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NASC Complex, Dev Prakash Shastry Marg

P.O. Pusa, New Delhi 110012 (India)

Phones: +91-11-25846054

E-mail: naas@vsnl.com

Website: www.naasindia.org

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Jeevan Rao, K. Professor and University Head, Department of Soil Science and Agricultural Chemistry, Professor Jayashankar Telangana State Agricultural University, Rajendranagar, Hyderabad, Telangana

Chapter 15. Soil and Climate Change

Pathak, H. Principal Scientist and Professor, ICAR-Indian Agricultural Research Institute, New Delhi

Benbi, D.K. ICAR National Professor, Department of Soil Science, Punjab Agricultural University, Ludhiana, Punjab

Ch Srinivasarao Director, Central Research Institute for Dryland Agriculture, Hyderabad, Telangana

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Ch Srinivasarao Director, ICAR-Central Research Institute for Dryland Agriculture, Hyderabad, Telangana

Lal, R. Distinguished University Professor, The Ohio State University, Ohio, USA

Rao, D.L.N. Project Coordinator ICAR-AICRP on Soil Biodiversity-Biofertilizers, ICAR-Indian Institute of Soil Science, Bhopal, Madhya Pradesh

Sahrawat, K.L. Visiting Scientist, International Crop Research Institute for the Semi-Arid Tropics, Hyderabad, Telangana

Gupta, Raj K. Team Leader, Research Station Developments, Borlaug Institute for South Asia, CIMMYT, New Delhi

Balloli, S.S. Principal Scientist, ICAR-Central Research Institute for Dryland Agriculture, Hyderabad, Telangana

Srinivas, K. Principal Scientist, ICAR-Central Research Institute for Dryland Agriculture, Hyderabad, Telangana

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Patra, A.K. Director, ICAR-Indian Institute of Soil Science, Bhopal, Madhya Pradesh

Ganeshamurthy, A.N. Principal Scientist, ICAR-Indian Institute of Horticultural Research, Bengaluru

Srivastava, S. Principal Scientist, ICAR-Indian Institute of Soil Science, Bhopal, Madhya Pradesh

Chapter 18. Soil Science Education in India

Datta, S.C. Principal Scientist, ICAR-Indian Agricultural Research Institute, New Delhi

Technology Frontiers for Improved Soil Management

INTRODUCTION

The challenge of producing more food would be much greater in the coming decades as the much-needed growth rates of food production is now supported by weak land-resource base with several soil-related production constraints in lesser available cultivable land area. It is projected that by 2030 India will require a minimum of 304 million tons (Mt) of foodgrains, 175 Mt of vegetables, 96 Mt of fruits, 170 Mt of milk and 21 Mt of meat, eggs and fish. Climate change in terms of increased number of droughts years, reduced number of rainy days, improper distribution of rainfall, cyclones, hailstorms and other adverse events, besides several biotic stresses are important challenges to achieve agricultural production and growth. The need of the hour is to (i) refine the existing technologies to meet the needs to contemporary agricultural systems, (ii) cope with the weather aberrations and (iii) meet the demands of diversified food preferences of the Indian population. Some of the technologies are discussed here after, which have the potential to improve the soil health, protect natural resources such as land and water, safe-guard environment, besides offering mechanisms to cope with the weather aberrations and extreme events.

Productivity enhancement due to the implementation of frontier technologies is mainly aimed at bridging the existing yield gaps. Rainfed systems have larger yield gaps due to uncertainty of rainfall as compared to irrigated ones (Srinivasarao et al. 2015). Proper implementation of these technologies reduce the existing gaps in food or other commodity productions at the farm level in different sectors of agriculture such as food, horticulture, livestock, dairy, poultry and fishery, and thereby eventually contributes to food and nutritional security of the country.

Improved soil management: Frontier technologies

Conservation agriculture

Conservation agriculture (CA) system is an encompassing term consisting of three essential principles, viz. minimal soil disturbance, permanent soil cover and crop rotation (FAO 2015). In recent years, CA has emerged as one of the important options for addressing the resource and productivity-related constraints and has

the potential for sustainable intensification of cropping/farming systems in rainfed regions. Research conducted in the developed countries has clearly shown that CA can enhance the productivity, improve the soil carbon, arrest land degradation and can positively contribute to the biodiversity while improving the soil quality.



Fig. 16.1 Conservation agriculture followed in maize-horsegram sequence in Alfisols (Source: Kundu et al. 2013)

Conservation agriculture is based on enhancing natural biological processes above and below ground. Considering the severe problems of land degradation due to runoff-induced soil erosion, rainfed areas, particularly in the arid and semi-arid regions need CA more than the irrigated areas in order to ensure sustainable production. Many experts believe that CA improves SOM content in soils (Srinivasarao et al. 2014a). The conversion of land into CA sequester atmospheric C ($\text{Mg ha}^{-1} \text{yr}^{-1}$) to the extent of 0.12-0.29 in Asia, 0.09-0.29 in Africa, 0.14-0.56 in the USA (Lal 1997). Kundu et al. (2013) assessed the effect of CA with balanced fertilization of maize-horse gram crop sequence (Fig. 16.1) and reported that SOC varied from 0.31 to 0.45% and it was slightly higher than that under conventional system (0.29-0.42%).

The permanent vegetative or residue cover on the soil surface in CA systems are reported to increase water infiltration, reduces erosion, moderates soil temperature, suppresses weeds, improves soil aggregation, reduces soil compaction, increases surface soil organic matter, increases microbial activity and reduces emissions of greenhouse gases (Hobbs et al. 2008; Giller et al. 2009). An evaluation of the data from 67 long-term experiments indicated an average rate of sequestration under no tillage at $57 \text{ g C m}^{-1} \text{yr}^{-1}$ with peak sequestration rates attained within 5-10 years after conversion (West and Post 2002). Conversion to no-till and retaining residues on the soil results in enhancing the soil carbon sequestration and the improvement in soil carbon ranges from 0.12 to 0.29; 0.09 to 0.29; 0.12 to 0.29 and 0.14 to 0.56 $\text{Mg C ha}^{-1} \text{yr}^{-1}$ in the continents of Asia, Africa, America, and the USA, respectively (Lal 1997). Improvements in soil C are associated with several associated benefits resulting in enhancement in agricultural productivity. Results from long-term experiments showed that each ton of soil organic carbon buildup improves crop productivity up to $100\text{-}350 \text{ kg ha}^{-1}$ among various dryland crops (Srinivasarao et al. 2013a).

The CA is gaining acceptance in many parts of the world and is being practiced in about 120 Mha (Derpsch et al. 2010). However, research in India on CA is at its infancy particularly under rainfed conditions due to several issues associated with the implementation of CA practices. The benefits associated with reducing the tillage intensity are limited in the absence of retention of crop residues. As crop residues for the predominant rainfed crops are valued for animal feed, particularly by the small farmers in drier environments of India, retaining the residues on the soil surface may not be a feasible option. Reducing the tillage intensity without appropriate vegetative cover may lead to compaction and surface sealing which will reduce water infiltration and crops may suffer from moisture stress, impacting crop yields. The non-availability of suitable implements for supporting CA systems in rainfed production system is also a serious limitation. Frequent flushes of weeds appear with the rain spells in rainfed regions and the absence of suitable post-emergence herbicides in a number of crops is a serious limitation for effective control of weeds in CA, particularly under rainfed crops. Termite infestation of crop residues is significant during the dry period and it reduces the surface cover significantly in the Alfisols, in particular.

Use of nano-fertilizers in soil improvement

Nano-technology is a novel, innovative, interdisciplinary scientific approach that involves designing, development and application of materials and devices at molecular level in nano-metre scale i.e., at least one dimension ranges in size from 1 to 100 nano-metres (Fakruddin et al. 2012). There are 'smart' nano-scale devices, which can be deployed for the efficient delivery of fertilizers, herbicides, insecticides and plant growth regulators, among others. The nano-scale carriers are designed in such a way that they can anchor the plant roots to the surrounding soil and organic matter; hence, leading to improved stability against degradation in the environment and thereby ultimately reducing the amount to be applied (Ditta 2012; Johnston 2010).

There are three types of nano-materials (NM) depending on their origin: natural, incidental and engineered (Ruffini and Cremonini 2009). Natural NMs have existed from the beginning of the earth's history and still occur in the environment (i.e. soil clay colloids, remnants of DNA strands). Incidental NM occurs as a result of industrial or mining processes. On the other hand, the engineered nanomaterials (ENM) and engineered nanoparticles (ENP) are (i) carbon-based materials, (ii) semiconductor, metal and metal oxide-based materials and (iii) polymers.

A survey by Salamanca-Buentella et al. (2005) predicted several nanotechnology applications for agricultural production for developing countries within the next 10 years. These include (i) Nano-form zeolites for slow release and efficient dosage of water and fertilizers for plants; drugs for livestock; nano-capsules and herbicide delivery, (ii) nano-sensors for soil quality and for plant health monitoring; nano-sensors for pests' detection, (iii) nano-magnets for the removal of soil contaminants and (iv) nano-particles for new pesticides, insecticides and insect repellents.

Encapsulation of fertilizers within a nanoparticle is nano-fertilizer through which the nutrient can be supplied to plants (Rai et al. 2012). When compared to chemical fertilizers requirement and cost, nano-fertilizers are economically cheap and are required in lesser amount. With experience, farmers have found that nitrogen uptake is the main reason for poor yield and there is a vast scope for the formulation of nano-fertilizers. Nano-fertilizer remains available in the emulsion form throughout the water layer in water logged condition. To block ammonia gas from escaping to the environment, a layer of inhibitors or nanoclusters on the surface of the soil (that is water logged) may be used (Giocchini et al. 2002). Significant increase in yields has been observed with 640 mg ha⁻¹ foliar application (40 ppm concentration) of nanosize phosphorus, which gave 80 kg ha⁻¹ P equivalent yield of clusterbean and pearl millet under arid environment owing to foliar application of nano-particles as fertilizer (Tarafdar 2012). Application of the nano-particles increased the growth rate and seed yield by 32.6% and 20.4%, respectively, compared to those of soybeans treated with a regular P fertilizer [Ca(H₂PO₄)₂] (Liu and Lal 2014). Mixture of nanoscale SiO₂ and TiO₂ hastens germination and growth in soybean (Lu et al. 2002). Compared to NPK chemical fertilizer, the application of slow/controlled release fertilizers, coated and felted by nano-materials, were reported to improve grain yield with an insignificant increase in protein content and a decrease in soluble sugar content in wheat (Qiang et al. 2008). Spraying with 0.5% ZnSO₄ resulted in higher peanut pod yield compared to no spraying (Prasad et al. 2012). Jinghua (2004) showed that application of a nano-composite consisting of N, P, K, micronutrients, mannose and amino acids enhanced the uptake and use of nutrients by grain crops. Further, the nano-composites being contemplated to supply all the nutrients in right proportions through the 'smart' delivery systems also need to be examined closely. Currently, the nitrogen use efficiency is low due to the loss of 50-70% of the nitrogen supplied in conventional fertilizers. New nutrient delivery systems that exploit the porous nanoscale parts of plants could reduce nitrogen loss by increasing plant uptake. Fertilizers encapsulated in nanoparticles will increase the uptake of nutrients (Tarafdar 2012). Indeed, the importance of chemical fertilizer has been addressed and the Government subsidized the cost of fertilizers. This resulted in imbalanced use of fertilization particularly in respect of use of urea. Further, this has led to groundwater pollution, decreased use efficiencies of N, P and K fertilizers. For providing food to an increasing population, there has to be a new technology giving more agronomic yield. That could address the problems such as low fertilizer-use efficiency, imbalanced fertilization, multi-nutrient deficiencies and declining soil organic matter.

Hydrogel for soil-water retention

Application of super absorbent polymers into the soil could be an effective way to increase water-use efficiency in crops. Laboratory and field investigations were conducted to study water retention and release characteristics of a crosslinked polymer of polyacrylamide and potassium acrylate (PAM) and evaluate its effects on yield and water productivity in tomato and maize grown on sandy-loam soils.

Results of two-year field experimentation on tomato showed that the spot application of PAM polymer at 25 kg ha⁻¹ with alternate week irrigation resulted in higher tomato yield and increased the water productivity to 291 kg ha-mm⁻¹, thereby saving 180 ha-mm irrigation water. Effect of row application of PAM polymer at 25-50 kg ha⁻¹ on rainfed maize revealed that application of polymers at 25 kg ha⁻¹ delayed the wilting by 5-6 days during initial dry spell at early growth stage and gave 16% higher maize yield than the control (CRIDA 2013-14).

Biochar for soil water and nutrient retention

The idea of using biochar as a tool for countering climate change and improving soil health is a recent development. Biochar is the carbon-rich solid product, produced by thermal decomposition of organic matter under limited supply of oxygen or oxygen-free environment, and at relatively low temperatures (<700°C) through a process called pyrolysis (Lehmann et al. 2006). Biochar appears to be one promising source of renewable and stable carbon to increase the rate of carbon sequestration in soil. Current availability of the unused surplus residues in India is estimated at 120-150 Mt/annum. Of this, about 93 million tons of crop residues are burned each year, such unused residues are valuable resources for production of biochar (Srinivasarao et al. 2013b).

Biochar can be produced by a number of methods. The ancient method for producing biochar was the 'pit' or 'trench' method. The common processes include slow and fast pyrolysis, and the most successful approach for high-yield biochar production is via slow pyrolysis. Under slow pyrolysis, a biochar yield between 25% and 35% can be produced (Hussein et al. 2015); fast pyrolysis processes aim at production of bio-oil and the amount of biochar formed is nearly 12 % of the total biomass (Cheng et al. 2012). The cook stove, earth mound kilns and drum kilns are the traditionally used for biochar production in India. A number of biochar kilns have been designed, developed and used for making biochar from the crop residue and forest biomass in India.

Various methods of biochar application in the soil, based on extensive field testing, include mixing the biochar with fertilizer and seed, applying through no till systems, uniform soil mixing, deep banding with plough, top-dressing, hoeing into the ground, applying compost and char on raised beds, broadcast and incorporation, mixing biochar with liquid manures and slurries (Hussein et al. 2015).

Numerous studies have reported on the beneficial impacts of biochar addition on soil health improvement and GHG emissions reduction. The incorporation of biochar into soil alters soil physical properties like bulk density, penetration resistance, structure, macro-aggregation, soil stability, pore size distribution and density with logical implications in soil aeration, wettability of soil, water infiltration, water holding capacity, plant growth and soil workability; positive gains in soil chemical properties include: retention of nutrients, enhancement of cation exchange capacity and nutrient use efficiency, decreases of soil acidity and increases of the number of beneficial soil microbes. Biochar has the potential to

counter climate change because the inherent fixed carbon in raw biomass that would otherwise degrade to greenhouse gases is sequestered in the soil for years. In recent years, the use of surplus organic matter to create biochar has yielded promising results in regard to sequestration of carbon. Lehmann et al. (2006) estimated that a potential global C-sequestration of 0.16 Gt yr^{-1} can be achieved from biochar production from forestry and agricultural wastes.

With limited studies on the use of biochar in different soil types, climatic zones and land use situations, it is difficult to predict its agronomic effects. Due to the heterogeneous nature of biochar, cost of production of biochar for research and field application is likely to remain a constraint until commercial-scale pyrolysis facilities are established. Some of the practical constraints on the use of biochar in agricultural systems include once applied to soil, it remains permanent, unavailability of enough biochar, dry biochar on soil surface is liable to aid wind erosion, response of local communities to adopt biochar systems; unavailability of farm labour, higher wage rates for collection and processing of crop residue, lack of appropriate farm machines for on-farm recycling of crop residue and inadequate policy support/incentives for crop residue recycling (Srinivasarao et al. 2013b; Venkatesh et al. 2015).

Land management for soil and water conservation

For reducing the risk of soil degradation, preserving the productive potential, decreasing the level of inputs required and sustaining agricultural productivity in the long-run, measures like land shaping, agronomic manipulations, vegetative barriers, alternate land-use systems and runoff-harvesting and recycling techniques have been proposed by the researchers. The agronomic measures are generally recommended on mildly sloping lands with the objective of maximizing *in-situ* rainwater conservation to ensure protection against erosion and achieving higher productivity. These include contour farming, intercropping, strip cropping, mixed cropping, soil-cover management, mulching, crop geometry, tillage practices and diversified cropping systems. Mechanical measures like land leveling, bunding, terracing, conservation bench terracing and contour trenching are adopted to support the agronomical measures on steeper slopes or where the runoff is high by way of reducing the length and or degree of slope to dissipate the energy of the flowing water. Studies carried out in the Doon Valley, India on the effects of different land-shaping measures on runoff, soil loss and yield of maize and wheat have revealed that contour bunding was economical and efficient in controlling 50-60% runoff and soil loss. Compared to contour farming, graded bund reduced runoff by 52-56 and soil loss by 65-72% while bench terracing reduced runoff by 85-92% and soil loss by 90-92% (Table 16.1) (Sharada 2011).

Biological waste recycling

Work on composting showed that while microbial inoculum in the cowdung mixture is sufficient when used in large quantities, compost accelerators containing inoculum of cellulose degraders like *Trichoderma viride*, *Trichurus spiralis*, *Aspergillus*

Table 16.1 Runoff (mm) and soil loss (t/ha) on different slopes and conservation measures in Doon Valley.

Land shaping measures	2% slope		4% slope		8% slope	
	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss
Contour cultivation	63.9	16.18	144.3	25.75	327.2	54.67
Graded bunding	27.8	4.28	67.9	7.24	156.1	19.40
Contour bunding	15.8	2.87	39.8	4.56	89.6	10.02
Bench terracing	9.3	1.53	16.2	2.15	27.2	3.01

niger, *Paecilomyces fusisporus* can be used with advantage. Enriched composts amended with mineral sources like rock phosphate, pyrites, mica and inoculated with phosphate solubilizing microorganisms, nitrogen fixers and plant-growth promoting rhizobacteria like *Bacillus*, *Aspergillus*, *Azotobacter* and *Azospirillum* in the mesophilic phase have been widely used and shown to result in fertilizer saving, improve nutrient use efficiency and improve crop quality. In this context, urban solid waste generation is increasing rapidly and technologies available off the shelf for quality compost production need to be promoted (Manna et al. 2014). Increased labour cost and quality inoculums are important components for the adoption of this technology. However, in view of soil organic matter depletion and soil health deterioration and large amounts of crop residue availability in different states which is currently being subjected to burning (cotton, sugarcane, rice, manure residues), besides being diverted to several competitive uses, composting technology need to be taken to practical agriculture for implementation, at the community and individual farm household level.

Biotechnological approaches of soil health improvement

Biofertilizers: Biofertilizers can save up to 25% of fertilizer nutrients; the quantum of biofertilizer production in India is more than 50,000 tons each year and is dominated by phosphate-solubilizing bacteria. Quality specifications are stipulated in Fertilizer Control Order (1985, as amended in April 2015), but there is still a need to further improve the standards, particularly in respect of *Rhizobium*. Two important developments are: (a) indigenous methods to improve biofertilizer quality at the farm level by pre-incubation with composts (except *Rhizobium*), and (b) liquid biofertilizer technology to improve inoculant performance and shelf-life (Trimurtulu and Rao 2015). Application of biofertilizers along with farmyard manure or vermi-compost has led to savings of 50% chemical fertilizers in arable cropping systems. Use of biofertilizers in horticulture is leading to improved produce quality in terms greater concentration of phyto-chemicals and nutraceuticals. Although the Government of India provides a 25% back-end subsidy (through banks) to set up production units, there is a need to incentivize it further, specifically to promote the use of rhizobial inoculants to boost pulse production.

Biotechnology and transgenes for soil-health assessment: There is increasing concern about the adverse impacts of fertilizers and pesticides on soil biological

health and thus there is a need to develop sensitive molecular methods of assessing soil microbiological quality. In a study on Vertisols, with high chemical inputs (at ~2.3 times recommended rates of fertilizer and pesticides) to black gram in Guntur district, of Andhra Pradesh, the soil biological properties were not affected adversely, but very high inputs of fertilizers and pesticides (~5 times the recommended dose of fertilizers and 1.5 the recommended dose of pesticides) adversely affected soil biology in the chili crop. There was a decrease in proportion of Actinobacteria at Munipalli and Jonnalgadda sites (Malhotra et al. 2015). In Aridisols near Hanumangarh, Rajasthan, there was improvement in 16S rRNA gene copy number and a greater diversity of eubacterial community owing to organic farming- 10% higher actinobacteria and 20% lesser Proteobacteria. In soybean and maize rhizosphere in Vertisols of Dharwad, Karnataka, eubacterial diversity was higher in organic management; actinobacteria was dominant in organic and Proteobacteria in chemical farming (Aparna et al. 2014). In a 100 year permanent manurial trial in an Alfisol at Coimbatore, Tamil Nadu, Proteobacteria were in higher proportions in chemically fertilized soils, while Acidobacteria and Actinobacteria were higher in organic management (Chinnadurai et al. 2014). Methods for measurement of soil biological health should therefore emphasize the relative proportions of Actinobacteria and Proteobacteria thus which serves as a good indicator of soil biological health.

There is concern about the effect of transgenic crops like Bt cotton on soil microbial communities although none of the effects have been scientifically proven. Several studies have shown that there were no differences or were temporary and did not persist till the next season. Obviously, there is need to use effective biotechnological tools for ensuring enhanced nutrient-use efficiency in production systems in future.

Precision agriculture and its role on soil management: Precision agriculture (PA) or satellite farming or site-specific crop management (SSCM) is a farming management concept based on observing, measuring and responding to inter and intra-field variability in crops vis-a-vis in soils. Soil and crop variability typically has both a spatial and temporal component which makes statistical/computational treatments quite involved. The holy grail of precision agriculture research will be the ability to define a Decision Support System (DSS) for whole farm management with the goal of optimizing returns on inputs while preserving (https://en.wikipedia.org/wiki/Precision_agriculture). The ushering in of modern spatial information technologies like Global Positioning System (GPS) is making it possible to consider the intra-field variations with respect to various parameters like soil, crop condition and, crop-growth stage among other factors thereby facilitating the adoption of Precision agriculture (PA). New advanced developments in the form of various types of sensors, mechanisms, control systems and information communication tools through advanced computing systems are aiding the faster adoption of precision agriculture practices. Many research findings in soil management aspect using precision farming techniques showed that the use of precision-farming technology has modest risk-reduction benefits in crop production. The benefits of this risk

reduction lead to higher profits in the long run. Overall, the use of site-specific strategies tends to decrease variability in the yields in a field.

There are several factors to consider before adopting precision-farming techniques in soil management. These include the extent of soil and crop variability as per the farmer's need and production system. Spatial information technologies include global positioning systems (GPS), geographical information systems (GIS), variable-rate technologies (VRT), and remote sensing (RS). If effectively used, precision nutrient application reduced the input cost, improves nutrient-use efficiency and reduces nitrous oxide (N_2O) emissions. Variable rate of application contributes further positively to use efficiency and crop productivity. Under irrigated conditions, gypsum or lime application as for soil pH information is one more area of precision farming application, which needs exploring in Indian conditions. The general observations with the pH soil sensor showed that, it is economically beneficial for the farmer if they were trained in the use of this technology. The pH sensor information based soil amendment application will give a moderate cost savings compared to the present practices of limited manual area sampling based recommendations. In irrigated crops in which more quantity of nitrogen is recommended, precise application of fertilizer dose in combination with quantified irrigation water reduces nitrogen losses from fields, besides achieving optimal levels of nitrogen for each area. Varying the water application rather than the nitrogen application as for the soil type and crop across a field, gives greater economic dividends as well as environmental benefits. This aspect also underlines the potentials of variable-rate technology (VRT) for increasing profit without affecting environmental quality. Nitrogen application using variable-rate technology has wider scope for crops like rice where flooding losses are more. Soil sampling is another important part of site-specific farming. Soil properties, such as texture, organic matter content, and landscape geomorphology have a considerable influence on the productivity of soils. The soil inventory ought to be done properly by soil surveying that combines GPS with the human-sensory capability. Self-surveying are remarkably appropriate for getting the basic soil information needed at a low cost. While many farmers in India use manual soil sampling, some research stations have begun to use sensing technologies to obtain soil information. The expected profit and profit variations from site specific inputs management depend on the accuracy of spatial information. In view of climate change scenario, the soil-management strategy is to monitor the lifecycle and optimize resource use at every step of the crop production chain and adopt the appropriate mitigation practices. The adoption of precision agricultural technology can also reduce the risk of non-point source pollution for multi nutrient elements in general. Similarly, precision tillage or guided traffic can reduce the risk of soil compaction and drainage problem in crop-production systems.

Improved fertilizer management tools/practices

Leaf colour chart: It is one of the non-destructive, quick, easy and low-cost technologies that can help the farmers in taking decisions of how much nitrogen

to be applied by comparing the colour of leaf from his field with the reference colour chart (Singh et al. 2010). In this method, leaf colour is generally used as a visual and subjective indicator for determining the need of N requirement of rice crop as the leaf colour intensity is directly related to leaf chlorophyll content and leaf-N status (Yoseftabar et al. 2012). The use of leaf colour chart for scheduling N application may not be uniformly applicable to all varieties that differ in inherent leaf colour and regions that differ in climate, thereby necessitating individual or group standardization in different cultivated areas.

Fertigation: Soil fertility is maintained/managed following by 4 R's—right fertilizer/manure, right time, right method and right place. A well-managed soil produces the maximum at the minimum cost. So maximizing soil health is also essential for maximizing profitability. Of the nutrient sources, fertilizers have been widely used for meeting the nutrient requirement of the plants. Due to some soil and climate-related properties and process like fixation, volatilization, leaching, erosion and denitrification, the efficiency of applied nutrients are very low. In order to enhance the efficiency of the externally added nutrients, researchers have proposed alternate methods/products like slow/controlled-release fertilizers, application of nutrients through irrigation water (fertigation) and as foliar sprays.

Fertigation is the application of water soluble fertilizer or liquid fertilizer through drip/sprinkler irrigation system. This system of applying water and fertilizer has impressed the farming community in humid, arid and semi-arid regions. Soman (2009) reported that through micro-irrigation such as drip application or fertigation, it is possible to increase the yield of vegetables, save water and also enhance the fertilizer-use efficiency by controlling the leaching losses, synchronization of crop need with nutrient application, supplying the nutrient directly to the root zone and by ensuring uniform flow of water and nutrients. The high cost of setting up fertigation system, clogging of lines due to precipitation of bicarbonates and insoluble dicalcium phosphate, magnesium phosphate and calcium carbonate and salt injury in arid regions due to evaporation of anions and accumulation of cations like sodium and calcium hinder the benefits accruing from fertigation. The benefits of fertigation can be maximized by the availability of soluble and compatible fertilizer, good quality of water, and synchronization of plant demand and supply of nutrients, lack of precipitation of phosphatic fertilizers with micronutrient mixtures, availability of corrosive resistant fertigation systems.

Foliar sprays: Foliar fertilization refers to the supplementation of major, minor, beneficial, plant hormones, stimulants and other beneficial substances to the plants by applying them through sprays. Foliar supplementation has several advantages such as meeting the nutrient demand of the crops through foliar sprays grown in moisture deficient soils in rainfed areas. During severe nutrient-deficiency conditions, it facilitates rapid absorption of the nutrient and thereby minimizes the deficiency impact. It also helps in avoiding the nutrient fixation and immobilization due to various soil chemical interactions. The advantages of foliar sprays are, among others, plant uptake, independent of root, use of only small quantities of

Table 16.2 Yield of maize under different nutrient treatments.

<i>Treatments</i>	<i>Quantum readings</i>	<i>Grain yield (t ha⁻¹)</i>	<i>Straw yield (t ha⁻¹)</i>
No fertilizers	0.684	1.8	2.1
RDF ^a	0.723	2.9	4.0
RDF + FS ^b of 1.5 KCl at 25 DAS ^c	0.717	3.1	4.2
RDF + FS of Se at 20 g ha ⁻¹	0.728	3.2	4.1
RDF + FS of 0.25 % ZnSO ₄ at 25 DAS	0.721	3.3	4.2
RDF + soil application of Se at 20 g ha ⁻¹	0.710	3.0	4.1
basal			
RDF + FS of 1.5% KCl + 0.25% ZnSO ₄ + Se at 20 g ha ⁻¹	0.743	3.4	4.8
LSD (P=0.05)	-	0.3	0.5

^aRDF, recommended dose of fertilizer (90-60-60, N-P-K); ^bFS, foliar spray; ^cDAS, days after sowing

fertilizer and ability to combine with other agro-chemicals in single application and increased quality and yields. Foliar spraying of 1.5% potassium chloride + 0.25% zinc sulphate + sodium selenite (@ 20 g ha⁻¹) to maize enabled the maize to withstand drought conditions as evident from the higher quantum readings (Table 16.2) taken after one month of spraying, photosynthetic efficiency in terms of chlorophyll fluorescence readings, showing drought tolerance (Table 16.2) which is enhanced due to increased quantum efficiency (CRIDA 2011-12).

Some of the constraints of foliar spray are the possible occurrence of foliar burns due to high dose of spray, solubility and compatibility problems with conventional fertilizers, the requirement of optimum weather conditions for application, the inability to supply sufficient chemical if deficiency is severe. Speciality fertilizers like water-soluble fertilizers which are 100% soluble in water, without leaving any residue, can overcome the problem of solubility and compatibility posed by the conventional fertilizers and can be successfully employed for meeting the nutritional requirement of rainfed crops through foliar spray.

Slow release and controlled fertilizers: The conventional fertilizers are coated with materials including sulphur, polymer, latex, oil and other synthetic substances, which control nutrient release that tends to match the nutrient need of the growing plants. Voluminous reports are available in the literature to prove that these products have been used successfully as they reduce nutrient losses and thereby enhance their use efficiency. Kabat and Panda (2009) have reported that in on-farm trials on improvement of N use efficiency in direct sown rice (cv. Durga), grown on alluvial soil under unfavourable rainfed lowland conditions of Cuttack district of Odisha, basal furrow placement of CRN (controlled release N fertilizer)-6C +PU (prilled urea) at 3:1 ratio registered 25% higher grain yield and higher N use efficiency (25 kg grain kg⁻¹ N added) than the conventional practice of basal broadcasting of PU (14 kg grain kg⁻¹ N added) (Table 16.3).

Table 16.3 Effects of placement of different nitrogen fertilizers (including CRN) on yield, N uptake and N use efficiency of rainfed lowland direct sown rice cv. Durga under farmers' field conditions of the village Samantrapur in the district of Cuttack.

<i>Treatment</i>	<i>Grain yield (t ha⁻¹)</i>	<i>Relative efficiency (%)</i>	<i>Total N uptake (kg ha⁻¹)</i>	<i>NUE (additional kg grain kg⁻¹ nutrient)</i>	<i>ANR (%)</i>
Control (N ₀ N)	1.76	69	33.0	-	-
PU basal broadcasting	2.60	100	56.4	14	39
PU basal furrow placement	2.92	112	51.4	19	31
USG deep placement	2.83	109	66.4	19	59
CRN-6C + PU (3:1) basal furrow placement	3.25	125	63.8	25	51
CD (P=0.05)	0.86	-	13.3	-	-

NUE, nitrogen use efficiency = $(Y_t - Y_0)/N$, ANR, apparent nitrogen recovery from fertilizer (%) = $100 (N_t - N_0) / N$, where, Y_t = grain yield in kg ha⁻¹ with N treatment, Y_0 = grain yield in kg ha⁻¹ with 'No nitrogen' control, N = amount of fertilizer nitrogen applied to the crop in kg ha⁻¹, N_t = nitrogen uptake by rice crop in kg ha⁻¹ with N treatment and N_0 = nitrogen uptake by rice crop in kg ha⁻¹ with 'No nitrogen' control. PU, prilled urea; USG, urea super granules; CRN, controlled release N fertilizer

However, controlled release fertilizers (CRFs) are more expensive than conventional fertilizers, nutrient release is difficult to predict for the CRFs and some coating materials can even harm the environment. Also, the CRFs mainly focus on regulating N release without considering the requirements of other nutrients such as P and K, and this may hinder balanced plant nutrition of crops. Low cost, effective and environment friendly controlled-release fertilizers are urgently needed for use in the semi-arid rainfed areas.

Integrated nutrient management: There is a growing concern about soil-health deterioration mainly due to low or depleting soil organic matter both in irrigated and rainfed agro ecosystems. This is quite serious in rainfed drylands as crop-growing period is shorter (mainly rainy season) and during most part of the year, soils are exposed, thereby allowing soil organic carbon loss in the form of CO₂.

Soil health and net primary productivity (NPP) is always governed by soil organic matter (SOM) dynamics. Low biomass production is due to decline in soil fertility in most of the tropical and sub tropical countries. The overall strategy for increasing crop yields and sustaining them at a high level are related to maintenance of soil health. Integrated nutrient management (INM), on-farm soil organic matter generation, cover crops, mulch-cum-manuring, residue burning and recycling, organic waste recycling, agro-forestry are important technologies to improve soil organic carbon status. Therefore, efficient natural resource management practices are needed for maintaining long-term sustainability and food security. Important selected strategies for maintaining soil organic carbon (SOC) are discussed below.

The INM options depending upon the locally available organic resources improve SOC sequestration rate and increases the concentration of SOC in major rainfed crop-production systems such as groundnut, finger millet, winter sorghum, pearl millet, cluster bean, castor, soybean, safflower, lentil and upland rice in soil of the semi-arid tropics, India (Srinivasarao et al. 2012; 2013a). This also impacts agronomic productivity as a result of increased SOC stock in the root zone, and by climate change mitigation (Srinivasarao et al. 2014a,b; 2015a).

Cover crops contribute to the accumulation of organic matter in the surface soil (Venkateswarlu et al. 2007), helps with the recycling of nutrients, especially when legume cover crops are used, through the association with below-ground biological agents and by providing food for microbial populations.

Green manures leave the residual N up to 60–120 kg ha⁻¹ to the succeeding crop (Srinivasarao et al. 2013a). *Gliricidia* and *Tephrosia* are two most commonly used green leaf manures. *Gliricidia* leaves contain 2.4% N, 0.1% P and 1.8% K besides all other secondary and micro nutrients. *Gliricidia* plants grown on 700 m long bunds can provide about 30 kg N ha⁻¹ yr⁻¹. Usually, about 1-2 t ha⁻¹ leaves can be applied. One ton *Gliricidia* leaves provide 24 kg N, 1 kg P, 18 kg K, 85 g Zn, 164 g Mn, 365 g Cu, 728 g Fe in addition to considerable quantities of S, Ca, Mg, B and Mo. Deciduous nature of *Faidherbia* during the rainy season provides a scope of successfully raising of annual crops under tree without much competition for light. Huge leaf fall of *Faidherbia* adds a significant amount of nutrients to the soil.

Agro-forestry systems like agri-silviculture, silvi-pasture and agri-horticulture offer opportunities of both adaptation and mitigation. Recent studies showed that by implementing above technologies at farmers' fields, overall village level carbon balance can be a positive. The FAO Ex-Act model-based studies indicated that besides improving village-carbon balance, these technologies have potential to reduce and mitigate principal greenhouse gas (GHG) emissions (Srinivasarao et al. 2015c).

CONCLUSION

Strong awareness need to be created to the effect that soil-health deterioration is a serious problem; and to effectively improve soil health, prudent soil-management technologies should be implemented at the farm level. Sole dependence on chemical technology-intensive agriculture is no longer sustainable; and regional level or ecosystem use of INM technologies need to be promoted with a suitable policy support, while bringing the INM technology in national programmes such as National Mission for Sustainable Agriculture (NMSA), Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA), Soil Health Programme, National Horticulture Mission (NHM) and Organic Farming. Improvement of soil biological health by organic matter recycling, agro-forestry involving N-fixing shrubs, CA practices, fortified composts, biofertilizers needs focused approach to bring them to the ground level. Location- specific integrated farming systems

models play a significant role in soil-health management and are included in NMSA. Modernization of soil testing laboratories, addressing training needs to staff and confidence building mechanism on soil-testing programme among farmers are also important. While financial incentives are required for farmers for practicing better soil and crop-management technology, appropriate attention is also required to discourage the farmers who practice crop-residue burning and indulge in indiscriminate use of chemical fertilizers. Linking the fertilizer subsidy to soil health card scheme would contribute to energy efficient agriculture, which is sustainable and eco-friendly with less GHG emissions.

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