extending the conference facilities for this event. Excellent logistic and administrative support received from Ms. Tripti Agarwal (CIMMYT), Ms. Simmi Dogra (TAAS) and Mr. Kailash Kalwania (CIMMYT) is highly appreciated.

New Delhi, India
September 16, 2015

Editors and organizers

1. Background

The 68th UN General Assembly declared 2015 as the International Year of Soils. The International Year of Soils aims to raise awareness among civil society and decision makers about the crucial role soil plays in food security, climate change adaptation and mitigation, essential ecosystem services, poverty alleviation and sustainable development. The major objectives include promoting investment in sustainable soil management activities to develop and maintain healthy soils for different land users and population groups; and support effective policies and actions for the sustainable management and protection of soil resources, at national, regional and global scale. Maintaining soil health while accommodating the increasing demand for food production is a continued and growing challenge for agricultural scientists, farmers, development agencies and policy planners in India and elsewhere.

Most of the agriculturally suitable land in India as well as other South Asian countries is already under cultivation, and there is limited scope for further horizontal expansion. Hence the pressure on land will increase to produce more from the same area under cultivation. Sustainably increasing food production to meet future food and nutrition needs while maintaining a healthy soil resource in such a landscape is a complex objective, particularly in the predominantly smallholder production systems. A healthy soil ensures its continued capacity to function as a vital living ecosystem that sustains plants, animals, and humans. Agro-climatic conditions, crop management and policy issues may often adversely affect the soil health. For instance, soil organic carbon (SOC) and its dynamics are key determinants of soil health and for the provisioning of essential ecosystem services. However, the SOC content in most cultivated soils of India is less than 5 g/kg compared with 15 to 20 g/kg in uncultivated virgin soils. Besides the subtropical environment that aggravates SOC losses in the sub-continent, intensive tillage, removal/burning of crop residues and mining of soil nutrients under intensive cropping systems contribute significantly to such SOC losses. Other crop management practices that could have enhanced SOC content, such as field application of FYM and other organic manure or green manuring are limited or non-existent among smallholder farmers.

Imbalanced and inappropriate fertilizer application adversely affects soil health and limits the capacity of the soil to produce optimally and sustainably at spatial and temporal scales. Age-old blanket fertilizer recommendations over large areas do not hold relevance under current perspective. In addition, the preferential application of nitrogen in imbalanced quantity, inadequate P and K application, and lack of secondary and micronutrient application are other fertilizer use related issues in India as well as other South Asian countries that potentially compromises our desired goal of sustainable food security while maintaining a healthy soil and environment resources for posterity. Scientists and policy planners have pointed out the declining nutrient use efficiency/fertilizer response, farm profitability, and sharp increase in areas with multiple nutrient deficiencies as well as increasing GHG emissions from soils as clear indicators of inappropriate fertilization approaches adopted by farmers of India and other South

Asian countries. Agriculture sector contributes 17.6% GHG emissions in India in addition to large amount (~100 Million tons CO_2-eq/year) from agriculture industry (fertilizer production and transport). Efficient soil and nutrient management practices as well and nutrient use efficiency has to play a key role not only for food security and farm profitability but also for mitigation-led future adaptation to progressive climate change. The climate change induced variability will result in significant economic losses for India across sectors. Production losses in rice, wheat and maize alone could go up to 208 Billion US$ in 2050. National policy is therefore an important aspect that needs to be considered as we try to maintain a healthy soil resource for India. Fertilizer subsidy policy is one example, where preferential subsidy for one plant nutrient over others have been promoting nutrient imbalance in farmers' fields through over-use of the highly subsidized nutrient. Besides reducing crop productivity and farm profitability, this has led to severe depletion of plant nutrients in soils adversely affecting its capacity to function optimally. Notwithstanding the fact that there are several other factors besides nutrient management that affect soil health, strategies of organic recycling, legumes, bio-fertilizers as well as application of fertilizer and organics in soils probably have the most significant impact on it.

Considering the above, a multi-pronged approach is required to address soil health issues in the realm of nutrient management in smallholder production systems. A scientific land use planning to help in location-specific cropping system optimization, balanced and adequate nutrient application to crops in an integrated manner, promotion of residue recycling, integration of legumes in cropping systems, and adequate policy support are some of the critical factors that may help us achieve sustainable food security in a healthy soil environment. The science, technology and policy aspects of maintaining a healthy soil would require the support of a robust extension mechanism for scaling- and adoption of efficient nutrient management practices. Support of innovative approaches and tools (Nutrient Expert® decision system, GreenSeeker™ sensors, remote sensing, GIS) and techniques would be critical to empower the extension system to generate and deploy recommendations that are farm-specific in accordance to soil health cards and match the resource endowment of the smallholder farmers.

The National Dialogue on **"Efficient Nutrient Management for Improving Soil Health"** intends to set the strategic pathways for ensuring a healthy soil environment through applications of farmer typology specific nutrient best management practices that can support future food demand and maintain our soil and environment resources for posterity of society.

2. Objectives

- Stock taking on trends in nutrient management practices and soil health in predominant production systems and ecologies
- Share experiences on recent advances in scalable tools, techniques and innovations for efficient nutrient management for improving soil health at landscape scale
- Create evidence based policy awareness for synergizing investments, institutions and innovations for scaling farmer typology specific nutrient management for soil health improvement
- Develop **"Roadmap"** to implement efficient nutrient management and soil health improvement strategies

3. Panel Discussion on "Soil Health: Concerns and Opportunities"

3.1 Efficient Nutrient Management a *sin qua non* of Sustainable Soil Health – Concept and Concerns

By J.C. Katyal

Former Vice Chancellor, CCS Haryana Agricultural University and DDG Education ICAR, New Delhi

Introduction

Fertilizer use efficiency means more output per unit of fertilizer input without causing physical, financial and environmental stress either on natural resources or human wellbeing. Among the nutrients supplied through fertilizers, nitrogen use efficiency (NUE) is a matter of grave concern, since it seldom exceeds 50%. Unused part is primarily: (i) associates with soil (immobilization), (ii) erodes from the point of application (runoff), (iii) shifts from the rooting zone (leaching) and (iv) exits from soil as gases (mainly nitrous oxide, N_2O). Guided primarily by economic, academic and environmental objectives, NUE is described differently e.g., agronomic efficiency (kg gain yield /kg fertilizer N), fertilizer N recovery (% fertilizer N absorbed of that applied) and physiological efficiency (kg yield gain/kg of fertilizer N absorbed by the crop).

Lexicographically, appended word health to soil connotes either a soil being robust or an ailing resource. It, thereby, signifies soil as a living and dynamic entity, which is an outstanding feature of any description of soil health. A soil in poor health needs more inputs, uses them inefficiently, gives less productivity per unit of input and perturbs ecological barograph.

'*Soil health*' is invariably interchanged with the term '*soil quality*'. The pioneer textbook on Soil Science, 'Nature and Properties of Soils' 14th Edition (NC Brady and RR Wells) describes the concepts of soil health and soil quality. According to the text "Although these terms are often used synonymously, they involve two distinct concepts. The soil health refers to self-regulation, stability, resilience, and lack of stress symptoms in a soil as an ecosystem. Soil health describes the biological integrity of the soil community – the balance among organisms within a soil and between soil organisms and their environment". Soil quality is a term that more often is used to describe physical attributes of a soil. These characteristics range between a simple trait like soil colour to more complex properties like fertility, erodibility and compactability. The Soil Science Society of America defines soil health as the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation.

Barring weathering induced features, like soil texture and soil depth, man's management has a profound influence on soil health (or soil quality). For example, pervading fertilizer-N use inefficiency has potential to affect soil biological activity (basal respiration), soil reactivity (pH), physical integrity (structure and filtration of pollutants) and global warming leading to climate change.

Chemical fertilizers, unquestionably, have been and continue to be an important driver of productivity growth. Asserted Dr. Norman Borlaug, "If high-yielding varieties are the catalysts that have ignited the Green Revolution, then chemical fertilizer is the fuel that has powered its forward thrust". This statement holds special significance for India, where soils are typically impoverished of fertility nurturing organic matter. Summarized by FAO, deficiency of macronutrient: N is universal (90%), P is widespread (80%), K is multiplying fast and S is common (75%). Among the micronutrient deficiencies: Zn and B top the list, respective incidence is seen in one out of two and one out of three soil samples analyzed. With input of native organic resources failing grossly to replenish the crop-mined nutrients, India to stay food-secure has no option except to depend on increasing use of fertilizers. Past success of reaching food self-sufficiency vis-a-vis role of fertilizers is a witness to that.

Besides water, of all the risks to sustainable growth of agriculture, poor state of soil fertility is the most serious threat. Along with soil test values, scourge of weakened nutrient availability was established by the results from thousands of farmers' field fertilizer response experiments conducted across length and breadth of the country. Contribution of fertilizers in increasing productivity antecedent to induction of modern varieties ranged between 50% and 70%, observed an IFA-UNEP Report in 2000. This finding synced well with the increase in food grain production and fertilizer consumption (R^2 0.94). Fertilizers account for about 10% of the operational cost of cultivation of rice and wheat and their impact on productivity is at least 6 times larger. Among the inputs and management interventions that influence response to fertilizers, irrigation remains a vital input. Results from fixed plot long-term experiments confirm that conclusion. Spell of GR sidestepping the rainfed areas is a major consequence of uncertain water availability evoking limited fertilizer use. On an average, irrigated crops are allocated 3 times more fertilizers compared to their un-irrigated counterparts.

Progressive fall in response to fertilizers (agronomic efficiency, gain in productivity/unit fertilizer nutrient) from 11 in 1970s to 5 during first decade of 21st century gave a wake-up call that all is not well with the fertilizer use. Falling response ratio signalled that proportion of applied fertilizer-NPK absorbed by the crop and hence translated into yield (physiological efficiency), has deteriorated with rising intensity of fertilizer use (kg NPK/ha consumption rose to ~141 in 2010-11 from ~14 in 1970-71). It is a vital clue confirming crumbling productivity growth from peak value of ~3% in 1980s to ~1.5% following that. It also motions growing wastage of fertilizer input (up to 70%) leading to ecological damage manifested as decline in quality of soil, water, biodiversity and air. From the point of adverse consequences of wasted fertilizers, N and P are the main culprits, with N playing the lead role. Post-application information on budgeting of these nutrients presents a very depressing picture on proportion used by the crop and that leftover in the soil. With N fertilizers, 40% to 70% remains unutilized by the crop that receives its application. Although a small part of it becomes associated with the soil, the remainder: (i) leaches into the soil - polluting ground water, (ii) runs off - contaminating river and lake waters and (iii) exits soil in gaseous forms – starting greenhouse effect. Leftover fertilizer-N in soil has hardly any measurable consequence on the following crop in the rotation. It does, however, influence useful soil biology, albeit in a transitory way. The unutilized fertilizer N that appears in gaseous forms - ammonia (NH_3) and nitrous oxide (N_2O) - are a cause of concern. Of the two, N_2O threatens sustenance of ecological services. It disturbs the integrity of protective ozone layer and is a source of global warming and climate change.

Contrary to unutilized fertilizer N, P and K largely stay in the soil and produce beneficial outcome favouring productivity of subsequent crops. From that angle use efficiency of P and K is not a substantive issue. However, soil held P remains vulnerable to erosion. This part in the company of erodible soil N, once dislodged from top soil, finds entry into rivers, lakes and ponds. Progressive enrichment of lake/pond waters with N and P gives rise to 'eutrophication'. It means lush growth of algal blooms charted by their death and decay, development of 'hypoxia' and finally collapse of aquatic life. Left to nature, eutrophication is a slow-aging condition of a water body. In contrast, wasteful use of fertilizers encouraging rapid enrichment of lake and pond waters with N and P gravely speeds up the process. The final outcome: biodiversity depletion and loss of climate pacifying water bodies inspire global warming.

Issues on fertilizer use efficiency, almost in toto, relate to rising consumption of N fertilizers. In India, like several other countries, urea is the dominant N fertilizer (82% of total N consumed in 2012-13). Justifiably maximum FUE research and development effort nucleates around NUE of this material.

Dismally low NUE (<50%) challenges sustainable intensification of farming soils in the face of exhausted possibility to amplify production and remain food secure. Saving land by increasing productivity/unit area remains the only option to feed the burgeoning population. Development of non-sustainable intensification is, thus, a consequence of man's quest to raise productivity without imposing holistic management. Holistic management, includes balancing yield maximization with minimization of disruption to the ecological services. Exclusive focus on yield pushing management practices, in particular, destabilize, natural nutrient cycle. 'Flux of nutrients across physical environment (soil, water and air), living organisms and back to physical environment' what constitutes a natural N (also other nutrients) cycle. Overdevelopment of native nutrient harvests (or soil mining) is a typical offshoot of disturbed native N cycle. Loss of useful soil biology, damage to soil health/quality and unprecedented changes in climatic patterns are other negative end products. Direct Impact of fertilizer-N on useful soil biology is transitory. Likewise, impairment of soil quality, in terms of chemical reactivity or physical attributes, in general, is offset by the inherent soil buffering capacity. Nevertheless, it is the poor NUE propelled global warming due to N_2O gas emissions or eutrophication that is the source of decaying soil health. Besides, poor NUE necessitates higher consumption and production of urea-N. Each ton of elevated production of urea-N costs 47 barrels of crude – estimated IFDC. Then expenditure of every 100 barrels of crude pumps 47 tons CO_2 in to the atmosphere. Poor NUE is a double whammy triggering global warming. It manifests in terms of heightened temperatures mediated reduction in labile/active pool (light fraction of C) of soil organic matter. Since with climate change extreme rain events are becoming frequent, even sustainability of stable carbon fraction (heavy fraction of C) gets weakened. Whether it is the plunder of active or recalcitrant carbon fraction, needless it is to mention, soil health suffers in all aspects.

Scientific evidence built up over the last 5 decades confirms that institution of holistic fertilizer management practices is imperative to maximize fertilizer use by crops and minimize its waste. In pursuance of holistic fertilizer management, it is inevitable to: (i) make soil test and crop need based applications that not only equal crop removals, but also balance fertilizer treatment in proportions that adequately ameliorate all deficient nutrients, (ii) adopt efficiency enhancing fertilizer methods, times, sources and doses and (iii) include supplementary treatment with indigenous sources and resources. Besides, these basic elements of efficient fertilizer management, it is inescapable to exclude practices like standard/precise agricultural methods and smart use of pesticides, water and energy. Above all, it mandates to prepare expert human resource for transferring all-inclusive information on a right management package. Working in a participatory mode with all stakeholders will hasten the understanding prompting lasting adoption of holistic fertilizer management by the client farmers.

The role of holistic fertilizer management scheme is summarized below:

- For optimum growth and maximum productivity, crops need sufficient, but rightly-proportioned supply of 17 essential nutrient elements. Apparently, current focus of soil fertility management primarily on N and to some extent on P is misplaced for the purpose of sustainable productivity growth. Findings from fixed site long-term experiments elucidated need for correcting the imbalance by including K treatment. Contrary to that need, public subsidy policy favoring urea, continues to distort the necessary NPK use ratio. With time, rise in proportion of K deficient soils is the consequence of continuous mining without K supplementation.

By and large, specifically in intensively cultivated regions, need for micro-nutrients - Zn and B and secondary-nutrient S came to the fore. Since facilities for soil testing in respect of these nutrients is almost non-existent, farmers remain in the dark whether or not and what nutrients to apply. Added to that is the insufficient expertize of technology transfer agents on instant ability to diagnose in-situ micro-nutrient disorders. With this kind of systemic weaknesses, farmers remain deprived of any real time credible source of advice to delineate deficient fields before cropping or take steps to alleviate the nutrient-specific hunger should their crops show deficiency symptoms after sowing/planting.

- Fertilizer use and management methods are divided into two categories – indirect and direct. The former class includes region- and crop-specific 'precise agronomic practices', like: land levelling and crop establishment, choice of variety, optimum seed rate/planting density and row orientation/ geometry, time of sowing, weed and pest control, smart water management, harvesting at prescribed physiological maturity and loss-free harvests. There exists an indisputable evidence that fertilizers alone fail to replace the yield loss caused by the non-adoption of any one technology constituting the package of standard agricultural practices. Once again, it is more necessary now than ever before that know-hows (scientists and extension functionaries) work hand-in-hand with the do-hows (peasantry).
- The expert fertilizer management scheme that directly influences FUE includes source, level, method and time of fertilizer application. Presently, these four practices are nicknamed '4Rs' (R stands for 'right' i.e., right source…) of fertilizer management. Guided by these 4 key elements (4Rs) of fertilizer management, a wealth of scientific information suggests that researchers were largely successful in demonstrating the strength of their findings even under farmer field conditions. Despite these well-meaning accomplishments, it is a paradox that level of NUE today remains what it was 50 years back. Pervading bleak scenario is an indication that either the scientist-suggested alternatives were not right for a vast majority of the farmers or farmers were unaware of these recommendations. Resultantly, easy to adopt, albeit wasteful broadcasting method of surface spreading and general recommendations on rates/proportions of application continue to dominate fertilizer management scene. New developments like site specific nutrient management (for example Nutrient Expert) or green sensors (GreenSeeker) or leaf color chart aided fertilizer dressings and role of sequencing fertilizer application with reference to irrigation seem to be aliens even to technology transfer agents. Emphasis on action research – scientists' facilitated, but farmers' led experimentation – needs to be revived by converging genuine commitment of ICAR institutes, State Agricultural Universities, State Extension Machinery and Krishi Vigyan Kendras.
- Another issue related to inefficient administration of fertilizers relates to relegated place of organic manures in soil fertility management. Organic manures undeniably are a store house of all essential nutrients, albeit in limited amounts. Besides, they have distinctive role in building soil biology, physical health and resilience - the contributory factors in sustaining tempo of productivity growth.

In view of their insufficient availability compounded with the limited effective nutrient potential, organic manures have crucial complimentary role in maintaining soil health. On all counts, it appears that the integrated use of chemical fertilizers and organic manures is the most viable and practicable strategy to sustain productivity surge and mitigate rising concerns on soil health and climate change.

- Despite clear understanding on efficient management of fertilizers, improving FUE continues to be an enigma. One prominent explanation seems to be that scientific findings were perhaps not aligned to farmers' situation and/or the native biophysical soil attributes and limitations. In general, research objectives seldom provided space accommodating farmers' needs and views; particularly the constraints faced by the small and marginal (S&M) farmers. Rarely did scientists attempt to work hand in hand with this category of farmers to validate practicality of their findings on improving the conventional methods of fertilizer management. Incidentally, S&M farmers (land holding size <2 ha) constitute a dominant category in India (~87% of the total ~138 M). They not only share sizeable part of the fertilizers consumed (53%), but the intensity of fertilizer use by them is also greater than the medium to large farm size groups (53 vs. 47 kg NPK/ha). Strangely, when it comes to transfer of technology, observed World Bank, small and marginal farmers remain the least preferred group to interact with. Likewise, on an overall basis, due to weak extension services even in 2012-13 round of NSSO, only 40% of the surveyed land holders accessed scientific information from all available sources. Interestingly, in 2003-04 NSSO round also, only 2 out 5 farmers made use of all technology transfer sources to improve farming. Partial adoption of a technology package till date remains a patent source of persisting gulf between the potential yield and the yield obtained by the farmers. It is reasonable to believe that at least one half of the observed yield gap (up to 3 tons/ha) can be assigned to inefficient use of fertilizers. It is reiterated, unutilized part of the fertilizers is potential source of pollution and contamination of soil, water and air. Need is to devise and induct a new look extension system, which besides being multi-agency, on the one hand will facilitate availability of inputs as per technological demands and on the other will offer advice on improved soil, water and input management including transfer of information on quality produce and nuances of markets and trade. Simultaneous launch of improved formal, non-formal and informal competence and capacity building HRD programs will be a fundamental necessity. It is seen to sustainably consolidate adoption and retention of efficient fertilizer use and management.
- While it is almost impossible to withdraw financial perks in the form of subsidy on fertilizers, an alternative could be to incentivize those who cooperatively save subsidy by leveraging practices leading to efficient use. One proposed option is to offer build-in efficiency in the freebies itself. For example, providing subsidy on the use of efficient nutrient sources, which otherwise are more costly. Another possibility is to reward efficient users of subsidized or free inputs. For instance, if farmers belonging to a village as a community reduce fertilizer use without compromising productivity levels, they as a group qualify to be rewarded. The sum of the incentive could be based on the amount of saved fertilizers, which otherwise would have been paid in the form of subsidy. Proposed incentive and reward scheme gives greater credence to inspire efficient use of inputs and helps protecting the environment rather than saving money for public exchequer. The investment on compensation for healthy environment for development is a win-win situation. It will both sustain food production and improvement in health of soils, water and climate. Effectivity or otherwise of this proposal can be tested on a pilot scale.

4. Challenges for Improving Soil Health

4.1 Soil Health: Monitoring Strategies for Smallholder Systems

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Introduction

Soil health has in recent years become associated with sustainability in agriculture. A web search of soil health brings up an abundance of factors that are considered important to calling a soil "healthy". However, this begs the question "what would a smallholder farmer consider in determining if a soil was healthy"? It is my opinion that "economically viable production" is the factor which best describes a healthy soil to most farmers, with less focus on associated biological, physical and chemical factors. As a result, any attempt to promote practices which lead to improved soil health must be linked directly to improved economically viable production from a field.

As soil scientists and agronomists working with nutrient management, we are all well aware that most of the biological, chemical and physical properties we attribute to improved soil health come from the maintenance, or improvement, of soil organic matter (Hati et al., 2008; Mandal et al., 2007). Soil organic matter helps to improve soil tilth, water infiltration and storage, CEC, microbial activity and macro, secondary and micronutrient availability. Long-term trials in South Asia clearly show that well managed, high yield cropping systems, which return crop residues to the field, do improve soil organic matter and related soil biological, chemical and physical properties (Singh and Singh, 2001; Singh et al., 2016). Work with conservation tillage and nutrient management further indicates that not only is soil organic matter improved, but the system can support current or higher yields, and reduce associated GHG emissions per tonne of grain production (Sapkota et al., 2014).

When we consider the current state of smallholder farming systems in South Asia, the most obvious challenge one has to address is the "poverty trap" associated with limited land area. This has resulted in farmers focused primarily on survival, rather than any attempt to run a farm as a business. Work conducted by IPNI with small holder farmers clearly shows that their ability to adopt, or even consider new technology, is dependent on their household resource situation (Banerjee et al., 2014). In the absence of some form of cash flow from off-farm employment, many of these small holders struggle to feed and cloth their families. This is clearly reflected in the large number of young people leaving rural India to find some form of employment as a means of survival away from the farm. This challenge is significant and will eventually force action to avoid a progressive decline in the current levels of productivity, not to mention future food grain needs with expanding population demands.

Relevance in Indian context

Crop residue removal/burning in India is a serious problem, leading to wide spread problems of secondary and micronutrient deficiency, explaining why we have the "yield stagnation" scenario presented so often. The current challenge is addressing the issue of small land holdings and poverty amongst these farmers. Unfortunately, poverty has made crop biomass an attractive fuel for farm homes, and an additional source of income. As farm size increases, alternative cooking/heating fuels will hopefully become more popular (gas/electricity) and crop biomass will no longer be in demand.

Solutions

I would like to suggest that this challenge will evolve into a solution as current farmers' age, and in the absence of family members who are prepared to continue their meager lifestyle, land will be leased to those remaining farmers who are focused on agriculture as a family business.

- There is a need to move farmers from small holders to larger land holdings, supported by mechanization,
- There is a need to increase the understanding of engaged young farmers that there are economic benefits to production from improved soil quality, and
- I question the need to conduct detailed evaluation of soil quality on farms, asking the question what is the benefit that can come from this? Rather I would suggest that any program on soil quality focus on those inputs which can be realistically sourced by small holders…such as livestock manure, crop biomass and farm yard compost. These amendments, when added to soils, can then be credited in any nutrient recommendation system that is properly designed to support soil quality improvement.

Way forward

- One challenge I have always faced when in India is the very wide diversity amongst farmers, ranging in education, land base, resources, technology use, etc. As a result of this, IPNI has focused their attention on current fertilizer users, supplying them with information which would help them in making better balanced fertilization decisions.
- The normal process of technology adoption and diffusion within a farming community requires that the "innovators" receive our attention to begin with, and associated information (radio and video) be directed at the larger, less innovative audience.
- The extension of publically good information must be tied to profitability on the farm. Failure to do this is destined to meet with failure.

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4.2 Nutrient Mining in Indian Agriculture: Past Trends and Future Challenges

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Introduction

The necessity of increasing food production to meet the demand of the ever-increasing population in India is self-evident. The total area under cultivation has remained more or less constant over the past several decades, and the agricultural lands are also gradually being diverted to non-agricultural uses. It is unlikely that sizable additional area will be brought in under cultivation in the foreseeable future. Therefore, there is no other viable option than increasing the crop production per unit area (productivity) for meeting the future production goals.

Maintenance of native soil fertility in the intensively cultivated regions of the country is one of the preconditions of maintaining and improving the current crop yield levels. Intensive cropping systems remove substantial quantities of plant nutrients from soil during continued agricultural production round the year. The basic principle of maintaining the fertility status of a soil under high intensity crop production systems is to annually replenish those nutrients that are removed from the field. The removal of crop residues from agricultural fields renders this a more difficult task (Sanyal et al., 2014). The term "*Nutrient Mining*" refers to a situation when the quantity of soil nutrients removed by a crop from an agricultural field exceeds the amount that is recycled back and/or replenished to the field. This causes a decline in the native soil fertility and may seriously jeopardize the future food security of the country.

Relevance in Indian context

A continuous mismatch between nutrient removal and replenishment, even at the recommended levels of fertilizer application, was evident in the long-term studies on various cropping systems. The long-term rice-wheat experiments in the Indo-Gangetic Plain (IGP) under the All India Coordinated Research Project on Integrated Farming Systems reveal that additions of N and P in different locations were greater than their removal by the crops. On the other hand, negative K balances were noted in all the treatments at all the locations. However, the effect of negative K balance may not be visible on the plant available K content of soil owing to the relatively high K supplying capacity from the respective non-exchangeable K (NEK) pools of the illitic minerals-dominated soils of the IGP. Indeed, the assessment of the plant-available K in soils does not measure the NEK pool, or its depletion. However, continued (unnoticed) excessive depletion of NEK from the interlayer space of the illitic clays may lead to an irreversible structural collapse of these minerals, thereby severely restricting the release of K from such micaceous minerals (Sarkar et al. 2013). This would impair the long-term soil fertility in respect of K, and its restoration may require much higher and thoroughly unwarranted investment in future. Further, the estimates of apparent N balance, which was positive at all the locations, may not also mean a sustainable input-output relation either. In rice soils, the inclusion of N losses from rhizosphere by leaching, volatilization and denitrification in the nutrient balance calculation may render the N balances negative at all the locations. Thus, the current practices of nutrient management in cropping systems are exhaustive in terms of N and K withdrawals, leading to depletion of these nutrients from the native soil reserves.

The nutrient output: input ratio (nutrient depletion factor) provides a measure of the extent of nutrient uptake exceeding the additions and provides gross estimates of possible depletion. Site-specific studies conducted across the rice-wheat growing regions of India indicates that crop uptake of P exceeds its input at 6 out of 10 locations, whereas the output: input ratio for K and S were more than 1.0 at all the locations (Table 4.1), indicating a stress on soil K and S supplies. These results become more revealing when nutrient uptake of P, K and S was furnished from the soil native reserves in the absence of their external input. Results show the largest nutrient removal accompanying the highest productivity level.

Table 4.1: Nutrient depletion factor and nutrient uptake from soil reserve under rice-wheat system with best management practices correcting all the existing nutrient deficiencies except that of the indicated nutrients

Location	Rice-wheat System yield (t ha^{-1})	Nutrient depletion factor (Output: Input Ratio)			Depletion of soil nutrients from soil reserve (kg ha^{-1})		
		P_2O_5	K_2O	S	P_2O_5	K_2O	S
Sabour	13.8	1.74	1.86	1.20	88	261	42
Ranchi	10.4	0.73	1.09	2.04	63	205	41
Ludhiana	16.1	1.36	2.29	2.07	126	354	58
Palampur	9.8	1.70	1.83	1.35	74	226	36
R.S. Pura	13.2	0.67	1.71	1.48	94	301	45
Faizabad	12.3	0.97	1.52	1.48	80	252	39
Kanpur	14.6	1.03	1.48	2.27	66	247	43
Modipuam	16.7	1.98	1.63	3.50	100	294	58
Varansi	12.1	1.35	1.50	1.60	65	221	38
Pantnagar	12.4	0.77	1.45	2.02	67	220	42

Source: Cited in Sanyal et al. (2014)

Solutions

It is apparent that well-documented soil-crop management practices are yet to address adequately the issue of nutrient mining from soil by the crops and cropping sequences, and the effect thereof on the long-term native soil fertility. There is thus a need for appropriate environmental auditing, concomitant with soil-crop management practices.

Indeed, Buresh et al. (2010) illustrates the nutrient balance methodology, based on the QUEFTS (*Quantitative Evaluation of the Fertility of Tropical Soils*) model, for estimating the K balances in agricultural fields for single crop and cropping systems involving cereals. The essential components of such K balance calculations included contributions (input) from the retained crop residues, irrigation water and added organic matter, as well as the loss (output) of K from the system through leaching and export through the grain of the crops. These authors (2010) examined two options for rice to calculate the fertilizer K rates based on partial maintenance of soil K level with gradual drawdown or depletion of such native soil K. In one option with partial maintenance, fertilizer K requirement was calculated as a fraction of the full maintenance. The other option with partial maintenance allowed K depletion from the soil reserves up to a threshold limit, which is treated as an input in the nutrient balance. In such approach, the indigenous soil K supply to support the targeted crop yield was obtained from the corresponding omission plot data. However, Singh et al. (2014) (cited in Sanyal et al., 2014) examined such nutrient balance in rice-wheat systems by replacing the omission plot data with the indigenous nutrient supply calculations of nutrient (N, P and K) contributions from the soil available pool (soil test data) and the appropriate nutrient use efficiency factors.

For addressing these issues, the nutrient input from irrigation water and losses through leaching would feature prominently in the nutrient balance equations that help estimate fertilizer requirement to achieve a targeted crop yield. A portion of the K and other basic cations added to the field through irrigation water, for instance, may also be lost via leaching from the highly permeable soils with adequate drainage and low CEC. Further, there are several researchable issues pertaining to the assessment of equitable distribution of crop residues among different competitive uses, such as between animal feed requirement and nutrient recycling in fields, thereby providing options for farmers to retain at least a part of the residues in the field. Critical estimation of the rate of mineralization of crop residues with different (C:N) ratios under varying agro-climatic conditions and management scenarios would also be required for assessing the nutrient availability from crop residues in the nutrient balance and nutrient mining calculations. The availability of organic resources, having several competitive usages, for agricultural uses, along with their nutrient loading needs to be ascertained for reliable nutrient balance computations in the context of the integrated nutrient management options.

A national portal for soil data repository is a critical requirement for assessing nutrient mining from soil. Such a national-level initiative to develop and maintain a soil data repository will allow tracking of soil fertility changes in intensive cropping regions over time. At this point, such databases are fragmented and maintained by several organizations, which are unavailable in the public domain. Integrating the former into one national portal will help the overall assessment of the national soil resources and developing other knowledge resources, such as fertility maps for different soil nutrients at a finer scale. Once developed, such a database could be periodically updated with contribution from different organizations. However, the data querying from several disparate sources may cause concern for the appropriate reconciliation of the soil test data. Creating a national committee to oversee the data input, with particular reference to data sources and data quality could minimize such concerns. Developing a national portal of soil data will strongly fit into the current initiative of generating the "Soil Health Card" for millions of geo-referenced farm field soils. This would be a logical starting point for a "national soil data repository" for the posterity, and will be an extremely valuable resource to facilitate research, planning and implementation of the improved agricultural practices at the local, regional and country scale. Such a repository will also help reorient fertilizer management practices, based on agro-climate, soil type and management practices to minimize soil nutrient mining while sustaining the soil fertility levels.

Way forward

- Nutrient mining in agriculture cannot be avoided altogether. Varying inherent buffer capacity and vulnerability of different soils, under similar cropping systems and comparable management practices are to be recognized. There is thus need for assessment of the allowable range of nutrient mining under variable climate-soil-crop-management domain at the regional scale. Multiple cropping systems and management practices further complicate the scenario.
- This talk primarily intended to bring the nutrient mining issue in our collective consciousness as a threat to the quality of soil resources and the food security for now as well as for the posterity.
- Hence, the need for a national effort to address the nutrient mining issue in the Indian agricultural context.

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4.3 Improving Soil Physical Health: Challenges and Opportunities

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Introduction

In India, millions of hectares of land in both irrigated and rainfed ecologies produce very low crop yields and low efficiency of nutrients due to unfavourable soil physical conditions. Improving soil health under such conditions is crucial for sustainably increasing crop productivity and nutrient use efficiency. Efficient nutrient management is therefore essential not only for improving crop production and use efficiency of nutrients but sustaining soil health as well. Nutrient use efficiency may be measured either as the fraction of added fertilizer recovered by the harvested portion of the crop or as unit of economic yield per unit of nutrient applied. Regardless of the manner of expression, all factors that affect crop yield with a given amount of nutrient, influence nutrient use efficiency. In fact the inefficient use of nutrients is linked to their losses from the soil plant system. Therefore any practice that enhances nutrient uptake, maximizes yield, minimizes losses and leads to enhanced nutrient use efficiency. Mass flow and diffusion are the two major processes by which nutrient ions are transported to the root. Immobile nutrients are absorbed through root interception. Management practices which alter water availability and root growth in time and space are likely to influence these processes. The major soil physical constraints identified are low water retention and high permeability, slow permeability, surface and subsurface mechanical impedance and shallow depth of the soils, which either restrict crop growth or reduce efficiency of basic inputs, such as water, fertilizer etc.

Low water retentive and highly permeable soils

These soils occur mostly in Rajasthan and some parts of Haryana and Punjab. The high permeability of these soils are associated with their sand and loamy sand texture. The soil has low bulk density but high hydraulic conductivity and infiltration rates (as high as 36.5 cm/h) for some profiles, which indicate high permeability and low water retention capacity of the soil. The fertilizer and water-use efficiency of these soils is very low and the nutrient losses are very high. These problems do not encourage the farmers to use high levels of inputs. The major crops grown on these soils are pearl millet (bajra), maize, wheat and barley in western parts of India and sorghum, maize, ragi (minor millets) and sugarcane in southern parts of India.

Slowly permeable soils

The slowly permeable soils occur in Madhya Pradesh, Maharashtra and also in parts of Rajasthan, Uttar Pradesh, Bihar and Tamil Nadu. The infiltration rate is as low as 0.2 cm/h and hydraulic conductivity is less than 0.15 cm/h for some of the profiles, which indicate slow permeability of the soil and possibility of submergence during rainy season. The very low permeability, which is associated with black clay soils, creates oxygen stress in the root zone due to stagnation of water. The prevailing anaerobic conditions cause the accumulation of carbon dioxide and other by-products in this zone which restrict the root growth. These black clay soils are sticky when wet and very hard when dry, thus could be cultivated or tilled only within a limited soil moisture range. In the valley lands where the topography is flat, weed menace is associated with humidity.

Crusting, hardening and shallow soils

These soils occur widely in Haryana, Andhra Pradesh and Tamil Nadu. It is to be noted that surface soil layer consists of 60 per cent coarse and 40 per cent fine fractions, a proportion optimum for crust formation when organic carbon is less than one per cent. Due to surface mechanical impedance, the emerging plumule faces resistance, bends below the crust and tries to come out at weak points of the crust; some of the seedlings injure their tips and fail to emerge. The emergence of pearl millet, cotton and jute seedlings is adversely affected if the crust is formed on the soil surface by the occurrence of rainfall within 48 hours of sowing. The red sandy clay loam 'Chalka soil' of Andhra Pradesh dry out very quickly due to low water retention capacity and become very hard. The maximum root growth of most of the crops is confined to the surface layer, and the crop growth suffers due to hardening. The crops grown on this soil include pigeonpea, maize, castor, groundnut and sorghum. The yield of groundnut is very low due to reduced size of pods caused by hardening of the soil.

Soils with sub-surface mechanical impedance

The subsurface mechanical impedance may be developed either due to the formation of plough sole as in the case of rice fields on medium-textured soil, use of heavy machinery on moist soil, accumulation of clay in B-horizon under sub-humid conditions or the presence of kankar layers. These high mechanical impedance layers are relatively impervious with the result that water stagnates on the soil surface after heavy rainfall or irrigation and the crops turn yellow due to oxygen stress. These layers do not allow the roots to penetrate deep into the soil. Shallow root system makes the plant drought-prone during dry spells and promotes lodging during unusually wet conditions. In high rainfall areas, the presence of such layers at shallow depth reduces the water storage capacity of the soil with the result that runoff starts even after a short shower, which causes floods in low lying areas.

Management of physically constrained soils

In highly permeable coarse-textured sandy, loamy sand soils, the use of a roller to attain sub-surface compaction, the application of organic manures, pond sediments or mixing of clay decrease the bigger pores and increase the smaller pores. This reduces hydraulic conductivity and increase water retention which helps in enhancing the crop yields and water and nutrient use efficiency.

In the case of fine-textured slowly permeable soils, use of 'raised and sunken bed technology involving growing of upland crops in 20 cm high and 3 m wide raised beds adjacent to 20 cm deep and 6 m wide sunken beds growing rice crop is useful. The application of organic manure, crop rotation and use of phosphatic fertilizers are also useful for such soils.

For the management of soils having layers of high mechanical impedence at shallow depths such as plough soles or pans of clay accumulation in B-horizon, chiselling or profile modification of the dry soil up to 40-45 cm depth at 50-90 cm intervals are useful. The structural management of acid soils involves application of lime followed by organic manures. To improve the structure and reclaim highly dispersed sodic (alkali) soils, application of gypsum/pyrites in combination with organic manures, green manuring or incorporation of crop residues are successful.

The 'crop residue recycling technology' involving incorporation of high C:N ratio organic materials, viz. powdered groundnut shells or paddy husk has been recommended for management of red sandy loam 'Chalka' soils which become very hard on drying. The 'seed line mulch technology' involving application of FYM or wheat straw @ 25 q/ha on seed-lines immediately after sowing of pearl millet and cotton seeds has been useful for management of soils susceptible to form a crust.

Management of soil structure and enhancing and sustaining crop yields under rice-wheat cropping system in alluvial soils of Indo-Gangetic plains are formidable tasks. Recycling crop residues with conservation agriculture based management have been found beneficial for improving soil physical properties.

Soil aeration and plant growth

The soil aeration may have direct and indirect effects on activities of higher plants and soil micro-organisms. The level of soil aeration determines the forms of several inorganic elements, soil reactions, microbial decay of organic matter, symbiotic nitrogen fixation and, in turn, the soil properties and plant growth. The harmful effects of poor aeration are described below:

- The growth of plants, particularly the root growth, is adversely affected by poor aeration. Waterlogging for more than 48 hours at knee-high and tasseling growth stages may retard the growth of maize crop. In some cases, an abnormal development of roots may occur, e.g. the de-shaping of sugar beet and carrots.
- The absorption of nutrients and water gets reduced in poorly aerated soils.
- Under anaerobic conditions, the formation of inorganic compounds, which are toxic to plants, is favoured.
- The changes in soil oxygen content may affect the susceptibility of plant roots to diseases, the virulence of soil-borne disease organisms, or both, resulting in increased disease incidence.
- The absence of sufficient oxygen in soil affects the nitrogen fixation by Rhizobium.
- The soil organic matter cannot be decomposed properly by soil micro-organisms unless sufficient oxygen is present in the soil. If anaerobic bacteria decomposes soil organic matter, toxic substances like sulphides, methane, organic acids, etc., are liberated which are harmful for plant growth.
- In well aerated soils, the oxidized forms of most of the elements are present, e.g. nitrate-N. These are desirable for most common crops. The reduced forms, specifically of iron and manganese, may be present at toxic levels in the moist acidic soils.

Management of soil aeration for enhancing fertilizer use efficiency

The proportion of air-filled pore spaces and the ease with which exchange of gases can take place between atmospheric air and soil air influence the aeration status. The practices encouraging the air-filled pore spaces and the gaseous exchange may improve the aeration status. The variation in tendency of plant species to tolerate water stagnation/poor aeration can also be utilized to harness better crop yields from such soils. The soil aeration under field conditions can thus be optimized by the following methods:

- Improving soil structure: An increase in the volume of air-filled pores can be attained by improving soil structure. The practices that help in the maintenance of stable soil aggregates such as use of animal manure, green manure, plant residue manure and growing of legume crops, will, in turn, encourage better soil aeration.
- Drainage: An aerobic soil environment can be maintained by providing surface and or sub-surface drainage. The soil pores get filled with water due to continuous seepage from canals, presence of perched or high water tables, and after heavy rains or irrigation. The drainage of such fields is essential for the supply of sufficient oxygen.
- Cultivation: A light cultivation of soil or inter-culture operation does not only control weeds but helps in the exchange of gases, specially in heavy textured poorly drained soils. After rains, an impermeable layer/crust is formed at the soil surface that hinders the gaseous exchange. A light cultivation will break it and help in improving soil aeration.
- Plant adaptations: Plant roots, in general, are adapted to aerobic respiration. However, some of the plant species develop mechanisms such as increase in the air space of roots (root porosity) or internal aeration through leaves and cortex cells and thereby can grow even in oxygen-deficient soils. The selection of crop species, therefore, is important for growing crops in waterlogged or poorly drained soils. For example, rice thrives well in submerged soil conditions. Also, soybean crop can tolerate temporarily waterlogged soil conditions better than maize, pigeonpea and other deep rooted crops.

Soil temperature and plant growth

Soil temperature influences the plant growth only indirectly, by affecting the physical, chemical and biological processes in soil and plants. Soil temperature influences the cell activity, biochemical reactions and physiological processes necessary for the overall growth and development of a plant. Seeds of most of the crop species germinate within a reasonable time between, 10 and 35°C. Unfavourable temperatures prevent the emergence of many tender seedlings.

Some plant species are adapted to low temperatures only while some are adapted to high temperatures. At higher soil temperatures, the roots of low-temperature crops start decaying and are damaged by soil organisms and plant diseases but the reverse is not true for high temperature crop. The temperature optima for root growth of most crop species is between 20 and 25°C. The optimum temperature for the root growth is often lower than for shoot growth. The optimum temperature for the activity of most of the micro-organisms is between 25 and 35°C. A low temperature produces toxic substances which are injurious to plants, whereas a high decomposition rate at optimum temperature usually results into the products which are beneficial to plants.

For many crops, particularly cereals, the shoot meristem, which is the site of temperature perception, lies below the soil surface for an appreciable period. The plant growth is initiated only when the minimum (or base) temperature is reached and the rate of growth increases up to the optimum temperature followed by a decline at the maximum tolerable temperature. The minimum and maximum temperatures differ in different crop species and at different stages of crop growth.

Management of soil temperature for enhancing fertilizer use efficiency

The primary source of heat energy to soil being the sun, practices encouraging the heat absorption and the flow in soil and those discouraging heat loss to the atmosphere would help in heat storage and temperature rise. The soil temperature under field conditions can thus be altered by mulching and vegetation, tillage, compaction, irrigation and drainage.

- Mulching and vegetation: Mulches, such as straw, tend to buffer the extremes in soil temperature. Mulching with the polyethylene sheets raises the soil temperature during the day. Mulches also conserve soil moisture. A polyethylene film laid on a soil surface is transparent only to the incoming radiations. The outgoing radiation is inhibited due to the condensation of water vapour and the presence of dust particles on soil side of the polythene surface. The vegetation, like straw mulch also intercepts both the incoming as well as the outgoing radiation from soil and therefore, reduces the temperature fluctuations. The overall effect depends on the proportion of shaded soil. Air temperature above a crop is lower than at the surface of soil on a clear night. Soil under vegetation warms up more slowly in winter than a bare soil. A soil under a dense vegetative canopy may remain at a uniform temperature in surface layers.
- Tillage: Tillage of any kind affects the pore-size distribution and wetness and consequently the soil temperature. The tillage forming ridges often creates a range of soil temperature regime. Rapid changes in soil temperature are observed on ridges, whereas furrows are generally cooler. In poorly drained soils, ridging improves the soil aeration. A tilled-surface soil is generally warmer during the day time because of its higher porosity and low thermal conductivity than a compacted untilled soil.
- Soil compaction: Compaction in soil brings its particles closer and regulates temperature in the root zone. The abrupt changes in soil temperature, as observed in the surface layers of a loose soil, do not occur in a compact soil due to its high thermal conductivity. The soil compaction under field conditions is often achieved using a tractor or bullock drawn roller.
- Irrigation and drainage: The soil water controls absorption of solar radiation, loss of heat energy to the atmosphere, and movement of heat in soil. Water resists changes in soil temperature because of its high specific heat and high heat of vaporization. A wet soil conducts heat faster than dry soil and therefore, temperature fluctuations in the surface layers are rapid and approach extreme values easily in drier soils than in wetter soils. The dry soils prevent heat flow and encourage temperature fluctuations. The rising of soil temperature by draining of waterlogged fields and stabilizing soil temperature by irrigating dry fields are the common practices used by farmers. Irrigation reduces both rise and fall of soil temperature due to high heat capacity of water and evaporative cooling. The irrigation in summer causes large evaporative cooling of the surface soil.

Practices to increase input use efficiency

Some of the practices which interact with nutrients for their effect on crop performance by affecting nutrient-water dynamics and root proliferation in soil include tillage, water management and mulching.

- Favourable effects of INM strategies are well documented in sugar cane (Babu et al 2007), rice-wheat (Aulakh et al 2000, Yadvinder-Singh et al 2004), soybean-wheat (Hati et al. 2008), and intensive cultivation of 100 years (Anderson et al 1990). Amongst various soil physical properties, aggregate stability (Thakuria et al 2009, Bossuyt et al 2001), infiltration and water transmission properties (Franzluebbers 2002) are the most sensitive to INM practices. Availability of large quantities of farm yard manure for INM is considered as a major hurdle in promoting INM programmes on mega-scales. But the FYM requirements can be supplemented with other organic materials. Encouraging results have been obtained with organic amendments (Zebarth et al 1999), town waste (Aggelides and Londra 2000), animal manures (Schjonning et al 1994) and crop residues (Skidmore et al 1986).

- Tillage influences nutrient use efficiency by affecting the availability and utilization of native and applied nutrients through its effect on soil environment and depth and density of rooting. Deep and dense rooting induced by deep tillage of low organic matter, structurally unstable loamy sand and sandy loam soils resulting in greater N uptake by corn and thus reduced the residual nitrate in the root zone. On very low water retentive sand soil, tillage effects on nitrogen use efficiency is also governed by frequency of irrigation.
- Water is a key element to influence transformation, transport and absorption of nutrients in soil-plant system. In fact, water and nutrients have been reported to exhibit strong interaction for their effect in crop growth and yield. There is interdependence between N and water for their effect on crop growth. Nitrogen use efficiency in wheat decreased with successive increase in N rates, more so on low water retentive loamy sand than relatively low water retentive sandy loam.
- Interestingly on loamy sand at 80 Kg N ha^{-1}, NUE increased with increase in water supply upto 200 mm. At 120 Kg N ha^{-1} NUE did not increase with water supply upto 125 mm but showed marked improvement at 200 mm. It shows that for higher N use efficiency, there is need to match the supply of these two important production inputs.
- Application of water and nitrogen should be in concert to ensure minimum losses of nitrogen from the profile and to maximize its uptake by the crop. On low Water retentive highly permeable loamy sand maximum wheat yield with 150 Kg N ha^{-1} in three splits was obtained when 360 mm of water was applied in seven splits. Application of 360 mm water in four splits and 150 kg N ha^{-1} at seeding resulted in the lowest yield. Heavy irrigation and lesser splits of N caused loss of N through leaching.
- In arid and semi-arid environments in well drained soils, crops generally suffer from water and thermal stress. In these areas, post sowing residue mulching has been found to increase nutrient use efficiency by modifying hydrothermal regime, which enhanced mineralization of N and promoted root growth. Straw mulching of corn on a sandy loam soil increased the dry forage yield by 13 per cent. It was because increase in N and P uptake was 43 and 13 per cent respectively.

Way forward

Increasing input use efficiency and lowering cost of production is a big challenge to agricultural scientists. Limited availability and high costs of the three vital inputs in agriculture viz., water, fertilizer and energy demand their rational and sustainable use. Soil-water-plant relationships play an important role in determining the input use efficiency of these vital inputs and it is, therefore, important that the management practices that moderate and modify these relationships are evaluated and understood in great depth and dimensions. It is important to prepare an inventory and mapping of soil-water relations of different agro-climatic situations and soil types, water and nutrient losses and associated changes in physical properties in different land management practices. Models need to be developed/calibrated for better understanding of soil-water-tillage-nutrient-plant interactions with respect to input use efficiency of water, nutrient and energy. There is a need to evaluate crop specific conservation tillage (zero/minimum tillage with surface retention of available residues as mulch) technology with different levels of water and nutrients vis-à-vis methods of water and nutrients application to ensure resource conservation and high input use efficiency. Role of organic mulches and plastic mulching in resource conservation ensuring productivity and quality of the produce in higher water and nutrients requiring cash crops need to be evaluated. Indigenous moisture conservation and nutrient management practices blended with modern scientific knowledge need evaluation in developing location specific technologies to achieve higher use efficiency of costly inputs.

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4.4 Conservation Agriculture and Soil Health vis-à-vis Nutrient Management: What is Business Unusual?

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Introduction

The challenges for agricultural scientists, farmers and policy planners for sustainable increase in food production to meet future food security needs are quite different and complex compared to that of pre-Green Revolution era. Nearly 94% of the agriculturally suitable land in South Asia is already under cultivation with limited scope for further horizontal expansion except rehabilitation of degraded land. Hence, the pressure on land will increase to produce more from the same area under cultivation.

During past half century, the transformation of agriculture from 'traditional animal based subsistence' to 'intensive chemical and machinery based' production paradigm have though led to multifold increase in food production but also multiple problems associated with sustainability of natural resources especially deterioration in soil health. The soil organic carbon (SOC) contents in most cultivated soils of India is less than 5 g/kg compared with 15-20 g/kg in uncultivated virgin soils (Bhattacharyya, et al., 2000), attributed mainly to intensive tillage, removal/burning of crop residues, mining of soil fertility and intensive monotonous cropping systems. Large acreage of cultivated lands shows fertility fatigue and multiple nutrients deficiency in many intensively cropped areas of the region. This adds to our challenge of making farming more profitable and resilient for future food security. For example, during last five decades nutrient use in India has increased by 1573% with only 125% increase in food grain yield. Therefore, the use efficiency of inputs particularly nutrients has been declining at faster rate, posing a threat to future food security and environmental sustainability. In addition, still there exist large 'management yield gaps' in India ranging from 14 to 47%, 18 to 70% and 36 to 77% in wheat, rice and maize, respectively, significant portion of which is attributed to nutrient management (Jat et al; 2011).

The non-sustainability of agricultural systems is primarily governed by 3 key factors (i) soil erosion, (ii) soil organic matter decline and (iii) salinization; and all are related to soil health. These problems are mainly caused by (i) tillage induced soil organic matter decline, soil structural degradation, water and wind erosion, reduced water infiltration rates, surface sealing and crusting, soil compaction, (ii) insufficient or non-return of organic materials and (iii) mono cropping in addition to other associated factors of water, labour and energy shortages and emerging challenges of climatic change induced weather variability. Therefore, we need to take immediate actions to take out the unsustainable elements of conventional agriculture systems such as intensive tillage, removing all the crop residues/non-return of organic material to the soils and monoculture. Simple step to eliminate the non-sustainable components of conventional tillage (CT) based agriculture, will result into Conservation Agriculture (CA). The CA based on 3 key and interrelated principles (minimal disturbance of soil, rational organic soil cover and efficient and viable crop rotations) is a resource-saving and production optimizing agricultural system that aims to achieve sustainable intensification while enhancing economic profits, improve natural resources and efficiency of external production inputs with environmental stewardship. CA principles are universally applicable to all agricultural landscapes, and land uses, with locally formulated adapted practices. With farm-typology specific adaptations and refinements, the CA systems have worked in all kind of environments/ecologies (Derpsch et al., 2010) and adopted over 11% of the global crop land and helped millions of farmers through arresting land degradation, improve input use efficiency, adapt and mitigate climatic extremes, and improve farm profitability (Kasam et al, 2014). CA based management practices have been practiced in over 2 million ha of irrigated intensive as well as rainfed extensive production ecologies of India and have paid dividends to farmers, small scale entrepreneurs and policy planners. Science based scalable evidence on CA revealed high rate of returns over investments, adaptation to climate risks, improved use efficiency of precious water, nutrient, energy, labour resources and reduced environmental footprints of food production compared to conventional tillage based practices.

Conservation agriculture and soil health

Understanding the continued capacity of soil to function as a vital living system, by recognizing that it contains biological elements critical to ecosystem function within land-use boundaries is important. These functions are able to sustain biological productivity of soil, maintain or enhance water and air quality, as well as promote plant, animal, and human health. To define this, the terms soil quality and soil health are used interchangeably although it is important to distinguish that, soil quality is related to soil function, whereas soil health presents the soil as a finite non-renewable and dynamic living resource. Soil health is an integrated function of biological, chemical and physical properties of soil. Healthy soils maintain a diverse community of soil organisms that help to control plant disease, insect and weed pests, form beneficial symbiotic associations with plant roots (e.g., nitrogen-fixing bacteria and mycorrhizal fungi); recycle essential plant nutrients; improve soil structure with positive repercussions for soil water and nutrient holding capacity, and ultimately improve crop production. To produce enough food to keep pace with growing population, maintaining soil health is important. The food production is the end product of soil degradative or conserving processes and is controlled by chemical, physical, and biological components of a soil and their interactions. The CA (as defined above) is not a single technology, but a direction towards sustaining soil health and other natural resources following key elements having flexibility in their applications suited to specific production systems, ecologies and farmer circumstances and have short to long-term benefits to ecosystem and farmers. Jat et al (2014) reviewed the role of Conservation Agriculture based management practices on soil health using published literature of large number of on-station as well as on-farm experimentations across range of soil types, cropping systems and agro-ecologies of India. They suggested that under most cases, CA based management practices led to significant improvement in physical, chemical and biological properties of the soils. However, the degree of improvement varies with different factors particularly recycling of residues and duration of CA.

Conservation agriculture, soil health vis-a-vis nutrient management

Traditionally, farmers in India as well as other South Asian nations apply fertilizer nutrients based on ad-hoc blanket recommendation for large area. Many farmers often use uniform rates of fertilizers that could be inconsistent from field-to-field and year-to-year depending on factors that are difficult to predict prior to fertilizer application and also no matter what crop management practices they have adopted. Also, farmers often apply fertilizer nutrient in doses much higher than the blanket recommendations to ensure high crop yields. Large temporal and spatial variability of soil nutrient supply restricts efficient use of fertilizer nutrients when broad based blanket recommendations are used even under contrasting management scenario. This leads to sub-optimal crop yields, low nutrient use efficiency, lower economic profitability and greater environmental footprints. Under such situations, in season site-specific nutrient management can effectively replace the blanket fertilizer nutrient recommendations for achieving high nutrient-use efficiency, economic profitability with lower environmental footprints. With 84% or more operational land holdings in India having less than 2 ha (remaining 10-15% up to 10 ha), it seems that high fertilizer nutrient-use efficiency can be achieved through field-specific fertilizer nutrient management considering both spatial and temporal variability in soil nutrient supply. However, quantifying the spatial and temporal variability of soil properties at scale using soil test based approach seems a wearisome task keeping in view of number of holdings and available resources in the region. However, the national mission on soil health launched by Government of India is welcome step in this direction. However, capturing temporal variability created due to contrasting management by the farmers and account that in fertilizer nutrient recommendations has to go a long way. Large studies on CA based system across a range of geographies suggests positive effects on soil health over a period of time and hence the fertilizer nutrient prescriptions has to be dynamic under those situations. Also, its just not only the rate of fertilizer nutrient application but method and time of application having congruence with soil moisture has to do a lot for improving efficiency as well as soil health. The changes in physical and biological properties of the soil associated with CA practices are expected to modify the direction and kinetics of the chemical and biochemical processes significantly affecting nutrient dynamics in the soil. Therefore, we need to have a paradigm shift in fertilizer nutrient management strategies (rate, time, method) under CA when we move from conventional tillage based management. In this paper, we attempted to provide evidence which suggests that we need a 'business unusual approach' for nutrient management when we move from CT to CA based production.

Way forward

CA with layering of adapted component technologies especially nutrient and water relevant to local circumstances can serve the foundation for our goal of improving soil health for resilient farming and future food security. However, business as usual approach may not help us meeting the goals and warrants following strategies for capitalizing the synergies in positive role of different elements of CA on soil health and efficient nutrient management practices relevant to those circumstances.

- Take a stock of the available technologies/practices for CA and nutrient management adapted to different production systems and define their recommendation domains for scaling and impact on smallholder farming systems.
- The innovation platform on CA with component technologies for nutrient and water management should have a continuum of 'strategic-applied research-capacity development-delivery'.
- Capture farmer innovations on CA and align them with scientific validation and refinements through participatory action research on layering efficient nutrient (and water) management portfolios for CA based production systems, for example, aligning 4R nutrient stewardship with CA and micro-irrigation.
- Create evidence base on complementarity of CA based systems with efficient nutrient management as indicators of improved soil health, food security, income and livelihoods over conventional farming practices and define their recommendation domains.
- Analyse adoption pattern and behavioural change of farmers under different farm typologies to understand adoption of CA in isolation vis-à-vis layered with precision nutrient and water management.
- Strengthen institutional arrangements and enabling policy environments for scaling CA systems through establishing a 'Farmer Centric' consortium of active and complementing stakeholders.
- Enhance capacity of stakeholders especially rural youth and women.
- Develop and demonstrate CA system led business cases to engage rural youth for scaling CA based innovation.

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5. Recent Advances in Nutrient Management

5.1 Fertilizer Policy and Nutrient Management: How to Connect?

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Introduction

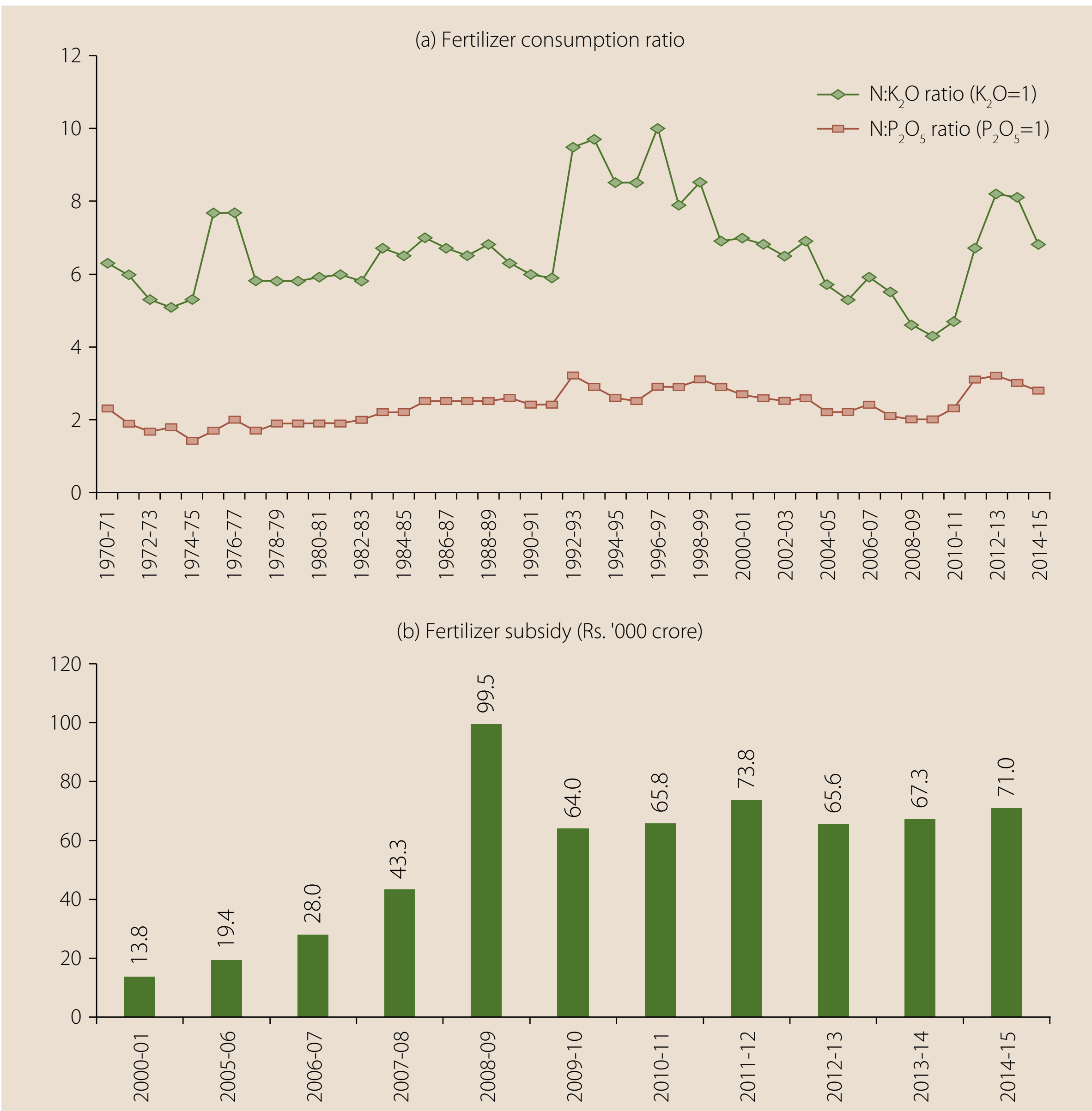
Soil fertility deterioration mainly due to excessive removal of nutrients by crops and their inadequate replenishment is considered one of the major constraints in attaining and sustaining high productivity. As a consequence of excessive nutrient mixing, widespread deficiencies of at least six nutrients viz. N, P, K, S, Zn and B have been recorded in Indian soils (Dwivedi, 2014). Unless plant nutrients are supplied in adequate quantities and balanced proportions, there will be much greater drain of native nutrients and the soil may not be able to support high yield, anymore in the times to come. There are adequate evidences to support that (i) crop nutrient demands could not be solely met through fertilizers, as an estimated annual gap of about 10 mt exists between nutrient removal and supply through fertilizers, and (ii) integrated nutrient supply through conjoint use of fertilizers and other nutrient sources of organic and biological origin is the best nutrient management strategy. Nonetheless, fertilizers remained major nutrient supplements in past half-century, and would continue to be so in the foreseeable future. Hence, fertilizer policies are inseparably linked with nutrient management, and any change brought in the former is likely to affect not only the rate and proportion of fertilizer input, but also nutrient use efficiency and overall economic returns. It is, therefore, imperative to understand as to what extent the recent change in fertilizer policies affected nutrient management, and suggest the way forward to ensure balanced and efficient use of fertilizers.

Fertilizer policies vis-à-vis nutrient management

The sale, price and quality of fertilizers is regulated under Fertilizer (Control) Order, popularly called FCO. With retention pricing scheme (RPS) implemented way back in 1977, fertilizer production and consumption increased significantly, although subsidy bill also increased simultaneously (Satish Chander, 2013) due to continuous rise in fertilizer production costs and relatively slow change in government controlled retail price of fertilizers. As there was abysmal investment in the fertilizer industry with less scope for any innovation, the need for policy reforms was badly felt. One of the major reforms took place in April 2010 with the introduction of nutrient-based subsidy (NBS), wherein the subsidy on P and K fertilizers was fixed annually, and the MRP was market-driven. Urea which constitutes more than half of the total fertilizer products used in the country, however, continues to be out of the ambit of NBS. With the implementation of NBS, the fertilizer subsidy load on the exchequer got reduced significantly from Rs. 99.5 thousand crores in 2008-09 to 71.0 thousand crores in 2014-15 (Fig. 5.1a). However, NBS had two apparent adverse implications. First, the retail price of urea (excluded from NBS) changed only marginally, whereas the prices of P and K fertilizers increased substantially during post-NBS period, resulting in widening of fertilizer (N: P_2O5: K_2O) consumption ratio from 4.3:2.1:1 in 2009-10 to 6.8:2.4:1 in 2014-15 (Fig. 5.1b). Second, total fertilizer consumption as well as intensity of fertilizer use (kg/ha) has come down drastically. Fertilizer consumption was 28.1 mt (141 kg/ha) during 2010-11 which was reduced to 24.5 mt (126 kg/ha) during 2013-14. There has been some improvement in fertilizer consumption during 2014-15, i.e. 25.6 mt (136 kg/ha).

Implementation of fractured NBS is often argued as the major cause of distortion in fertilizer consumption ratio and fall in consumption; and bringing urea under NBS is advocated as the sole solution to these problems. It is said that farmers use urea in excessive amount due to its cheaper price. These arguments need to be analyzed in the light of fertilizer consumption statistics (FAI, 2015). During the period 2010-11 and 2013-14, the consumption of N increased by 2.8% only, whereas P and K consumption registered a decrease of 24 and 29%, respectively. This suggests the decrease in P and K consumption owing to

Figure 5.1: Fertilizer subsidy and consumption ratio in India



exorbitant price as the major cause for distortion of fertilizer consumption ratio. Bringing urea under NBS may of course help narrowing the consumption ratio, owing to fall in N consumption (as happened in case of P and K). As Indian soils are universally deficient in N and also inherently low in N supplying capacity, the fall out of decreased N consumption on foodgrain production can be very well understood. The farm-level nutrient management should obviously consider both total amount of fertilizer use and ratio. Inclusion of urea in NBS may, therefore, be considered in a phased manner.

Neem oil coating of urea to the extent of 20% of total production was introduced in 2010, and then up to 35% in 2011. From this year (2015), neem oil coating has been made mandatory for 100% of the indigenous urea production. This policy reform is likely to have far reaching effect on N management, as the advantage of neem oil coating on N use efficiency is well-documented. Besides, neem coating would also prevent any possible misuse of urea for industrial or non-agricultural purposes. New Urea Policy-2015, New Investment Policy (NIP)-2012, promotion of water soluble fertilizers and customized fertilizers, and coating/fortification with secondary and micronutrients are other important policies that directly or indirectly affect nutrient management.

Way forward

- Bring urea under NBS in phased manner only; also extend NBS to micronutrients.
- Enhance investment in fertilizer product research in order to develop sustained release/smart fertilizers with high nutrient use efficiency, and reduce dependence on conventional fertilizers, i.e., urea, DAP and MOP.
- Evaluate the significance/utility of customized fertilizers with respect to their grades, variation in soil fertility in recommendation domains and economic returns.
- Mechanism for inclusion of fertilizers in FCO needs a fresh look in view of availability of only few products in the market despite listing of more than 100 fertilizers in FCO.
- Ensure timely availability of required fertilizers in adequate amounts for balanced fertilization.

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5.2 Soil Test Crop Response: What Can Be Learnt?

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Introduction

Ensuring food security for burgeoning population necessitates the production of additional food grain from the same land without losing the production potential of the soil. This, in turn, requires extensive research to provide a scientific basis for enhancing and sustaining food production as well as soil productivity with minimum environmental degradation. Balanced nutrition does not mean the application of nitrogen, phosphorus and potassium alone in certain proportion through fertilizer, but it should ensure that the nutrients in available forms are in adequate quantity and in required proportion in the soil to meet the requirement of the crops for obtaining the desired levels of yield. Nutrients available in soil are rarely present in adequate amounts and in balanced proportion to meet the nutrient requirement of the crops. In order to attain this it is essential that the amount of nutrients removed from the soil should be replenished through judicious use of fertilizers and manures. This needs a more comprehensive approach for fertilizer use, incorporating components like soil test, field research and economic evaluation of the results. Soil test provides the requisite information about the amounts of nutrients available in the soil and their imbalances, while fertilizer recommendations aim at correcting the imbalances in nutrients according to crop requirements.

Liebig's law of minimum states that the growth of plants is limited by the plant nutrient element present in the smallest amount, all others being in adequate quantities. From this, it follows that a given amount of a soil nutrient is sufficient for any one yield of a given percentage nutrient composition. Ramamoorthy and his co-workers in the year 1967 established the theoretical basis and experimental proof for the fact that Liebig's law of the minimum operates equally well for N, P and K. This forms the basis for fertilizer application for targeted yields, first advocated by Truog in the year 1960. Among the various methods of fertilizer recommendation, the one based on yield targeting is unique in the sense that this method not only indicates soil test based fertilizer dose but also the level of yield the farmer can hope to achieve if good agronomic practices are followed in raising the crop.

The fertilizer recommendations based on qualitative/semi-quantitative approaches or methods do not give expected yield responses. Therefore, inductive approach, a refined method of fertilizer recommendation for varying soil test values has been developed by All India Coordinated Research Project Soil Test Crop Response (AICRP-STCR) for different crops under different agro-ecological sub-regions. Soil Test Crop Response studies have used the targeted yield approach to develop relationship between crop yield on the one hand, and soil test estimates and fertilizer inputs, on the other. Considerable agronomic and economic benefits were accrued when farmers applied fertilizer nutrient doses based on soil test. Lately, the calibrations are being developed under integrated supply of organics and fertilizers keeping into account the nutrient contribution of organics, soil and fertilizers. The technology of fertilizing the crops based on initial soil test values for the whole cropping system is also being generated. Studies on soil biological parameters in guar-wheat cropping system under arid condition revealed that soil microbial biomass, dehydrogenase activity and organic carbon was higher in STCR based nutrient application as compared to general fertilizer recommendations. Ready reckoners in the form of fertilizer prescription equations have been developed by different centres for facilitating users for profitable use of fertilizers based on soil test values and the same has been demonstrated through various multi-location/verification follow up trials as well as frontline demonstrations. In these trials soil test based rates of fertilizer application helped to obtain higher response ratios and benefit: cost ratios (Table 5.1) over a wide range of agro-ecological regions (Dey and Srivastava, 2013). It is evident from above tables that STCR based approach of nutrient application has definite advantage in terms of increasing nutrient response ratio over general recommended dose of nutrient application. Front Line Demonstrations conducted under Tribal Sub Plan (TSP) in Assam, Bihar, Chhattisgarh, Gujarat, Himachal Pradesh, Jammu & Kashmir, Jharkhand, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Manipur, Odisha, Rajasthan, Tamil Nadu, Telangana, Uttar Pradesh and West Bengal with tribal farmers' also clearly brought out the superiority of STCR-based fertilizer recommendation for different crops over blanket recommendation and farmer's practice.

Economic analysis of fertilizer doses associated with different yield targets

An appraisal of the effect of nutrients (NPK) applied on crop yield and benefit: cost ratios (BCR), both under (NPK) alone and under IPNS for 15 agricultural and horticultural crops (Dey and Santhi, 2014) showed that out of 66 crop x target combinations, the BCR was between 1 and 2 in 35% cases and between 2.1 and 3.0 in 62% cases. In 3% cases BCR was above 3. Irrespective of the crops, higher yield has been recorded at higher yield targets over lower target coupled with higher net return and BCR. As in the case of yield, wherever three targets (low, medium and high) were tried, the BCR was relatively higher between low and medium target levels then between medium and high target levels both under NPK alone and IPNS. Again, irrespective of the crops and yield targets, yield increase was higher with IPNS then under NPK applied through fertilizers alone. In this regard, farmers can choose the desired yield targets according to their investment capabilities and availability of organic manures but would generally benefit from adopting an appropriate IPNS package as apart from contributing nutrients, organic manures also improve soil physical conditions. At present, the soil test based recommendations are relatively on a stronger footing when these involve only fertilizers as compared to IPNS. This is because there are several issues concerning the nutrient which need to be sorted out as illustrated using STCR information from Andhra Pradesh. One of the outstanding problems is that while the composition of fertilizers is fairly standard, that of organic manures can vary several-fold even within the same location or form lot to lot.

Fertilizer recommendations for fixed cost of investment and allocation under resource constraints

A new dimension to the value of the utility of soil testing has been added by the concept of fertilizer application for targeted yield demonstration in farmers' fields by choosing the yield target at such a level so that the cost of fertilizer requirement becomes more or less same as what was being practiced by farmers already. When fertilizer availability is limited or the resources of the farmers are also limited, planning for moderate yield targets which are, at the same time, higher than the yield levels normally obtained by the farmer provides means, far saturating mare areas with the available fertilizers and ensuring increased total production also.

New initiatives

Of late, STCR has developed algorithms of leaf colour chart, SPAD and fieldscout CM 1000 meter values at three critical growth stages with yield in rice-wheat system; also developed fertilizer prescription equation for hitherto untouched secondary nutrient (sulphur). Besides, soil testing protocol for organic farming system including characterization and quantification of microbiologically exploited organic phosphorus-pools in organic farming systems has been developed.

Expert systems developed by AICRP (STCR)

An expert system developed in collaboration with NIC, Pune which calculates the amount of nutrients required for specific yield targets of crops based on farmers' soil fertility (Majumdar et al. 2014). It is accessible on Internet (http://www.stcr.gov.in/). Also developed a Decision Support System for Integrated Fertilizer Recommendation (DSSIFER 2010) for Tamil Nadu state encompassing soil test and target based fertilizer recommendations through Integrated Plant Nutrition System. Using this software, fertilizers doses can be prescribed for about 1645 situations and for 190 agricultural and horticultural crops along with fertilization schedule. If site specific soil test values are not available, data base included in the software on village fertility indices of all the districts of Tamil Nadu will generate soil test based fertilizer recommendation. Besides, farmers' resource based fertilizer prescriptions can also be computed.

Way forward

- STCR recommendations for drip fertigation for enhancing nutrient use efficiency.
- Anomalous potassium response in Vertisols of India: Accounting contribution of non-exchangeable-K.
- Development of DSS by integrating GPS/GIS-based soil fertility maps with STCR prescription equations.
- Development of universal extractant/method and its calibration for target yields of different crops.
- Use of STCR prescription equation for development of customized fertilizers.

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Table 5.1: Response Ratios (RR) in existing and improved practice for different crops at different sites in India: Results from AICRP on STCR

Crop	Location/AER	Soil type	Fertilizer Response Ratio (kg grain/kg nutrient)			
			Present practice		Improved practice	
			Fertilizer dose	RR	Fertilizer dose	RR
Rice	Coimbatore/8.1, Hot dry semi-arid	Alfisol	GRD: 120-38-38	15.4	STCR: 7 t/ha 179-71-19	16.1
Rice	Hisar, Haryana/ 2.3 Hot typic arid	Podzolic	Farmers' Practice 75-30-0	18.31[2]	STCR: 7 t/ha 139-63	23.49[2]
Rice	Jabalpur/ 10 Hot sub-humid	Medium black	GRD: 80-70-40	8.47	STCR: 3.5 t/ha 76-66-0	11.13
Rice	Kalyani, WB/ 15.1 Hot moist sub-humid	Deep loamy to clayey alluvial	80-40-40	8.02	Soil test based 62.5-28-62 + 7.5 t/ha FYM	13.19
Rice	Narsinghpur, MP		GRD: 80-70-40	11.45**	STCR: 4 t/ha 91-74-0	19.07**
Rice	Pantnagar, Uttaranchal/14.5 Warm humid/perhumid	Medium to deep loamy tarai	Farmers' Practice 120-0-0 GRD: 120-40-40	12.5 8.5	STCR: 4.0 t/ha 94-36-0	16.15

Contd...

Crop	Location/AER	Soil type	Fertilizer Response Ratio (kg grain/kg nutrient)			
			Present practice		Improved practice	
			Fertilizer dose	RR	Fertilizer dose	RR
Wheat	Jabalpur, MP/10 Hot sub-humid	Medium black	GRD: 100-60-30	14.77**	STCR: 4 t/ha 59-57-28	41.01**
Wheat	Palampur, HP***/14.3 Warm humid to per humid transitional	Podzolic	Farmers' Practice 30-0-0 GRD: 120-60-30	14.83 3.52	STCR: 4.0 t/ha 176-187-75	6.95
Wheat	Pantnagar, Uttaranchal/14.5 Warm humid/perhumid	Medium to deep loamy tarai	GRD: 120-60-40 Farmers' Practice 115-20-0	10.68 6.67	STCR: 4.0 t/ha 104-60-57	11.31
Finger millet	Kolhapur, Maharashtra Rainfed submontain zone	Black soil	GRD: 60-30-0	10.1	STCR: 1.6 t/ha 45-34-17	10.9
Maize	Palampur, HP***/14.3 Warm humid to per humid transitional	Podzolic	Farmers' Practice 40-0-0 GRD: 120-60-40	13.1 7.14	STCR: 4.0 t/ha 189-0-73	8.91
Chickpea	Durg, Chhattisgarh/11 Hot/moist/dry sub humid transitional	Vertisol	Farmers' Practice 10-30-0 GRD: 20-50-20	2.78 2.76	STCR: 1.2 t/ha 20-0-0	7.90
Chickpea	Jabalpur/ 10 Hot sub-humid	Medium black	GRD: 20-60-20	9.00	STCR: 1.5 t/ha 22-36-0	12.76
Urid	Jabalpur/ 10 Hot sub-humid	Medium black	GRD: 20-50-20	0.361** (Mean of three trials)	STCR: 1.2 t/ha 25-35-0	0.464**
Groundnut	Coimbatore, north western zone of TN/8.1, Hot dry semi-arid	Red soil, Irugur series	GRD: 18-36-54	4.62	STCR: 2.5 t/ha 55-55-71 STCR: 2.5 t/ha with 12.5 t/ha FYM 17-37-31	5.5 5.92
Groundnut	Kakapalayam, TN/8.1, Hot dry semi-arid	Red soil, Irugur series	GRD: 18-36-54	6.7	STCR: 2.5 t/ha 50-43-72 STCR: 2.5 t/ha with 12.5 t/ha FYM 15-25-32	6.9 7.4

Contd...

Crop	Location/AER	Soil type	Fertilizer Response Ratio (kg grain/kg nutrient)			
			Present practice		Improved practice	
			Fertilizer dose	RR	Fertilizer dose	RR
Groundnut	Kolhapur, Maharashtra	Typic haplustert	GRD: 25-50-0	20.9	STCR: 2.5 t/ha 55-62-24	13.8
Groundnut	Tumkur, Karnataka		GRD: 25-75-38	5.50	STCR: 2.0 t/ha 16-144-53	6.20
Linseed	Jabalpur, MP/10 Hot sub-humid	Medium black	GRD: 60-40-20	5.21	STCR: 2.0 t/ha 89-51-19	8.29
Mustard	Durg, Chhattisgarh	Vertisol	Farmers' Practice 60-40-0 GRD: 120-80-40	2.71 6.53	STCR: 1.3 t/ha 103-83-0	6
Mustard	Jabalpur, MP/10 Hot sub-humid	Medium black	GRD50-30-20	4.38	STCR: 1.6 t/ha 68-42-16	5.44
Mustard	Jabalpur/ 10 Hot sub-humid	Medium black	GRD: 50-30-20	2.29	STCR: 2 t/ha 88-46-35	2.34
Mustard	New Delhi/ 4.1 Hot semi-arid	Alluvial soils	Farmers' Practice 60-57-0 GRD: 80-40-40	6.4[1] 7.8[1]	STCR: 2.5 t/ha 90-43-48	8.6[1]
Onion	Coimbatore Tamil Nadu/ 8.1, Hot dry semi-arid	Red Inceptisols	FP: 80-80-60 GRD: 60-60-30	41.7 61.8	STCR: 20 t/ha: 118 to123-32 to 43 - 15 to 78	62.1
Raya	Hisar, Haryana/ 2.3 hot typic arid	Podzolic	Farmers' Practice GRD	3.0 3.9	STCR: 2.0 t/ha	5.0
Safflower	Bangalore, Karnataka/ 8.2 Hot moist semi arid	Black soil, sandy clay loam	GRD: 38-50-25	5.78	STCR: 1.5 t/ha 54-0-13	10.9
Soybean	Durg, Chhattisgarh/11 Hot/moist/dry sub humid transitional	Vertisol	Farmers' Practice 12-30-0 GRD: 20-50-20	20.2 15.0	STCR: 2.0 t/ha 20-35-0	20.1
Soybean	Jabalpur, MP/10 Hot sub-humid	Medium black	GRD: 20-80-20	8.28	STCR: 2.5 t/ha 15-52-0	13.77
Sunflower	Coimbatore, north western zone of TN/8.1, Hot dry semi-arid	Red soil, Irugur series	GRD: 60-40-40	4.34	STCR: 2.0 t/ha 87-63-13 STCR: 2.5 t/ha with 12.5 t/ha FYM 52-45-0	7.05 7.57

Contd...

Crop	Location/AER	Soil type	Fertilizer Response Ratio (kg grain/kg nutrient)			
			Present practice		Improved practice	
			Fertilizer dose	RR	Fertilizer dose	RR
Sunflower	Jabalpur/ 10 Hot sub-humid	Medium black	GRD: 80-40-25	4.31	STCR: 2 t/ha 197-27.4-0	5.10
Sunflower	Kalipalayam, TN/8.1, Hot dry semi-arid	Mixed black (Inceptisol)	FP: 50-40-50 GRD: 40-20-20	4.76 6.26	STCR: 2 t/ha 92-28-10 STCR: 2 t/ha with 12.5 t/ha FYM 62-13-5	6.86 7.33
Bhendi	Kalipalayam, TN/8.1, Hot dry semi-arid	Mixed black (Inceptisol)	FP: 100-60-60 GRD: 40-50-30	30.7 25.4	STCR: 1.5 t/ha 72-21-15	77.9
Bhendi	Suradevanapura, Bangalore/ 8.2 Hot moist semi-arid	Medium to deep red laom	125-62.5-62.5	17.88	STCR: 8 t/ha 91-74-56	24.25
Brinjal	Rahuri, Maharashtra/ 6.1 Hot dry semi-arid	Typic ustorthent	GRD: 150-75-75	73.3	STCR: 5 t/ha 140-20-110	124.9
Cabbage	Rahuri, Maharashtra/6.1 Hot dry semi-arid	Ustorthent	GRD: 180-80-60	6.88	STCR: 3.5 t/ha 256-129-193	5.33
Chilli	Thirumalayampalayam Madukarai Block. Coimbatore, TN/8.1, Hot dry semi-arid	Red Inceptisol	GRD: 75-35-35	3.7	STCR: 2 t/ha 108-62-68	4.1

IPNS = Integrated Plant Nutrient Supply; STCR = Soil Test Crop Response; * Higher yield obtained with lesser fertilizer dose than farmers' practice; ** Response ratio calculated over farmers' practice; [1] Average of two demonstrations; [2] Average of four demonstrations; *** In case of wheat and maize at Palampur the high response ratio in farmers' practice is due to very low rates of fertilizer application. Even though the response ratio is high the level of yields the farmers are getting is very poor. In STCR technology the response ratio is not as high as in farmers' practice but the yields are very good.

5.3 Advances in Precision Nutrient Management Decision Support: What are the BIG Gains?

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Introduction

Commercial fertilizer use is estimated to attribute half of the current crop production in the world. For sustainable access to food for an increasing population in the coming decades, crop production would have to increase on essentially the same or less land area, with less water, nutrients, fossil fuel, labour and as climate change. This requires that resources, including nutrients, have to be used in a precise manner to accommodate the growing demand for crop production without compromising the natural resources upon which agriculture depends. The increasing input cost, unavailability of labor, economic concerns associated with smallholder farming, and the growing popular consciousness on environmental footprint of intensive agriculture are also forcing stakeholders to look for precision approaches.

Farming in India is dominated by smallholder farmers, operating under a wide range of soil, bio-climate, and socio-economic conditions, where farm resource endowment plays a potentially important role in determining profitability of production systems (Banerjee et al., 2014). Development of such smallholder systems is strongly constrained by limited availability of key resources such as land, plant nutrients, water, cash, and labor. Interactions between these limiting resources can strongly influence the efficiency with which the resources are used. Typically, low resource availability to the farmers and low productivity of crops demand that inputs, including fertilizer, should be used in a precise manner to close the yield gap and maintain farm profitability in smallholder systems.

Relevance in Indian context

Scientists and policy-makers have time and again pointed out the significant decline in crop production per unit of fertilizer use in India. Conventional blanket fertilizer recommendation prevalent in the country, leading to imbalanced use of fertilizers and lower fertilizer use efficiency, has been identified as one of the main reasons. Its economic and environmental consequences are evident from long-term fertilizer experiments and other independent studies. Imbalanced fertilizer use has been associated with soil, air and water pollutions in numerous studies. However, connecting the soil nutrient status to soil health issues is less forthcoming. A recent study (Sanyal et al., 2014) highlighted the extent of nutrient mining in production systems around the country, and identified it as a potential soil health issue that is aggravated by blanket fertilizer application. The authors pointed out that the limitation imposed by inadequate nutrient status strips the soil off its "capacity to function or perform", and adequate availability of essential nutrients in the soil is critical for sustained soil health. Nutrient inadequacy and imbalance in the soils adversely affect the soil organic matter status, a critical soil health parameter. Besides it has a cascading effect on the air and water quality as a consequence of transformation and movements of nutrients that are essentially triggered by nutrient imbalances.

Way forward

The 4R Nutrient Stewardship Principles of applying the right source of plant nutrients at the right rate, at the right time, and in the right place is at the core of the precision nutrient management approach. The 4R Nutrient Stewardship provides the scientific principles that are the basis of applying balanced and adequate amounts of nutrients to crops, and also connects the outcome of crop nutrient management to social, economic and environmental sustainability of production systems. The principles are equally applicable at the broad acreage farms where sophisticated machinery is used for precision application of nutrients or in smallholder systems where fertilizer is manually mixed and applied by farmers in their small fields.

In the context of precision, there are options to fine-tune the 4Rs to match the site-specific requirements of a particular production system. For example, the choice of fertilizer sources needs to match the soil characteristics; nutrient application rates should match the crop requirement while factoring in the indigenous nutrient supply and crop yield target; time of fertilizer application must match crop physiological requirement to ensure high efficiency and to reduce possibility of nutrient losses; while placement of fertilizer should ensure that crop roots have easy access to the nutrients. The 4Rs are thus highly crop and location specific to target social, economic and environmental benefits out of a nutrient management protocol.

On-farm evidences of the benefits of such site and crop specific nutrient management protocols are providing guidance for large-scale precision nutrient management in smallholder systems. Soil fertility maps developed from geo-referenced soil sampling and analysis has helped researchers and extension agents optimize nutrient use in landscapes with high field-to-field nutrient variability (Chatterjee et al., 2015). Optical sensors have emerged on the agriculture scene in recent years as a means of making in-field adjustments of N application to crops as part of a split-N application program. While developed and implemented first under conditions of mechanized agriculture, the later low-cost variants of the optical sensors have been used effectively in smallholder systems to make split-N application decisions across variable landscapes (Bijay-Singh et al., 2015). Significant advances were also made in the field of smallholder farm machinery that is providing better control over the nutrient application methods in small farms. However, optimizing only one 'R' of the '4Rs' often does not achieve the desired benefit or outcome. The Nutrient Expert® tools for rice, wheat and maize developed by the International Plant Nutrition Institute (IPNI), jointly with the International Maize and Wheat Improvement Center (CIMMYT) and in collaboration with several NARES partners, are providing guidance to optimize source, rate, and time of fertilizer application to ensure significant improvement in yield and economics, with decreasing environmental footprint of fertilizer use in disparate geographies in China, Southeast Asia and India (Table 5.2). The Nutrient Expert® tools have been recommended by the Ministry of Agriculture, Government of India, as an ICT tool for site-specific nutrient recommendation in the centrally sponsored Soil Health Card Scheme (*www.argicoop.nic.in*).

The economic gain from precision nutrient management practices is quite obvious and apparent. Optimization of nutrient use either reduces the cost of production as in China (Table 5.2), or increases production as in India and South East Asian countries (Table 5.2), either way providing economic benefits to the farmers. We often, however, ignore its positive impacts on soil health through improved organic matter content and sustained soil fertility status that are critical for continued capacity of the soil to support plant growth. Experimental evidences have also shown that precision management of nutrients, through right source, rate, time and method of application can significantly reduce environmental footprint of agricultural nutrients (Sapkota et al., 2014).

The present talk at the National Dialogue on "Efficient Nutrient Management for Improving Soil Health" aims to highlight the importance of precision nutrient management to improve production economics of smallholder farmers, leading further to improved soil health, and overall social and environmental benefits to the society, especially in long-term agricultural production system.

Table 5.2: Nutrient Expert® tool-based location specific nutrient recommendation improved maize yield and farmer profitability in Asia

Parameters	Unit	Gains from Nutrient Expert® recommendations (NE-FFP)			
		India (n = 412)	Indonesia (n = 26)	Philippines (n = 190)	China (n = 541)
Grain yield	t/ha	+ 1.27***	+ 0.92 ***	+ 1.10 ***	+ 0.3 ns
Fertilizer N	kg/ha	– 6 ns	– 12 ns	+ 3 ns	– 72 ***
Fertilizer P_2O_5	kg/ha	– 16 ***	– 5 ns	+ 18 ***	– 6 ***
Fertilizer K_2O	kg/ha	+ 22 ***	+ 15 ***	+ 18 ***	+ 21 ***
Fertilizer cost	USD/ha	– 1 ns	+ 16 ns	+ 37 ***	– 38 ***
Gross profit	USD/ha	+ 256 ***	+ 234 ***	+ 267 ***	+ 129 ***

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5.4 Micronutrients Management: A Way Forward to Food and Nutritional Security and Human Health

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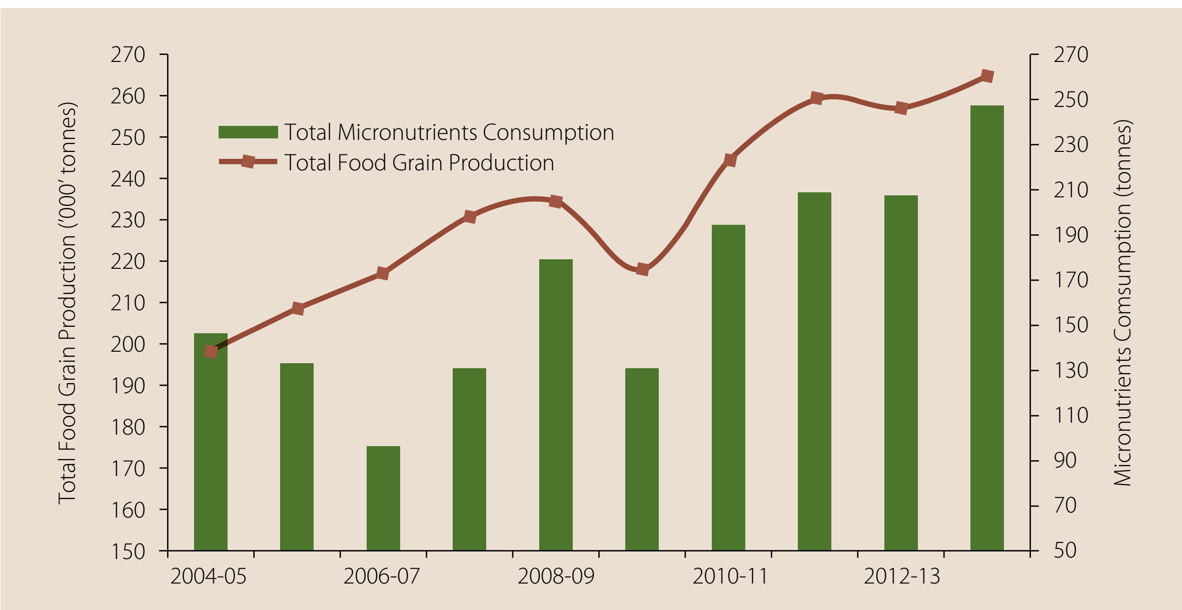
Introduction

Soils of India are generally poor in fertility, particularly in micronutrients. The intensification of agriculture, commonly referred as "Green Revolution" has made the country self-sufficient in food grain production to feed its burgeoning population but depleted the soil micronutrients reserve due to shipping away of micronutrients from limited soil nutrient stockpile of finite soil resource. Estimates suggest that at the current level of food grain production (263 Mt) about 188.4 thousand tonne micronutrients (Zn-23.9, Fe-110.6, Cu-37.4, Mn-63.3, B-9.2 and Mo-0.99) are removed annually. Such huge mining of nutrients over the years have been rendering the soils deficient in micronutrients across the country (Singh, 2008; Shukla et al, 2014). A recent analyses of 127751 geo-referenced soil samples collected across the country indicates that the deficiency of micronutrients (Zn-43.4%, Fe-14.4%, Cu-6.1%, Mn-7.9% and B-20.3%) is taking a toll on the food and economic security of the country in terms of the yield and economic losses due to unmatched yield goals. Since little scope exist for horizontal development of agriculture, thus, the future food, fruit, fodder, fiber, fuel requirement has to be met through vertical growth, i.e., increasing crop productivity per unit area. This would mean a further whooping nutrient mining pressure on the finite micronutrient soil resource that would cause the deficiency of other micronutrients to crop-up besides aggravating the existing ones (Takkar, 1996). Further, micronutrient deficient soils result in production of food/feed/fodder low in micronutrient content/density and that in the long run have been inflicting their deficiency in human and animal, and thus distressing their health and productivity, and economy of the nation (Shukla et al, 2014). Micronutrients, essential for plant, animals and human's growth, has been receiving increased attention as their deficiency threatening the agricultural sustainability, nutritional quality as well animal and human health. Fortunately, most of the micronutrients like zinc (Zn), copper (Cu), iron (Fe), manganese (Mn), boron (B), molybdenum (Mo), chlorine (Cl), nickel (Ni), cobalt (Co) for legumes only, essential for plants are also essential to human. However, some elements, like I (iodine), Se (selenium), F (fluoride), Cr (Chromium) are essential for human but not for plants, but absorbed by plant from soil and water and moved to animal and human through food chain. Hence, the rampant micronutrient deficiency in soils has resulted in increased incidence of micronutrients deficiencies in animal and human in recent years.

Thus, for sustainable agriculture, micronutrients should be looked with broad spectrum to "enhance soil productivity through a balanced use of local and external sources of plant nutrients in a way that maintains or improves soil fertility, environmentally friendly and can produce nutritious food. Another way of sustainable agriculture is to look for micronutrient efficient crops and/or their cultivars. Thus, the importance of micronutrients should be viewed in food systems context, as inclusion of micronutrients in balanced fertilization schedule would optimize micronutrient supply and availability in the entire food consumption cycle. The focus of improving the micronutrient quality of crops notes the density of bioavailable micronutrients in crops as consumed in order to take into account crop factors which increase or decrease the bioavailability of crop micronutrients. By considering the benefits of micronutrients in harvested plant products for human nutrition and in forages for animal nutrition, the benefits can be further extended beyond yield enhancement. Hence, a need has increasingly been felt to search best management practices and policies for managing the soil, fertilizer and manurial micronutrient resources more judiciously, efficiently, in balance amount and proportions for sustainable high agricultural productivity, nutritional quality of food to keep the national population hale and hearty and environmental pollution under check. It is presumed that malnutrition, including trace element deficiencies, is the result of dysfunctional food systems based in agricultural systems that provide the nutrients to feed the world. Thus, farmers should be thought of as nutrient providers. Unfortunately, agriculture has never had an unequivocal goal of improving human health and the nutrition and health communities have never used agricultural tools as a primary strategy to address malnutrition. This must change! The future requires that we closely link agriculture to human health to find sustainable ways to reduce micronutrient deficiencies. There is nothing more important than supplying all the nutrients required for good health, felicity, and longevity of the human race. The sustainable means to this end must come from agriculture.

Figure 5.2: Micronutrients use vis-à-vis food grain production during last decade



Way forward

i. The precise information and knowledge on extent of micronutrient deficiencies and their budgeting under different soil-cropping system/conditions in each agro-ecological region need to be created for correcting micronutrients deficiencies in soil through providing reliable soil testing advisory services and information on micronutrient technology to the farmers to achieve the target of producing 340 million tonnes of food grain by 2025 AD.

ii. Five (one each in north, south, east, west and central part of India) 'Advanced Micronutrient Testing Laboratory' for soil, plant, animal and human sample analysis need to be created to regulate/monitor soil status, ensure quality of food and status of micronutrients deficiency in animal/human, with adequate funding and human resources so that information on trends of existing and emerging micronutrient problems impacting soil, crop, animal and human health may be generated.

iii. In the target areas with high incidence of micronutrient deficiency, fertilizer strategy should be applied nationwide to alleviate their deficiency in soil-cropping systems. Programs of genetic/agronomic bio-fortification of cereal food grains with Zn and Fe needs to be launched in a mission mode to combat their deficiency in humans especially the poor section of the society unable to afford supplements or fortified foods with micronutrients.

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5.5 Bringing Precision Nutrient Management to Smallholder Farmers Using Recent Advances in ICTs

***By Sheetal Sharma*[1], *Roland J. Buresh*[1], *Rowena L. Castillo*[1], *R.K. Malik*[2], *Virender Kumar*[1], *U.P. Singh*[3], *Anshuman Kohli*[4], *Ravi Gopal Singh*[4], *K.K. Rout*[5], *C.M. Khanda*[1], *Amaresh Nayak*[6]** *and* ***Andrew Mcdonald*[2]**

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Introduction

Better fertilizer management has contributed to increasing production of cereal-based cropping systems since the Green Revolution. In recent years, much has been written about soil quality and health in relation to food security (Lal and Stewart, 2010) because of a renewed awareness of the relationship between human population and the Earth's capacity to produce enough food to sustain the world's burgeoning population. The current focus in soil and crop management is on maintenance of soil quality or soil health. That raises the issue of how fertilizer use affects the soil other than its effects on crop yields. While soil health can be affected by limited nutrient input from fertilizers, application of amounts of fertilizer nutrients above the crop's needs for optimum growth can be equally detrimental to soils and reduce economic profitability. Main constraints in promoting balanced use of fertilizers identified by the Department of Agriculture and Cooperation, Ministry of Agriculture GOI, include inadequate and ill equipped soil testing facilities, neglect of organic manures, inadequate extension system, wide gap in dissemination of knowledge between research institutions, soil testing laboratories and the extension machinery, and lack of awareness among farmers about benefits of balanced fertilization (DAC, GOI, 2008).

Relevance in Indian context

In general, across India, fertilizer recommendations are generally made as blanket recommendations and do not reflect differences in indigenous soil fertility, prevailing crop management practices, yield responses, or attainable yield potential across sites or years. Existing approaches to improving this scenario through soil testing or STCR approach have proven too costly or difficult to extend to large numbers of farmers. Future gains in productivity and input-use efficiency will require soil and crop management technologies that are more knowledge-intensive and tailored to the specific characteristics of individual farms and fields. Site specific fertilizer recommendations approach manages the field to field variations in soil nutrient supply and crop responses to added nutrients (Buresh and Witt, 2007). SSNM was a general concept for optimizing the supply and demand of nutrients according to their variation in time and space. However, for scaling SSNM approach, new ways need to be identified and developed.

Solutions

IRRI in partnership with CIMMYT and NARES has developed a web- and mobile phone based application/software' Crop Manager', which uses SSNM principles, to calculate a field specific nutrient management recommendation based on information provided through a farmer's interview about field and crop management. The tool is being tailored to specific local conditions. The tool includes both web-based and mobile Android application with a simple, user-friendly interface providing personalized fertilizer guidance for small-scale farmers and extension workers. The farmer has to provide information about their fields by responding to a set of 12-15 brief questions about field location, planting method, seed variety, typical yields, choice of fertilizer, method of harvesting and other factors. *The Crop Manager* was adapted, evaluated, and verified for cereal based systems in Bihar and eastern UP, Odisha and Tamil Nadu through support from the Cereal Systems Initiative for South Asia (CSISA), funded by the Bill and Melinda Gates Foundation and the U.S. Agency for International Development during 2012 to 2015. Till date a number of nutrient omission plot technique (NOPT) trials and RCM evaluation trials have been conducted in several districts of the states. The data is being used to update SSNM-based approach and algorithms to enable rapid development of field-specific K and P management recommendations (Buresh et al 2010). Initial results have shown comparative advantage of using Rice Crop Manager as a tool for providing site-specific nutrient and crop management advisory to the farmers. Initial field trials conducted across seasons and crop in South Asia indicated that the field- and farmer-specific management recommendations generated through the developed 'Crop Manager' tools can increase yields about 0.4 t ha^{-1} for wheat and up to 1 t ha^{-1} for rice, while increasing income by US$ 97 ha^{-1} for wheat and by US$ 188 ha^{-1} for rice. In some cases where farmers already use high levels of fertilizer, cost savings and yield enhancements can be achieved while reducing overall applications rates of fertilizer and rebalancing what is applied to better match crop requirements.

Way forward

The mobile phone and internet penetrating fast in rural India. India has 110 million mobile internet users of which 25 million are in rural India – these ICT-based tools, especially in future, will serve as a useful platform to take knowledge to the farmers easily and at the time when they need it. Initiatives like Digital India and Soil Health Scheme lay a big opportunity for these tools as medium of transferring site specific fertilizer management information and knowledge to farmers at the desired time using mobiles and web based advisories.

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5.6 Strategies for the Last Mile Delivery of Efficient Nutrient Management

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Introduction

In India, intensive agriculture powered by improved varieties of seeds, application of fertilizers and assured irrigation has resulted in impressive growth in food grain production. The fertilizer consumption is increasing quantitatively, the corresponding yield increase per unit of nutrient has diminished over the years. High disparity between nutrient applied and nutrient uptake by harvested products is a serious threat to long term soil health, crop productivity and sustainability of agriculture. This is mainly because nutrient recommendation for crops are based upon crop response data averaged over large geographic areas and do not take into account the spatial variability in indigenous nutrient supplying capacity of soils. In general, blanket fertilizer recommendations are followed for N, P & K which rarely matches soil fertility need, and often ignoring secondary and micronutrients, in various cropping systems. Many farmers use uniform rates of fertilizers based on expected yields (yield goal) that could be inconsistent from field-to-field and year-to-year depending on factors that are difficult to predict prior to fertilizer application. Also, farmers often apply fertilizer nutrient in doses much higher than the blanket recommendations to ensure high crop yields.

Large temporal and spatial variability of soil nutrient supply restricts efficient use of fertilizer nutrients when broad based blanket recommendations are used. This leads to sub-optimal crop yields, low nutrient use efficiency, lower economic profitability and greater environmental pollution. Under such situations, in season site-specific nutrient management (SSNM) can effectively replace the blanket fertilizer nutrient recommendations for achieving high nutrient-use efficiency, economic profitability with lower environmental footprints. High nutrient-use efficiency can be achieved through field-specific fertilizer nutrient management considering both spatial and temporal variability in soil nutrient supply. However, supplying crop demand based right information as per spatial and temporal variability of soil at a farm scale seems a wearisome task with available resources for the national extension system.

After Green Revolution in India, nutrient use has increased by twelve folds in comparison to increase in average yield of total food grains. Therefore, the use efficiency of inputs particularly nutrients has been declining at faster rate, posing a threat to future food security and environmental sustainability. Improving nutrient efficiency is a worthy goal and fundamental challenges faced by today's Indian agriculture. The challenges and opportunities are existing before the national extension system with wide open hands. To cope up the challenges delivery tools are available to accomplish the task of improving the efficiency of applied nutrients. Judicious application of fertilizer best management practices (FBMPs), right rate, right time, right place, and right agronomic practice targeting both high yields and nutrient efficiency will benefit farmers, society, and the environment alike. In India, synergies of different technologies is required to increase the nutrient use efficiency of cereal crops from its current level (N-30-50%; P-15-20%; K-70-80%; S-8-10%; and micronutrients-1-2%). The NPK ratio have been continuously widening since last 5 decades and the situation is worst in food basket of the country which comprises Punjab (61.7:19.2:1), Haryana (61.4:18.7:1), Uttar Pradesh (25.2:8.8:1), Rajasthan (44.9:16.5:1) etc. Further, improvement in nutrient use efficiency is possible through balanced use of nitrogen, phosphorus, and potassium fertilizers, and by rational use of organic manures and residue management in the cereal systems. Increased nutrient use efficiency through precision nutrient management can substantially reduce production cost thereby increasing economic benefit and also reduce environmental burden from farming. The major concerns in Indian agriculture are (i) inadequate and imbalanced fertilizer use; (ii) increasing multi-nutrient deficiency; (iii) lack of farmers awareness about modern tools; (iv) poor SSNM); (v) improper residue management in cereal based cropping system; (vi) limited ICT services which resulted in declined the fertilizer response ratio from 13.4 to 3.7 in last 40 years (1970-2010) in the irrigated ecosystem.

4R approach – way ahead

At present, most national agricultural research systems provide nutrient management recommendations on a regional or district basis. However, the problems of farmers at the individual level vary based on varying cropping system based management practices. Therefore each farm is a unique entity and this uniqueness is hardly addressed by the present information provision system. 4R Nutrient Stewardships a new innovative approach for FBMPs that considers economic, social, and environmental dimensions of fertilizer management and is essential to sustainability of agricultural systems. The concept is simple: apply the right source of nutrient, at the right rate, at the right time, and in the right place. All farmers, irrespective of the size of farm, knowledge and awareness levels, thinks what fertilizer to apply, how much to apply, when to apply and how to apply before making a fertilizer application decision in any crop. The 4R Nutrient Stewardship principles connects these fertilizer application decisions to scientific principles and guides the application decisions specific to crop growths, soils and local site. It is considered the foundation of precise management of nutrients in any production system. The four "rights" helps farmers and advisors to identify opportunities for improvement in fertilizing each specific crop in each specific field, that are expected outcomes associated with applying fertilizer best management practices.

Site specific nutrient management (SSNM)

FBMPs aims to account for indigenous nutrient sources, including crop residues and manures; and apply optimal rates of fertilizer at critical growth stages to meet the deficit between the nutrient needs of crop and the indigenous nutrient supply. Site-specific nutrient management (SSNM), on the other hand, is a set of nutrient management principles that aims to supply a crop's nutrient requirements tailored to a specific field or growing environment. SSNM information is available at the national and international research institutions; it remains inaccessible to small and marginal farmers because of the missing last mile accessibility on the information highway. Residue recycling and legumes integration is now a days key to increase the nutrient use efficiencies under intensive cropping systems of South Asia. Farmers rarely have access to consistent, reliable, updated information that is tailored for their use. Further, no single source is able to provide the breadth of information required by the farmer through the demands of the farm cycle (Surabhi Mittal 2010).

Integrated approaches for smart nutrient application

Nutrient use efficiencies (NUE) could be increased by making available nutrient management technologies/practices adapted to different production systems as per the defined domains for scaling up and –out. Capturing modern tools and technologies and farmer innovations on indigenous nutrient management practices may help in increasing the nutrient use efficiencies. The new decision support tools (Nutrient Expert, GreenSeeker, remote sensing etc.), based on the principles of SSNM, help extension workers to quickly develop fertilizer recommendations in presence or absence of soil test data to increase the nutrient use efficiencies. These tools provides critical nutrient management support to increase the productivity of resource poor small and marginal farmers who do not have access to soil testing. Information and communication technologies (ICTs) can help smallholder farmers maximize the return on agricultural inputs, provided timely and relevant information is provided to them. Such decision-making support tool using modern communication platforms are being used as "one-stop solution" for effective last-mile delivery by several private service providers, for example, Tata Kisan Sansar, IFFCO Kisan Sanchar Ltd that ensures the availability of the right products at the right time and at a fair price, together with free farm advisory services. IFFCO Kisan Sanchar Ltd has its own Agri-portal for localized text messages (SMS) and Voice alerts to the registered mobile phones to the farmers related to weather and crop management options. Information on various crop management practices is also provided on demand over mobile phones through Interactive Voice Response Systems (IVRS) which are triggered through coded SMS by the farmer. Information obtained by the toll free numbers of ICAR institutes, SAUs and state DoA from answers of farmers to questions about their location-specific cropping conditions may be supplemented with Internet-based soils information to enhance the robustness of nutrient management guidelines provided to farmers.

Last mile delivery approach

The last-mile delivery of customized services to farmers will require the full attention of all stakeholders involved in the agri-food chain. Farmers need access to timely information and new technologies through training, extension services, reliable local networks of professional agro-dealers, and modern information and communications technologies. Without effective last-mile delivery, small-scale farmers are unlikely to bridge the yield gap and escape the poverty trap. Effective last-mile delivery includes: (i) providing services that facilitate access to inputs and technologies; (ii) capacity development and empower youth and women; (iii) Convergence and synergy of investments; (iii) providing services (e.g. advice and market information) that optimize the use of inputs and technologies; (iv) align remote sensing and GIS with new decision support tools and technique; (v) soil health/fertility mapping. Encouraging the adoption of FBMPs through effective delivery systems is the best option to maximize the benefits and minimize the negative impacts associated with fertilizer use. To improve last mile delivery, ease credit policies, location-specific technology/recommendations are essential, including cropping system-specific fertilizer recommendations. ICTs related information such as weather forecasts, input prices and sources, and output market information increases receptivity. Due consideration should be given to innovative approaches to the creation of user-friendly and real-time knowledge sharing platforms.

Way forward

Imbalanced application of fertilizers is under prevalence due to lack of timely, accurate and reliable information on nutrient management and crop cultivation practices. Yield and profitability can be increased by effective last mile delivery for adopting SSNM. Various tools, techniques and decision support systems are available to develop site-specific nutrient management plan. There is urgent need for enabling innovative extension policies and institutional and agri-industry framework for wide-scale adoption. ICTs/ mobile phone growth over last few years have made it a ubiquitous device and can help reach out farmers in remote and far flange areas. Farmers still need to attain greater level of awareness on managing practices and ICT based technologies can be the vehicle to support last mile delivery of the technologies to the stakeholders.

6. Organic Recycling and Soil Health

6.1 Estimates and Analysis of Nutrient Imbalance and Subsidies in Indian States

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Introduction

Fertilizer has to play larger role in growth of agricultural output in future as other resources like land and water are facing serious stress. This requires a policy favourable for attaining optimum application of plant nutrients. Over time, emphasis of fertilizer policy has been to reduce share of N and raise the shares of P and K in total use of fertilizer in the country. This has been based on the axiom that ideal combination or composition of N, P and K is 4:2:1 and any deviation from this norm constrains growth in productivity and also causes adverse effect. We opine that there is no scientific rationale to support the existing NPK norm in current situation and such norms are meaningful only at disaggregate level and in a situation where plant nutrients are used in adequate quantity. Thus, the shift in fertilizer policy towards balanced use of N, P and K based on inadequate and outdated norm, will not yield desired results. Second, the approach towards balanced use of fertilizer based on aggregate of the country is totally irrelevant as the optimum ratio of N, P and K differs significantly across states according to the types of crops grown and soil fertility status and other factors.

We found that farmers tended to reduce imbalance in NPK but external shock and policy distortions reversed the trend towards balanced use of NPK. It is ironical that fertilizer policy reforms during 1992 and nutrient based subsidy scheme in year 2010, though aimed at reducing share of N and raising share of P and K in total fertilizer use, ended up in encouraging imbalance by favouring higher use of N relative to P and K.

Our study prepared the estimates of required level of application of N, P and K for the current cropping pattern at the state level based on recommendations of SAUs and ICAR Institutes and these estimates were compared with the actual use. It was found that about one third of the major states in the country apply excess N and two third of the states use less than required level of N. At the national level the actual level of nitrogenous fertilizer use falls short of the normative use levels by a margin of 2 per cent. Hence, effectively there is minor deficiency in the use of N at national level, if entire sale of fertilizer is used for crop production; all it needs is reallocation among states.

Excess use of N in seven states namely Andhra Pradesh, Assam, Punjab, Bihar, Haryana, Jharkhand and Karnataka is enough to meet deficiency in the remaining 13 states. We concur that it will be wrong to discourage use of N in the country but it certainly need to be curtailed in some states and promoted in most of the states.

Use of P was more than what was required in Andhra Pradesh, Punjab and Tamil Nadu and it was deficit in all the other states. Use of K was much below the required level in all the states except Assam.

Judicious or optimal use of NPK implies increase in use of P and K rather than reduced use of N at national level. Almost entire imbalance towards N can be corrected by bringing regional balance in use of N. We are of the view that issue of imbalance in the country has been exaggerated and misunderstood. According to our findings, imbalance matters only when use of a plant nutrient exceeds optimum level. At below optimum level of application, imbalance in terms of composition does not have any adverse effect. Thus the policy goal should be to achieve optimum level of application of N, P and K rather than achieving a particular ratio in composition.

Our estimates of the state wise requirement of N, P and K and optimum ratio based on that indicate that the existing norm of 4:2:1 is skewed towards N and the ideal ratio for the country based on current crop pattern and recommendations of State Agricultural Universities and ICAR Institutes was found to be 2.56:1.42:1.0. This norm implies that nitrogen should comprise of about 52 per cent and P and K should constitute 28 and 20 per cent, respectively, of the total fertilizer applied in the country. These shares are much different than the share based on the ratio of 4:2:1 which implies that N should constitute 57.8 per cent and P and K should constitute 28.6 and 14 per cent share respectively.

State level results show that the officially accepted norm of 4:2:1 was close to the required norm estimated by us only in traditional green revolution belt of North West India. This is not surprising as the officially accepted norm was based on the agronomic trials in this region and for wheat and paddy which dominate the cropping pattern in this region. The desired mix of NPK in other states, except Rajasthan, implies lower share of N and higher share of P and K than what is implied by the ratio of 4:2:1. The study shows that optimum and balanced use of fertilizer in the country require higher use of N, P and K in Chhattisgarh, J&K, Kerala, Madhya Pradesh, Himachal Pradesh, Gujarat, Uttar Pradesh, Maharashtra, Uttarakhand, West Bengal; higher use of P and K in Bihar, Haryana, Jharkhand, and Karnataka; higher use of P in Assam, and higher use of K in all the states except Assam. Optimum use imply reduction in use of N in Punjab, Haryana, Bihar, Jharkhand, Andhra Pradesh and Assam and reduction in use of P in Andhra Pradesh, Punjab and Tamil Nadu.

In nut shell the study questions the common and strong view held in the country that balanced fertilizer use requires three major plant nutrients namely, N, P and K to be used in the ratio of 4:2:1 and that deviation in fertilizer use from this norm was constraining growth in crop productivity. This perception, which has been officially accepted, has led to wrong policy on fertilizer because the so called norm of balanced use is based on outdated and inadequate experiments conducted during the early 1950s. The study demonstrates that balance use of fertilizer comes into picture only when different plant nutrients are applied in adequate quantity and it differs widely across states. It pleads for a policy to address deficit and excess in use of N, P and K rather than chasing the imbalance in fertilizer use. We estimated the actual and normative quantity of N, P and K for each state of the country corresponding to the current cropping pattern. Contrary to the notion of excess use of Nitrogen in the country, it was found that 13 major states of the country use less than the required level of N. The country faces large deficit in use of P and K compared to optimum level. It calls for curtailing use of N in one third of the states and raising it in the remaining two third states.

6.2 Organic Resources for Agriculture: Availability, Recycling Potential and Strategies to Convert Waste to National Resource

By Yadvinder Singh[1], Parvinder Singh[2], H.S. Sidhu[3] and M.L. Jat[2]

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The nutrient needs of crops and associated nutrient losses of Indian agriculture are so large (and growing each year) that no single source, be it inorganic fertilizers, organic manures, or crop residues can meet them by itself. Indian soils are still estimated to be losing close to 9 Mt N+P_2O_5+K_2O (NPK) annually even after harnessing currently utilizable organic resources plus input through BNF on a gross basis (Tandon, 2007). It is projected that in the year 2050, the food grain production (estimated at 457 Mt) would remove about 58 mt of NPK with an addition of 48 Mt of fertilizer nutrients if the current linear trend in fertilizer consumption observed over the last twenty years is continued for the next 35 years. This would result in a negative gap of 10 Mt per annum of NPK. At the present NPK consumption in India is 25.53 Mt. Divergent assumptions are made by various workers regarding nutrient use efficiency and nutrient inputs from organic sources which is a major problem while working out net nutrient balances. The negative nutrient balance may be a potential threat to the soil quality and sustainable agriculture. This gap can be bridged by the recycling of the huge of quantity of organic wastes and municipal solid wastes (MSW) because these can serve as valuable sources of plant nutrients if recycled in agriculture through proper technology. Similarly, a vast amount of human excreta is generated in the country but not recycled in proper manner to benefit agriculture.

Adoption of integrated nutrient management (INM)

Organic manures alone may not be able to meet the nutrient requirement of high yielding crops to produce the required food grains for the burgeoning human population due to their low nutrient contents and slow rates of nutrient release. Thus, integrated use of the chemical, organic and biological sources of plant nutrients and their different management practices have a tremendous potential not only in sustaining agricultural productivity and soil health but also in meeting a part of chemical fertilizer requirement for different crops and cropping systems in India. INM concentrates on a holistic approach to optimizing plant nutrient supply and its main considerations are; (1) Quantifying nutrient value of on-farm resources such as manures and crop residues; (2) Calculating supplemental nutrient needs (total nutrient needs minus on-farm available nutrients) that must be met with "off-farm" nutrient sources; (3) Developing a program to optimize nutrient utilization through selection of appropriate nutrient sources, application timings and placement; and (4) Minimization of losses and replenishment of nutrients from both internal and external sources are of major interest. Many INM guidelines have already been considered but not adopted on a large scale in India.

Major organic sources

The organic materials most commonly used to improve soil fertility include animal manures, composts (mixture of decomposed plant residues etc.), crop residues, urban organic wastes (either as such or composted), poultry manure, green manures, bio-gas spent slurry, vermicompost, agro-industrial wastes (oilseed cakes, press mud cake, rice husk and biomass ashes), residues from processing of animal products (blood, horn-and bone-meal), etc. Sewage sludge and some of the industrial wastes also find application in agriculture. In India, out of 980 Mt of solid wastes being produced annually, around 350Mt are organic wastes generated from agricultural wastes. The total nutrient (NPK) potential of various organic resources was estimated at 14.85 Mt in 2000, which would become around 32.41 Mt by 2025. The total MSW generated by urban India is estimated to be 188,500 t per day (or 68.8 Mt per year). About 8.9 Mt of pressmud cake and 12.1 Mt of poultry manure are available annually in India. It is estimated that 5-14 Mt of compost can be prepared from MSW depending upon the method of composting. In India sewage and industrial wastes are often discharged into water bodies with resulting environmental and health consequences. Techniques for land treatment of wastes are available in developed countries, and application of these in India is a huge opportunity. It is estimated that, a gross quantity of 686 Mt of crop residues are available annually in India. Annual national potential of surplus residues from major crops is about 234 Mt/year, i.e. 34% of gross residue generated in India. Only 5% of the crop residues are presently recycled in agriculture and the remaining residues are consumed as cattle feed or burnt in the field itself. The amount of NPK contained in rice and wheat residues produced is about 4.1 Mt in India. In addition, approximately 25 Mt of rice husk and about 4.5 Mt of rice husk ash are produced in India. Currently, almost 2/3rd of the total dung produced is not recycled in agriculture and is burnt in the form of dung cakes. The present FYM availability in the country is estimated to be around 1.7 t ha^{-1} of net cultivated area. Organic manures can be used for biogas digestion and the residual product could then be used as N-rich biogas slurry. There were about 512 million animals in 2012 of which around 300 million (60%) are cattle and buffaloes. Four animals plus kitchen waste can meet the fuel needs of farming family and yielding about 3 t of dry manure per year. Considering 5% total NPK (dry wt. basis) in BGS gas slurry, total NPK potential from 300 million cattle and buffaloes will be about 4 Mt annually. This move will save huge amount of subsidy on fertilizer and cooking gas and foreign exchange needed for fertilizer imports. Aerobic decomposition (composting) is used in India, which leads to a stabilization of N in organically bound forms and large gaseous losses of NH_3. If the organic material has not been sufficiently stabilized, its application increases ammonia volatilization, decreases the soil oxygen concentration, produces some phytotoxic compounds and immobilizes soil mineral N. Therefore, organic products of high quality must be produced and their stability must be accurately assessed. With regard to heavy metals, their accumulation in soils is the most often cited potential risk, particularly for MSW.

Management practices for organic sources

Management strategy for organic sources is to optimize plant nutrient recovery and to minimize pollution, particularly from N and P, and other constituents. The agronomic value of organic manures as fertilizer is determined by their ability to increase the yield or quality of crops. Crop yield responses to addition of organic materials are highly variable and are dependent upon the crop, soil type, climatic conditions, management practices and the quality of the organic manure used. Organic manures decompose or mineralize in soil at variable rates. They do, however, have a greater residual effect on soil fertility than chemical fertilizers, because of slow release of nutrients. Application of organic manures generally increases crop yields above those of fertilizers alone. This increase in yield potential is due to many components present in the organic manures and their effects on improved soil structure, water regime, trace element supply, and partly to synergism. This also suggests that organic manures have considerable potential in increasing the use efficiency of chemical fertilizers by crops. Slow nutrient release from manures and composts provides stable supply of NH_4 and thus support maximal yields. If mineralization-immobilization rate is slow, a crop may not derive any benefit from the immobilized N during a normal growing season. This probably underlines the importance of time of incorporation of manure before seeding/planting of crop. The timing of incorporation of organic sources also affects the N release pattern of organically bound N, because of the effects of variations in soil temperature and moisture on decomposition. To fully realize the potentially high N use efficiency of anaerobically stored manures, farmers should replace simple land spreading with narrow band spreading or shallow injection techniques when applying slurry, and they should rapidly incorporate solid manures following land application to prevent excessive losses of NH_3. Mineralized N (e.g. in animal waste) added to soil during the non-growing season is at immediate risk for loss because of surface runoff or drainage. Delaying incorporation until shortly before seeding might however, increase the risk for N deficiency in the subsequent crop because net N release may occur too late for optimal utilization by the crop. In the case of green manure crops or poultry manure, early incorporation may lead to fast release of N, with low availability at later growth stages or losses in rice.

Approaches employed for the evaluation of organic manures

The nutritional value of organic manures has traditionally been estimated by two approaches, the decay series or the fertilizer equivalence. The decay series approach has been widely adopted as a means to estimate both initial and residual availability of N (and P) in organic wastes. A decay series is essentially a quantitative estimate of the amount of N that will be mineralized from an organic waste over a period of several years, and is usually based on laboratory N mineralization studies. While the use of decay series is conceptually sound, it is obvious that many factors can affect the success of this approach, including heterogeneity of the wastes, annual variations in climate, management effects (tillage, irrigation, etc.). Multiyear field calibration studies are essential to verify a decay series for organic wastes. Such information for different organic sources is, however, lacking in India. The fertilizer N equivalent approach includes estimation of the amount of fertilizer N that 1 t of manure replaces in terms of crop production. Field studies comparing several rates of fertilizer N and organic manures are used to determine the amount of total N in organic manure needed to obtain yields or N uptake by a crop equivalent to that obtained with fertilizer N. Results are expressed in equivalent rates (kg N ha^{-1}) or as percentage of total N. Recent examples of this approach can be found in the studies by Yadvinder-Singh et al. (1995) and Bijay-Singh et al. (1997). Evidently, the only property of manure in these experiments that is influencing yield is the N furnished by the manure. The fertilizer N equivalents cannot be calculated when the factors limiting yields with and without manure are different.

Effects of organic amendments on plant nutrition and yielding responses

Organic manures increase crop yield as a consequence of organic carbon pool enhancement. Several long-term experiments on crop nutrition and yielding responses demonstrated that benefits of increased organic matter content will differ on the basis of the rate supplied. The beneficial use depends on choosing the best amount and frequency of compost application. The literature pointed out that the use of composts or of other organic amendments in combination with mineral fertilizers enhanced crop yield in many cropping systems over more than 10 years, compared with compost and amendments alone. The maize grain yield was the highest where FYM (10 t ha^{-1}) was applied along with recommended NPK fertilizer for 34 years, under a maize–wheat system (Kaur et al., 2008). In fact, when the application rates of manure are calculated on the N crop requirement, the amount of P added often exceeds the plant P requirement, resulting in soil P accumulation, e.g. high P content in press mud cake. Improved synchronization between N net mineralization from organic materials and plant N demand has been advocated as a means of improving N use efficiency, especially in tropical cropping systems. It is essential that adequate amounts of N be present during periods of plant N uptake, whereas minimal amounts of N should be present during periods of no N uptake and when there is a high risk of leaching.

Way forward

Improving nutrient balances, improving crop yields and maintaining soil quality call for conscious moves for managing organic sources. Organic nutrient sources have widely varying composition and differ in their nutrient availability. The INM has a great potential to offset the heavy requirements of chemical fertilizers in crops, to achieve maximum yields and to sustain the crop productivity on long term basis. With detailed information on the quality of the organic material and our improved understanding on the decomposition processes, we may nevertheless be able to predict nutrient release with higher accuracy. Post-harvest residues should be utilized to the fullest extent. However, to accomplish this objective, feasible technologies are needed for *in situ* recycling (e.g. use of Turbo Happy Seeder)/rapid composting of on-farm residues and wastes, in addition to extension efforts to change the mindset of the farmers. There are a number of gaps in our knowledge for developing quantitative estimates on different aspects of integrated nutrient management for specific environments. Priorities for future research are as under:

1. Preparation of inventory of organic sources and recyclable wastes under different farming situations and estimations of nutrient from organic sources. Studying decomposition and nutrient release patterns from diverse sources of organic materials under simulated field conditions.
2. Proper storage, composting and application techniques of manures are needed to avoid nutrient losses and conserve maximum nutrients.
3. Technologies for in-situ recycling of crop residues (e.g. use of Turbo Happy Seder) need to be popularized.
4. Research on developing cultures of microorganisms and techniques which hasten the process of composting in order to produce good quality of compost will be useful.
5. Nutrient supply packages with optimum application rates of all the sources of organic manures and inorganic fertilizers should be developed. Economic evaluation of the each integrated nutrient management technology and identification of constraints in the adoption of new technology.
6. Evaluation of long term benefits of organic materials on soil quality, heavy metal accumulation and climate change mitigation by C sequestration.
7. Develop technologies to manage agro-industrial/ municipal wastes for nutrient supply and quality assessment of waste waters and their recycling.

Policy options

The availability of organic manures in adequate amounts and at costs affordable by the farmers is a major problem. Subsidizing biogas plants to meet fuel needs of the farming families as an alternative to burning of cattle dung cake can provide some FYM for recycling in agriculture. Subsidizing the high-quality compost to farmers who bring urban waste to the composting plant is one option, though this would require support from the municipal authority. Similarly, subsidizing machinery needed for managing organic sources (e.g. Happy Seeder for managing rice residues) will help in scaling the technologies. The development of source separation schemes for MSW, where households divide their garbage into organic and inorganic materials, is one of the key approaches needed to be adopted in many Indian cities to reduce solid waste management problems. The scope for decentralized composting plants in India could be explored, particularly through NGOs and civil society organizations.

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6.3 Legumes in Cropping Systems: Soil Health and Human Nutrition

By V.K. Singh

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Introduction

Indian farming is dominated by cereal based cropping system and about 85% of the total cropping system followed in India are cereal-cereal systems e.g., rice-wheat (9.8 mha), rice-rice (5.9 mha) pearl millet-wheat (2.3 mha), sorghum-wheat (2.3 mha) and maize-wheat (1.9 mha) etc. On the other hand, glory of green revolution is under stress as continuous cereal-cereal cropping system have also led to several new challenges like decline in factor productivity, degradation of land and water resources, diminishing biodiversity, depletion of ground water table, degrading soil health, increase in environmental pollution and resultant climate changes. Under such situations, diversification has assumed paramount importance in areas where a specific cropping system, more particularly cereal-cereal system are being followed continuously for several years.

Crop diversification through legumes has own a strategic position in intensive as well as subsistence agriculture, as they are an excellent source of dietary protein for millions of people, nutritional feed for livestock and mini-nitrogen plant having profound ameliorative effect on the soil. Availability of short duration varieties coupled with matching agro technologies has resulted in identification of several remunerative, and more productive cropping systems which have either already shown their promise or have tremendous potential for expansion in new niches and diversification in the existing cropping systems. Vast potential available for intercropping of quick maturing pulse crops with wide spaced planted crops like sugarcane, banana, cotton, sorghum etc., are least utilized. With the introduction of drip irrigation, scope to grow short duration pulses with horticultural crops is also enormous. Apart from this, crop diversification helps in rotational use of basic resources like as land, water and vegetation in such a way that it serves the objective of accelerated growth, employment, and eco-system protection.

Opportunities for diversification/intensification through legumes

a) Legume as summer/catch crop

The most feasible way of including legumes in cereal based systems without decreasing land area of the cereal crops is to grow legume as catch crop. For this, period between wheat harvesting and rice planting can be utilized for growing short duration (60-70 days) summer legumes. Studies conducted under ages of All India Coordinated Research Project on Integrated Farming Systems (AICRP-IFS) at Masodha, Varanasi and Ludhiana indicated that inclusion of mung bean in rice-wheat system (RWS) enhances the total productivity and net returns as compared to RWS alone. Recent work at Modipuram revealed an appreciable increase in the use-efficiency of N and P fertilizers in rice-wheat system with the inclusion of summer cowpea along with nutrient recycling, and improvement in soil physical and chemical properties. Raising forage cowpea in summer increased N and P use efficiencies in subsequent rice and wheat crops, besides minimizing movement of NO_3-N to deeper soil layers beyond effective root zone.

b) Legume as substitute crop

The substitution of pre dominant crops like rice or wheat largely depends on nature of stress increased in different agro-ecologies. For instance, in Trans-Gangetic Plain (TGP), where water table depletion is serious concern, there is scope for substituting rice with pigeon pea. Similarity in eastern part of India, where wheat productivity is generally low because of climatic constraints particularity higher thermal regimes, wheat need to be substituted with chickpea, lentil, pea or groundnut. Extensive studies on comparative performance of rice-wheat vs. rice–pulses or pulses-wheat at different location of AICRP_IFS reveals that growing legume in system with recommended rate of NPK helped to improve system productivity and profitability than non-legume based system. In *Tarai* region, the annual productivity in terms of rice equivalent yields, energy production and net return increased tremendously in rice-wheat system, when maize+cowpea fodder crop was introduced during post-wheat summer season. Diversifying wheat with chickpea was further advantageous.

c) Legume as intercrop

Inter-cropping is one of the important ways to increase the productivity and provide income stability under limited soil moisture conditions. Pulses such as pigeon pea, black gram, mungbean, and soybean are ideal intercrops in upland direct seeded rice. The scope of pulses intercrop under cereal dominated system further increases under water scares conditions or aberrant weather situation, as it not only increases total productivity of the system but also play an important role in economizing the use of resources, particularity N fertilizer. Some of the promising inter-cropping system identified under AICRP-IFS are maize + black gram at Palampur, Ranchi and Banswara, maize + cowpea at Karjat, sorghum + pigeon pea at Indore, pigeon pea + mung bean at Bichpuri and Hanumangarh, and rice + soybean at Kalyani and Jabalpur.

d) Legume in fallow lands and new niches

There is a scope for introduction of pulses in new niches such as wasteland, reclaimed soils and rice fallow land by efficient watershed management and as a replacement of less remunerative crops or intensification. To sustain and improve rice productivity, pulses have to be introduced in rice based cropping systems in different rice growing areas in Peninsular India including the deltaic areas of important river viz, Krishna, Godavari, Kaveri, etc.

e) Legume inclusion as break crop

In intensively cultivated areas where cereals are staple food and boon for food security, crop substitution or inclusion during the calendar year are no way feasible, the idea of inclusion of legumes as break crop may be more salable. Studies conducted at Modipuram reveals that inclusion of legume as fodder at 2-3 year interval has pronounced effect on nutrient use efficiency of succeeding crops along with improved soil health and reduced noxious weed infestation.

The fore going discussion clearly reveals the assured advantage of inclusion of legume in continuous cereal based systems. Although substitution of a crop in intensively cultivated areas is quite difficult however, attempts should be made to harness the advantages of legumes in bi-exploiting one or the more avenues indicated in these studies. The inclusion of legumes as summer forage or as break crop may be more promising in the areas where cereal-cereal systems are pre-dominant staple food grain crops.

6.4 Bio-fertilizers: Current Scenario and Future

By D.L.N. Rao

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Introduction

Unscientific agricultural intensification, intensive tillage, non-return or diminished recycling of organic residues etc., lead to reduction in soil organic matter, loss of soil health and fertility. Consequently, there is a renewed emphasis now on conservation agriculture, organic farming and microbial inoculants. A wide spread consensus has emerged that sole dependence on chemical input based agriculture is not sustainable in the long run and only integrated plant nutrient systems (IPNS) involving a combination of fertilizers, organic/green manures and biofertilizers are essential to sustain crop production, preserve soil health and soil biodiversity. This is especially important for India where soil organic matter content is low; cost of chemical fertilizers is high and the use efficiency of applied chemical nutrients is poor. This also becomes important in the context of climatic aberrations imposing severe abiotic and biotic stresses on crops. Considering the high import cost of fertilizers, it is imperative to reduce a part of chemical fertilizer inputs by biofertilizers. In India, where ~70% lands are under dry farming, where average pulse yields are only ~700 kg/ha, biofertilizer technologies have to be given a high priority and any neglect would be detrimental.

Biofertilizers are now included in the Fertlizer control order 1985 (amended upto April 2015) which specifies revised standards for ten preparations namely: *Rhizobium*, *Azotobacter*, *Azospirillum*, Phosphate solubilising bacteria, Mycorrhizal biofertilizers, Potassium mobilizing bacteria, Zinc solubilizing bacteria, *Acetobacter*, Carrier based consortia and Liquid Consortia. The global market for biofertilizers in terms of revenue was about 5 billion USD in 2011 and forecasted to double by 2017 (quoted by Malusa and Vassilev, 2014). Biofertilizer production in India is around 50,000 tonnes per year but the potential requirement is much higher. Application of biofertilizers is not a priority for farmers; the main issues are lack of timely availability at sowing time and poor quality in some areas. Other constraints are lack of awareness about biofertilizers due to poor extension efforts and improper application.

Relevance in Indian context

Application of organic manures is required in very high quantities to meet nutrient demand of crops; chemical fertilizers are becoming increasingly expensive. Biofertilizers are thus attractive as they are applied in small quantities, are cheap and when used along with small doses of organic manures and reduced dose of chemical fertilizers, give synergistic benefits on productivity, nutrient use efficiency, crop quality, soil health and disease suppression. By using biofertilizers farmers most commonly report earlier germination, more greenness, greater tillering and healthy crop stand. About 10% higher yield and 25% nutrient savings have been widely observed. In addition, significant improvement in use efficiency of applied nutrients has been observed in hundreds of experiments (Rao, 2014). Biofertilizers also improve quality in terms of phyto-chemicals and are contributing to improvement of nutritional security, particularly among those cultivating vegetables. Increased emphasis on organic farming, horticulture and commodity crops will require increased supply of quality biofertilizers.

Solutions

There are many success stories of biofertilizer usage all over India e.g., *Azospirillum* for rice in Tamilnadu, *Rhizobium* for soybean and phosphate solubilizing bacteria (PSB) all over the country. Biofertilizer adoption is easy in vegetable growing and very successful since farm yard manure is invariably applied and good irrigation regimes are maintained. This leads to improvement of the quality and shelf life of the produce, and improved nutrient use efficiency. These success stories need to be replicated more widely. The production of biofertilizers and usage is more in southern and western India but is now also picking up in eastern India. The main issues pertain to selecting the best suited and most efficient microbial strains for a crop/soil/region; use of certified mother cultures supplied by R& D laboratories for industrial production, using only sterile methods of production and maintaining high quality at all stages – production, storage and till its supply to the farmer. It should be mandatory for the industry to disclose details of strain used and its source in the registration certificates and inoculant literature.

Rhizobia rapidly die off in surface soil layers due to heat and desiccation. Improving the pulses production thus requires inoculation each year and greater production of quality rhizobial inoculants. The share of rhizobia in biofertilizer production is only 15%. To cover the entire legume acreage (including soybean and groundnut) the production of rhizobia needs to be increased 3-4 fold to at least 20-25,000 tonnes. To cover all crops, including horticultural and plantation crops with reasonable rate of application, total biofertilizer production in India needs to be increased 8-10 fold from the current 50,000 tonnes to about 0.4-0.5 million tonnes each year. This requires major policy directives to boost infrastructure and encourage the private sector. Allowing market force mechanisms for maintaining quality through creation of brand equity by reputed players will give a fillip to the industry.

Liquid biofertilizers with added cell protectants to enhance the shelf life have shown good agronomic performance (Trimurtulu and Rao, 2014). Addition of small amounts of humic acid has been shown to promote survival of bacteria in solid carriers. Microencapsulation through immobilization of microbial cells or their consortia in biodegradable polymers to protect them against dryness and other environmental stresses during storage needs more research. Viability of custom coating of seeds with nutrients, fungicides and biofertilizers is uncertain due to infrastructure problems of cold storage and other logistical difficulties. An ecological approach based on bio-films are showing promising effects and research is underway on natural clay based nano-biofertilizers. Production of mycorrhiza needs to be stepped including production in synthetic or semi-synthetic media. The use of microbial consortia having two or more beneficial organisms is showing promising results. Extensive field experiments conducted in farmer fields under the ICAR-All India Network Project on Soil Biodiversity-Biofertilizers in eastern India have demonstrated the benefits of microbial consortia. For example in Bihar for rice, use of *Azospirillum*, blue green algae and *Pseudomonas* has been shown to confer differential benefits at different plant growth stages. The use of carrier based biofertilizer inoculants pre-incubated in FYM or microbially enriched compost have both shown excellent responses in all crops, particularly vegetables in Odisha and Assam respectively. Other inoculants used though in lesser quantities are blue green algae and *Azolla*; there is a great potential to step up their production through de-centralized units using local strains – many Krishi Vigyan Kendras of ICAR are already producing them and need to be supported vigorously. Research is underway on newer plant growth promoting inoculants like Actinomycetes and *Arthrobacter* which are showing promise on a wide variety of crops. *Methylobacterium* has shown promise in imparting stress resistance to rice under drought conditions. In diversification of usage, improvement in yield of fibre crops like jute and cotton, particularly on quality aspects; floriculture-size and shelf life of flowers; high value crops like hot chillis etc., are recent results that need to be further exploited widely by scaling-up.

Way forward

- Greater attention on rhizobial research to boost pulses production: Improve strategy for selection of superior rhizobia in various agro-climatic zones by assessment of proportion of nitrogen fixed by legumes using stable isotope methodology.
- Improved fermentation technology for inoculant production by industry, sterile methods of manufacture, employing qualified personnel, creating brand equity as part of corporate social responsibility.
- A further 10-fold improvement in BIS quality standards of microbial inoculants both for solid and liquid biofertilizers; establishment of high-grade quality control laboratories in all states, strictly monitor quality control.
- Improved application technology of liquid and granular biofertilizers in mechanized faming.
- Promote supply of quality biofertilizers, spread awareness on microbial inoculants and soil health through mass media and greater diffusion of technology through mass demonstrations.

Epilogue

The constraints to fuller implementation of biofertilizer technologies in Indian agriculture are not scientific, but largely organizational and logistical. There is a need to develop an integrated strategy to replicate the success stories and raise the general awareness about the benefits of biofertilizer usage to a level where it is implemented as a normal package of practice by the farming community to improve yields and benefit soil health.

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7. Group Work on Overarching Strategies for Better Soil Health through Nutrient Best Management Practices

Ensuring soil health in the vast tracts of agricultural lands in our country is easier said than done. Implementation of nutrient best management practices in the smallholder systems of India and beyond is also a challenging task. The National Dialogue on "Efficient Nutrient Management for Improving Soil Health" provides an opportunity to bring into fore the knowledge and dissemination gaps in efficient nutrient management that influences the health of our soils, and prioritize them as pre-requisites for sustained future food security. The group work in the National Dialogue was designed to allow all participants to share their rich experiences on key issues that are critical for soil health to help develop the roadmap and formulate future policies for scalable fertilizer best management practices not only to improve soil health but efficiency, productivity and farm profits while reducing environmental footprints.

The following topical issues have direct connects with the theme of the national dialogue and have been chosen for elaborate discussion by the participants during the group work:

Organic recycling in agriculture: what, how much, where, how?

India has vast potential of organic waste resources, recycling of which is vital for supplementing plant nutrients and maintenance of soil health. Organic recycling in agriculture is limited in our country because of several competitive uses of crop residues, animal waste etc. This group will discuss the synergies and tradeoff in recycling organics and the realistic potential of organic resources that could be recycled back to the farmland to improve soil physical, chemical and biological health.

Soil health card and beyond

The Government of India has undertaken a massive effort to provide soil health cards to all farmers. How best the soil health information could be used to provide rational fertilizer recommendation on both spatial and temporal scales to the farmers ensuring sustained soil health while we try to feed the burgeoning population would be the key discussion point in this group.

Soil pollutants and soil degradation

The hazards of soil degradation and presence of pollutants in the soil adversely affect the soil health. This issue needs to be addressed on a priority basis to save our farmland's capacity to produce food, feed, and fuel for the growing population. Are there proven strategies or mechanisms that needs to be prioritized, and what are the performance indicators that could be used to identify the reversal of soil degradation/soil pollution etc., are some of the discussion points in this group.

Fertilizer nutrient use trends, scalable technological innovations and tools for improving nutrient use efficiency

Balanced fertilization, a prerequisite of high nutrient use efficiency, has been in discussion for a long time. However, the acceptance and adoption of balanced fertilization at farmers' level is far from the expectation. One of the major issues that restricted the adoption of balanced fertilization is the lack of easily available and usable tools that can allow farmers and their advisors to implement balanced fertilization quickly in their fields. This group will discuss some of the scalable approaches that might help large-scale implementation of balanced fertilization in farmers' fields to improve nutrient use efficiency.

Institutions, policies, partnerships, scaling strategies and capacity for a healthy national soil resource

A healthy national soil resource will require strong policy support, institutional mechanism and capacity development of stakeholders to implement strategies that promote soil health. What policies need to be in place to help scaling of strategies that has the overarching influence on efficient nutrient management leading to soil health improvement will be discussed in detail in this group.

Annexure

Program

Day 1: September 28, 2015		
0830-0930	Registration	Tripti, Simmi, Munmun
0930-1125	**Inauguration and Award Function**	
0930-0935	Lighting of the Lamp	Dignitaries on the Dais
0935-0940	Welcome Address	T. Mohapatra, Director IARI & Trustee, TAAS
0940-0950	About TAAS activities	R.S. Paroda, Chairman, TAAS
0950-0955	Brief Remarks	Usha Zehr, Barwale Foundation
0955-1000	Brief Remarks	S. Nand, Deputy Director General, FAI
1000-1005	Brief Remarks	Adrian Johnston, Vice President, IPNI
1005-1010	Brief Remarks	Martin Kropff, Director General, CIMMYT
1010-1020	Address by Guest of Honour	S. Ayyappan, Secretary, DARE & Director General, ICAR & Trustee, TAAS
1020-1025	Citation of Awardee	P.L. Gautam, Vice-Chairman, TAAS
1025-1030	Presentation of Award	M.S. Swaminathan, Chief Guest
1030-1110	Response by the Awardee and Foundation Day Lecture on *"21st Century Challenges and Research Opportunities for Sustainable Maize and Wheat Production"*	Thomas Lumpkin, Former Director General, CIMMYT
1110-1120	Address by the Chief Guest	M.S. Swaminathan, Founder Chairman MSSRF
1120-1125	Vote of Thanks	N.N. Singh, Secretary, TAAS
1125-1145	Coffee Break & Group Photograph	
1145-1315	**Panel Discussion on "Soil Health: Concerns and Opportunities"** **Chair:** Martin Kropff, DG, CIMMYT **Co-Chair:** Alok K. Sikka, DDG (NRM), ICAR **Context Setting:** *Efficient Nutrient Management a sin qua non of Sustainable Soil Health - Concept and Concerns* by J.C. Katyal (15 Min) **Panelists:** S.M. Virmani, J.K. Ladha, Ashok K. Patra	
1315-1400	Lunch	
1400-1530	**Technical Session-I: Challenges for Improving Soil Health** **Co-Chairs:** Gurbachan Singh, Chairman ASRB & J.C. Katyal, Ex VC, CCSHAU **Facilitator:** Y.S. Saharawat, ICARDA	
1400-1420	Soil Health: Monitoring Strategies for Smallholder Systems	Adrian Johnston, IPNI
1420-1435	Nutrient Mining in Indian Agriculture: Past Trends and Future Challenges	Saroj K. Sanyal, BCKV
1435-1450	Improving Soil Physical Health: Challenges and Opportunities	S.K. Chaudhari, ICAR
1450-1505	Conservation Agriculture and Soil Health vis-à-vis Nutrient Management: What is Business Unusual?	M.L. Jat, CIMMYT
1505-1530	Discussion and remarks of Co-chairs	
1530-1600	Coffee Break	

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1600-1800	**Technical Session-II: Recent Advances in Nutrient Management** **Co-Chairs:** Adrian Johnston, Vice President, IPNI, & R.K. Tewatia, ADG, FAI **Facilitator:** T. Satyanarayana, IPNI	
1600-1620	Fertilizer Policy and Nutrient Management: How to Connect?	B.S. Dwivedi, IARI
1620-1635	Soil Test Crop Response: What Can be Learnt?	Pradip Dey, IISS
1635-1650	Advances in Precision Nutrient Management Decision Support: What are the BIG Gains?	Kaushik Majumdar, IPNI
1650-1705	Micronutrients Management: A Way Forward to Food and Nutritional Security and Human Health	A.K. Shukla, IISS
1705-1720	Bringing Precision Nutrient Management to Smallholder Farmers Using Recent Advances in ICTs	Sheetal Sharma, IRRI
1720-1735	Strategies for the Last Mile Delivery of Efficient Nutrient Management	Rajbir Singh, ICAR-ATARI, Ludhiana
1735-1800	Discussion and remarks of Co-chairs	
1930-2200	Dinner Hosted by Organizers at NASC Lawns	
Day 2: September 29, 2015		
0900-1030	**Technical Session-III: Organic Recycling and Soil Health** **Co-Chairs:** J.S. Sandhu, DDG (CS), ICAR & A.K. Singh, Vice Chancellor, RVSKVV, Gwalior **Facilitator:** Sudarshan Dutta, IPNI	
0900-0925	Estimates and Analysis of Nutrient Imbalance and Subsidies in Indian States	Ramesh Chand, NITI Ayog
0925-0945	Organic Resources for Agriculture: Availability, Recycling Potential and Strategies to Convert Waste to National Resource	Yadvinder Singh, PAU
0945-1000	Legumes in Cropping Systems: Soil Health and Human Nutrition	V.K. Singh, IIFSR
1000-1015	Bio-fertilizers: Current Scenario and Future	D.L.N. Rao, IISS
1015-1100	Discussion and remarks of Co-chairs	
1105-1130	Tea Break	
1130-1330	**Group Work: Overarching Strategies for Better Soil Health through Nutrient Best Management Practices (Parallel sessions)**	

Groups	Theme	Group Chairs
I	Organic Recycling in Agriculture: What, How Much, Where, How?	R.K. Malik, CIMMYT
II	Soil Health Card and Beyond	Vandana Dwivedi, MoA
III	Soil Pollutants and Soil Degradation	S.S. Kukal, PAU
IV	Fertilizer Nutrient Use Trends, Scalable Technological Innovations and Tools for Improving Nutrient Use Efficiency	A.K. Singh, ICAR-ATARI, Kolkata
V	Institutions, Policies, Partnership, Scaling Strategies and Capacity for a Healthy National Soil Resource	S.K. Chaudhari, ICAR

1330-1430	Lunch

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1430-1630	**Plenary Session** **Chair:** R.S. Paroda, Chairman, TAAS **Co-Chair:** A.K. Sikka, DDG (NRM), ICAR **Facilitators:** Kaushik Majumdar, IPNI & M.L. Jat, CIMMYT	
1430-1530	Synthesis Report from Technical Sessions and Group Works	Facilitators
1530-1600	Reaction on the reports	Participants
1600-1610	Remarks of the Co-Chair	A.K. Sikka
1610-1625	Remarks of the Chair	R.S. Paroda
1625-1630	Vote of Thanks	N.N. Singh

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