REVIEW ARTICLE OPEN ACCESS

Soil Health Improving Strategies for Resilient Rice Based Cropping Systems of India

Ch. Srinivasarao, K. Srinivas, K.L. Sharma, Sumanta Kundu

Central Research Institute for Dryland Agriculture, Saidabad, Santoshnagar, Hyderabad- 500059
Email Id: cherukumalli2011@gmail.com

Received: 22nd June, 2016 Accepted: 4th January, 2017

Abstract

Rice and rice based cropping systems contribute largely to the total food production, sustainability of this system is vital for food and nutritional security. Because of its wide adaptability to diverse soil types and conditions including problem soils (for its beneficial effects during soil amelioration), the crop encounters a variety of field problems which are further aggravated by improper and inefficient management of resources and inputs. Sustainable rice production through soil health management can be achieved by adopting integrated nutrient management, site specific nutrient management and also conservation agriculture practices. Research reports of long term studies reveal that organic manures in addition to fertilizers sustain high crop yields over long periods compared to application of only fertilizers. The results also indicate the scope for substituting more than 25% of recommended dose of NPK with organic sources in intensive cropping systems. Under ideal conditions, green manures and grain legumes when integrated into the cropping system have the potential to meet more than 50% of N requirement of the immediate rice crop. Similarly, site specific soil nutrient management (SSNM) approach was utilized in rice-wheat system at several locations to evaluate its application for achieving total system productivity of 15-17 tons/ha and also in rice-rice cropping systems. Conservation agriculture based resource conserving technologies (RCT's) such as zero tillage and bed planting were also being promoted in rice-wheat system for maintenance of soil fertility. This paper deals with some of the important strategies of soil health and nutrient management for Resilient Rice Based Cropping Systems of India.

Keywords: Soil Health, Rice based cropping systems

Introduction

Rice is the most important food crop of the country contributing nearly 45% to the total food grain production. The crop ranks first in the use of land (> 44 M. ha) and water resources (> 50% irrigation water), and inputs (38-40% of fertilizers and 17-18% of pesticides) but the efficiency of these inputs is considerably low (RKMP, http://www.rkmp.co.in/fertimeter).

Rice farming is practiced in diverse agro-ecological zones, but most of the rice farming occurs in warm/cool humid subtropics, warm humid tropics and in warm sub-humid tropics. Rice farming is practiced in several agro ecological zones in India. No other country in the world has such diversity in rice ecosystems than India. Because the rice cultivation is so widespread in India, the following four distinct rice ecosystems have been recognized (DRD, 2014).

- Irrigated Rice Eco System
- Upland Rice Eco System
- Rainfed Lowland Rice Eco System
- Flood Prone Rice Eco System

In irrigated rice ecosystems, the rice fields have assured water supply for one or more crops a year. This is the major rice ecosystem. The rainfed lowland ecosystem is characterized by low soil moisture and the soils are often hungry and thirsty for major part of the year. The upland rice ecosystem exists in several forms such as shifting or Jhum rice and permanent settled rice cultivation. This is cultivated on level to sloppy fields/plots. These fields are rarely flooded and mostly aerobic. Rice is directly seeded on plowed dry soil or dibbled in soil. In flooded rice ecosystem, the fields are level to slightly sloping or depressed fields. Fields are flooded to 50 cm or more for more than ten consecutive days during crop growth. Rice is transplanted in puddled soil.

Some of the rice based cropping patterns being followed in India are: Rice-Rice-Rice, Rice-Rice-Cereals (other than rice) Rice-Rice-Pulses, Rice-Groundnut, Rice-Wheat, Rice-Wheat-Pulses, Rice-Toria-Wheat, and Rice-Fish farming system (DRD, 2014). Among the above mentioned cropping patterns followed in the country, Rice-wheat cropping pattern is the largest one and is being practiced in the Indo-Gangetic plains of India for a long time.

With no scope for further increase in net cultivated area (~142 M. ha), much of the desired increase in food grain production in India has to be attained through productivity enhancement of major crops like rice, wheat, maize (which contribute > 80% to total food grain production) by 3.0 to 7.5% annually (NAAS, 2006). While fertilizers, together with improved varieties and irrigation have contributed significantly to the overall growth in productivity of rice, declining use of organic manures, imbalanced and blanket application of fertilizers without proper rationale are causing deterioration of soil health in soils under rice production. While there is further need to increase cropping intensity, efficient management of inputs and resources including organics and inorganics to enhance input use efficiency is essential to economize on input costs and to improve factor productivity.

Rice growing soils in India

More than 15 major soil groups of diverse characteristics are cropped to rice under different ecosystems (rain fed upland to deep water and irrigated), and agro climatic conditions. The crop is grown in 11 out of 15 agro climatic zones (west and eastern Himalayas, IGP, major portion of southern and eastern plateau region, eastern and western coastal region and the islands of Indian Ocean). Major soil types that are cropped to rice and rice based cropping systems listed in the Table 1 suggest that predominantly alluvial soils, red and yellow loams, shallow to deep black soils and lateritic soils are cultivated to rice. More than 50% of land area in the country is affected by various soil problems that influence the agricultural productivity. Rice having the largest area (~ 45.0 M.ha) in the country and the world is grown in a variety of soil types with wide range of characteristics. In brief, the soil characteristics vary widely from sandy loam to clay in texture; soil pH from 3.0-10.5; organic carbon from 0.2 to > 2.0%; cation exchange capacity (me/100g soil) from < 10.0 – 50.0; and very low to high available nutrient status (Rao *et al.,* 2013).

Table 1. Major rice soils in India

Soil	Classification
Riverine and coastal alluvium	Inceptisols, Entisols
Red and yellow loams	Alfisols
Hill, submontane and terai soils	Inceptisols, Alfisols, Mollisols
Laterites	Ultisols, Oxisols
Peaty soils (acidic)	Inceptisols
Shallow black soils	Inceptisols
Medium and deep black soils	Vertisols

Rao et al., (2013)

Flooding and puddling of a soil brings about a series of physico-chemical changes, the intensity and extent of this change depend, however, on the initial soil characteristics before flooding.. Flooding soil is a great pH neutralizer. In problem soils, this neutralizes acidity and alkalinity thereby influencing favorably to an extent in the release and availability of plant nutrients. As rice and rice based cropping systems contribute largely to the total food production, sustainability of this system is vital for food and nutritional security. Further, water shortage being experienced in the country is threatening the conventional rice cultivation system warranting a re-look into the current practices and design strategies for enhancing resource quality and water productivity.

Because of its wide adaptability to diverse soil types and conditions including problem soils (for its beneficial effects during soil amelioration) the crop encounters a variety of field problems which is further aggravated by improper and inefficient management of resources and inputs. Important soil and management related constraints / problems encountered in rice production in India are listed as follows:

Soil and management related constraints in rice production in India

- Increasing area under soil salinization (8-10 M ha) (salt affected) - major portion is cropped to rice
- About 15 M.ha of rice soils are acidic associated with toxicity of Fe, Al, Mn and As
- Deficiency of K, Ca, Mg, B, Si, and problem of P fixation
- About 8.0 M.ha of rice area is deficient in zinc (Zn)
- Nearly 50 and 80% of Indian soils are responsive (low to medium) to potassium and phosphorous, respectively
- Blanket fertilizer management/recommendation over large domains
- Nutrient depletion (N, K, S) and loss of soil organic matter in intensive cropping systems
- About 3.0 M ha area in northwestern states under rice-wheat cropping system is affected by Mn deficiency
- Nutrient problems related to deficiency of N, P, K, Zn, Fe, S, Ca, B, and toxicity of Fe, Al, H_2S, As and Se
- Overall stagnation or deceleration of growth in productivity of crops and cropping systems
- Wet season rice followed by dry season fallow causes considerable buildup of nitrate in soil profiles. This NO_3 gets lost from the soil when fields are reflooded and puddled for planting rice in the following wet season
- Data indicate that iron (Fe) content of ground water in all the districts is high due to high content of Fe-bearing minerals in soils, and such ground water is not suitable for irrigation unless properly managed. Continuous

use of such irrigation water causes Fe- toxicity and other nutrient imbalances in crop plants. It also greatly reduces P availability in the soil. Precipitation of iron in surface and subsurface layers may clog the pores of the soils. As a result, drainage is impeded and crop plants suffer from inadequate O_2 supply in the root zone.

Sustainable rice production through soil health management can be achieved by following integrated nutrient management, site specific nutrient management and by following conservation agriculture practices.

Nutrient requirements of rice based cropping systems

Production of each ton of rice grains removes 20.1 kg N, 4.9 kg P, and 25.0 kg K, while one ton of wheat grains removes 24.5, 3.8, and 27.3 kg N, P, and K, respectively (Tandon and Sekhon, 1988). Information on nutrient removal by intensive cropping systems is required for developing future nutrient management strategies which vary substantially.

Integrated Nutrient Management

The basic concept underlying INM is the maintenance of soil fertility, sustainable agricultural productivity and improving profitability through judicious and efficient use of fertilizers, organic manures, crop residues, bio fertilizers, suitable agrochemical practices, conservation agricultural practices and nutrient efficient genotypes. The system also involves monitoring all the pathways of nutrient flows in the cropping system from all the sources to maximize the profits.

Organic sources of plant nutrients include growing of legumes in the cropping system, green manures, crop residues, organic manures (FYM, compost, vermicompost, biogas slurry, phosphocompost, biocompost, pressmud, oil cakes etc) and bio fertilizers. Available information show that organic manures in addition to fertilizers sustain high crop yields over long periods as compared to application of only fertilizers as observed in many long term studies. The results indicate scope for substituting more than 25% of recommended dose of NPK with organic sources in intensive cropping systems. Under ideal conditions, green manures and grain legumes when integrated into the cropping system have the potential to meet more than 50% of N requirement of the immediate rice crop. Further, addition of organic manures as part substitutes or supplementary (add on) improved soil physic-chemical and biological properties and ultimately its quality. Biofertilizers (N fixing, P solubilising, cellulolytic microorganisms) facilitate economizing fertilizer nutrient use through utilizing BNF systems, solubilising less mobile nutrients from fixed components and recycling of nutrients from crop residues. Integration of such systems makes the production system more stable and sustainable.

Legumes and green manures

Legumes are considered as soil builders and rice-legume is more ideal in terms of nutrient addition, especially N and also helps regenerate destroyed rice soil structure (on account of puddling) through their favourable rhizosphere effects. Similarly, in upland rice-chick pea system, chick pea system improves P availability by acidifying its rhizosphere due to its acidic root exudates like citric acid. This supplies P in addition to N to the succeeding upland rice which lacks advantage of flooding. Inclusion of legumes in the cropping sequence gives a lot of scope to economise on certain nutrients. The experimental results from rice-wheat and berseem-rice indicated that there is considerable opportunity to save on P application for rice, if the preceding crops of wheat and berseem receive recommended dose of P. In cereal-legume or oil seed-legume, legumes need small amounts of P fertilizer and virtually no N and the fertilizer inputs can go to the non-legume component.

Grain and fodder legumes and green manures can fix atmospheric N to the extent of 50-500 kg/ha. The residues of legumes after harvest contain 25-100 kg/ha N which is available to the next crop upon decomposition. Green manures under many situations can meet N demand of crops more efficiently than fertilizer urea (Rao *et al.*, 1991). The rate of N release from the green manures depends on the characteristics such as N content, lignin content, etc The practice of growing green manures is on the decline due to increased cropping intensity and availability of fertilizers at subsidized rates, and non availability of green manure seed. Inclusion of grain or fodder legumes in the cropping system is a viable alternative to green manure crops.

Crop residues

Crop residues are good sources of plant nutrients and are important components for the stability of agricultural ecosystems. About 500 million tons of crop residues are produced in India alone (MNRE, 2009). In areas, where mechanical harvesting is practiced, a large quantity of crop residues are left in the field, which can be recycled for nutrient supply. About 25% of nitrogen (N) and phosphorus (P), 50% of sulfur (S), and 75% of potassium (K) uptake by cereal crops are retained in crop residues, making them valuable nutrient sources. Both rice and wheat are exhaustive feeders, and the double cropping system is heavily depleting the soil of its nutrient content. A rice-wheat sequence that yields 7 tons per ha of rice and 4 tons per ha of wheat removes more than 300 kg N, 30 kg P, and 300 kg K per ha from the soil. If crop residues could be better managed, this would directly improve crop yields by increasing soil nutrient availability, decreasing erosion, improving soil structure and increasing soil water holding capacity as a consequence of improving soil organic matter content (Yadvinder Singh *et al.,* 2005).

Rice residue management options

There are several options for managing crop residues. These include being removed from the field, left on the soil surface, incorporated into the soil, burned *in situ*, composted or used as mulch for succeeding crops. Throughout the tropics, there is little recycling of crop residues in the field – these are either harvested for fuel, animal feed or bedding or are burned in the field. Crop residues removed from the field can also be used as bedding for animals, a substrate for composting, biogas generation or mushroom culture or as a raw material for industry. In many parts of the tropics, crop residues are burned in the field due to the ignorance of farmers about their value and lack of proper technology for in situ incorporation of residues. For example, in the intensive rice-wheat cropping system in the Indo-Gangetic plains of South Asia, crop residues, particularly rice straw are not used as animal feed and are disposed of by burning. Complete burning of rice straw at 470°C in muffle furnace resulted in 100, 20, 20 and 80% losses of N, P, K and S, respectively (Sharma and Mishra, 2001).

Decomposition of rice residues

Decaying of crop residues starts as soon as the residues come into contact with the soil. The process of decomposition is controlled by the interaction of three components:the soil organisms or biological processes, the quality of crop residues, and the physical and chemical environment. Burying of rice straw in soil has been reported to accelerate the decomposition in comparison with placing the straw on the soil surface (Kumar and Goh, 2000). Residues rich in lignin and polyphenol contents experience the lowest decay. A large number of organic compounds, particularly phenolic acid and acetic acid are released during the decomposition of crop residues under anaerobic conditions. The accumulation of these organic compounds can adversely affect the seedling growth.

Residue management effects on soil properties

Crop residue management is known to affect either directly or indirectly most of the soil quality indicators-chemical, physical and biological. It is perceived that soil quality is improved by the adoption of sound crop residue management practices (Karlen *et al.,* 1994). Long-term application of crop residues increased the organic matter, total N content and availability of several nutrients (though to a small extent) in soils. The rate of increase in soil organic matter is low due to high turnover rates of C under tropical conditions. Mineralization and immobilization of N occur simultaneously in the soil. The residue quality and availability of soil N are important determinants of N mineralization-immobilization occurring during residue decomposition. The application of crop residues can cause short-term immobilization of both P and S, particularly in aerobic soils. Only a small fraction (5%) of the residue P is available to the plants in the first year, and a major fraction is immobilized as microbial biomass (Stevenson, 1986). Crop residues contain large amounts of K, which upon incorporation increased K availability in soil and helped to reduce K depletion from non-exchangeable K fraction of soil (Chatterjee and Mondal, 1996). Microbial biomass, a small (1-5% by weight) but active fraction of soil organic matter, is of particular concern in soil fertility considerations because it is more susceptible to management practices than the bulk organic matter (Janzen, 1987).

In South Asia, rice crop occupies a major share of total arable land. The recycling of its residues has the great potential to return a considerable amount of plant nutrients

Table 2. Effect of long-term crop residue management on grain yields (t ha^{-1}) of rice and wheat

Crop Residue	N applied (kg ha^{-1})			Mean
	60	120	180	
	Rice (Mean of 10 years)			
Burned	4.65	5.65	6.42	5.57
Removed	4.46	5.50	6.04	5.53
Incorporated	3.62	4.63	5.26	4.51
Mean	4.24	5.26	5.91	
LSD (P=0.05)	Residue 0.55	N 0.16	Residue × N NS	
	Wheat (Mean of 11 years)			
Burned	3.46	4.26	4.64	4.12
Removed	3.48	4.14	4.42	4.02
Incorporated	2.94	3.87	4.34	3.72
Mean	3.29	4.10	4.47	
NS LSD (P=0.05)	Residue 0.25	N 0.22	Residue × N NS	

(Mandal et al., 2004)

to the soil in the rice based crop production systems. Particularly the rice-wheat cropping system is the most intensive production system in the country (Table 2). The yield stagnation consequent upon the declining soil organic carbon is a major threat to this system. Therefore, it is a great challenge to the agriculturists to manage rice residues effectively and efficiently for enhancing sequestration of carbon and maintaining the sustainability of production.

Organic manures

Organic manures vary in their nutrient content, quality and utility as sources of nutrients. When properly managed, they have potential as nutrient sources to supplement 25-35% of nutrient requirements of crops. In rice-wheat system, FYM @ 15.3 t/ha applied to rice was up to 90% as efficient as 150:60:60 kg NPK, while in wheat, FYM applied @ 20-40 t/ha was only 35-45% efficient because of slow nutrient release due to low temperatures. While FYM alone was not so efficient, combined application of FYM and NPK was found to be highly efficient (DRR, 2007; 2008). Long term studies by DRR (DRR, 2007) indicated significant improvement in soil organic carbon with FYM. The increase ranged from 4-49% (Swarup, 2002). FYM influenced soil nutrient status positively and brought about many changes in the physical and biological properties of the soil (Hegde, 1998).

Vermicomposts

Vermicomposts contain higher concentrations of NPK compared to FYM and are usually more effective in promoting crop growth than FYM, presumable due to higher nutrient concentration and better manure characteristics (Barik *et al.*, 2006). The impacts of vermicompost on soil quality were found to be superior to FYM in many cropping systems.

Poultry manure (PM)

Poultry manure has much higher concentrations of NPK, especially P, which makes it a good nutrient source. A laboratory study showed that 45% of PM-N mineralized in 4 weeks as against 12% from FYM (Yadvinder Singh *et al.*, 1988). As nutrient source for rice, 4 t PM + 60 kg N/ha was equivalent to 120 kg N/ha as urea (Yadvinder Singh and Meelu, 1995).

Biogas slurry (BGS)

Biogas slurry contains about 1.4, 1.2 and 1.0% NPK and was as effective as urea for rice and wheat in light textured soils at IARI. It is more efficient source of nutrients than urea alone when more than 50% N requirement is substituted with BGS.

Biocompost (BC)

Biocompost is prepared by mixing press mud cake (PMC) with spent wash from distilleries and contains 1.9, 1.85 and 1.5% NPK besides many micronutrients. It was reported to be a more efficient source than fertilizers when applied @ 5 t/ha BC + 50% RDF for wheat. The material also influenced soil quality (nutrient supply, OC) and recorded 22% more wheat yield (Tripathi *et al.*, 2007).

Press mud cake (PMC)

Press mud cake is a waste product of sugar industry, and about 9.0 m.t. is produced annually. It contains about 1.6, 1.0 and 0.8% NPK. Applied @ 5.0 t/ha along with 40-60 kg N/ha to rice, PMC was equally effective as 120 kg N/ha as urea with significant residual effects on wheat to the extent of 40 kg N and 13 kg P/ha (Yadvinder singh *et al.*, 2003). The material also improved soil OC by 50%, total N by 60% and the biological properties by 91% (SMBN).

Phosphocompost (PC or PEC)

Phosphocompost enriched with P (SSP or RP) can be a good organic source of nutrients particularly of P in phosphorous fixing soils. Following NADEP method of composting Increase in P content from 0.69 to 0.92 and 0.98% when enriched with RP and SSP, the latter also improving N content by preventing loss of N through ammonia volatilization during composting has been reported. Combining PSB inoculation with phospocomposting (RP) improved the citrate soluble P (Mishra *et al.*, 1984) which makes it useful even in calcareous soils.

Biofertilizers

Biofertilizers are cultures of micro organisms that are capable of fixing atmosphere N, solubilise less soluble P, mobilise native soil P and K and for accelerating decomposition of organic material while composting or in the fields that of crop residues. N fixers are symbiotic (Rhizobium sp.,) and non symbiotic (Azotobacter; Azospirillum; blue green algae, Azolla *etc.*). Rhizobium cultures are used for the legumes, the residues of which can be recycled into the cereal crop system while Azospirillum BGA and Azolla are directly used in the rice fields. Estimates of N fixation in rice fields ranged from 25-30 kg N/ha by BGA and was reported to increase rice yield by 14%. These were found complimentary to GM and use of neemcake coated urea (NCU) (Singh *et al.*, 1990). BGA inoculation with 50% N as NCU was reported to be equivalent to 120 kg N/ha as urea.

Azolla (fern) has been used as N fixer in rice in China since 6th century. Under field conditions, it can fix 30-40 kg N/ha but requires 15-20 kg P205/ha to fix N. Azolla is grown simultaneously with rice as a dual crop but it is more useful as a source of N when used as a green manure. Phosphate solubilizing organisms (PSB, PSO, PSF) play an important role in solubilizing insoluble P compounds in soil..The organic acids (gluconic, lactic, citric, tantaric acids) released by PSO decompose rockphosphates and release P.

Application of RP with PSO is reported to increase yields of rice. Comparable efficiency of RP + PSO and DAP which improved further with the supplementation of crop residues has been reported. PSOs along with RP are more effective for pulses with different levels of yield improvement but more in the presence of soluble P inoculated with PSO.

Nutrient efficient genotypes

Genotypes differ in their response to applied nutrients, utilization efficiency and nutrient requirement. Exploiting this variability to identify and utilize in specific environments would economize costs on nutrient use and conserve resources. Some of the rice varieties like Rasi, Vikas, RP 5929, some of rice hybrids, etc are reported to be efficient utilizers of nutrients.

Site Specific Nutrient Management (SSNM)

Major factors contributing to the low and declining crop responses to fertilizer nutrients are continuous nutrient mining from the soil due to imbalanced nutrient use (7:2.8:1 NPK) leading to depletion of some of the major, secondary and micro nutrients like N, K, S, Zn, Mn, Fe, B *etc.*, decreasing use of organic nutrient sources such as FYM, compost and green manures / grain legumes in the cropping systems and mismanagement of irrigation systems leading to serious soil degradation.

Sustainable crop production management involves replenishing of nutrients that are removed by crops while taking into consideration other net influxes of nutrients. Indian agriculture is operating at an estimated negative nutrient balance of 10 M. tons. Trends in nutrient use of 23 M tons in 2007-08 is expected to increase to 29.0 M tons (20.7 N, 6.8 P_2O_5 and 2.1 K_2O M. tons) by 2025. However, at the estimated nutrient removal of 37.5 M. tons of NPK (11.9 N + 5.3 P_2O_5 + 20.3 K_2O M. tons), the balance indicates an excess use of N and P_2O_5 and deficit use of nearly 18 M tons of K_2O nutrients which would be alarming. Potassium accounts for 55% of NPK removal, while N and P accounts for 31 and 14% of crop uptake. To achieve the projected food grain demand of 300 M. tons by 2025, about 30 M. tons of NPK from various sources are required in addition to 15 M. t. for the commercial crops totaling nearly 45 M. t (Tiwari, 2001).

Rice – Wheat - Cowpea fodder system removes about 270 kg N/ha, 150 kg P_2O_5/ha and 390 kg K20/ha (total > 800 kg/ha). Annual removals of NPK could range from 440 - 815 kg/ha under high intensity cropping systems. Production of about 8-12 tons of grain/ha is associated with nutrient uptake of 140-330 kg N, 70-120 kg P_2O_5/ha and 200-390 kg K_2O/ha which provides guidelines for framing nutrient management strategies.

Nutrient Management and recommendation process in India is still based on response data arranged over large domains. The SSNM provides an approach for need based feeding of crops with nutrients while recognizing the inherent spatial variability. It aims at nutrient supply at optimal rates and times to achieve high yield and efficiency of nutrient use by the crop. SSNM approach involves three steps – establishing attainable yield targets, effectively use existing nutrient sources and application of fertilizers to fill the deficit between demand and supply of nutrients. Soil nutrient supply potential and its spatial variability, productivity potential and targets for crops and cropping systems, estimation of nutrient requirements, and fertilizer use efficiency besides assessment of resource quality and socioeconomic background of the farmers are essential for developing site specific IPNS.

The SSNM approach followed in India aims at maximizing farmers' profits by achieving maximum economic yield (MEY). The SSNM approach was introduced in priority areas facing one or more of the problems like imbalanced nutrient use with low yields, crops showing nutrient deficiencies in large scale, endemic to pests and diseases linked to nutrient management, evidences of P and K mining and in areas of multi-nutrient deficiencies particularly of secondary and micronutrients. The available knowledge on SSNM was utilized in rice-wheat system at several locations to evaluate its application for achieving total system productivity of 15-17 tons/ha (Tiwari *et al.*, 2006) and also in rice-rice cropping systems. The results were encouraging with highest annual grain yields of > 16t/ha at Modipuram, Ludhiana; 14-16 t/ha at Kanpur; 12-14 t/ha at Faizabad, Varanasi, Pantnagar, Sabour, R.S.Pura; 10-12 t/ha at Ranchi and 8-10 t/ha at Palampur. Averaged over all locations, SSNM showed yield advantage of 3.4 t/ha or 34% over farmers' fertilizer practices with benefit cost ratio of 4.9 (additional income > Rs 15000). In many locations yields of rice were more than 10 t/ha because of hybrids.

Real time N management using LCC

Leaf colour chart approach is very important in managing N in rice crop. Some of the steps include

- Leaf color chart (LCC) is used only for top dressing of N
- Read the color of top few leaves at 7-10 days interval from early tillering to booting stage
- Apply fertilizer N @ 50, 75, 100 or 125 kg urea / ha as top dressing, respectively for low, medium, high, or very high response environments each time at tillering and 3-5 days before panicle initiation stage

Management of nutrients other than Nitrogen:

Phosphorous (P) management:

The second most important plant nutrient, P is required for better root and shoot growth, starch mobilization and as source of energy. P is mobile within the plant and promotes tillering, root development, early flowering, and ripening. It is particularly important in early growth stages. Hence all recommended P should be applied as basal dose. Rice requires 5-9 kg P_2O_5 / ton of grain and recovers about 15-25% of applied P with substantial residual effects. Depending on site characteristics, for a 6.0 t target yield/ ha, about 50 kg P_2O_5 /ha fertilizer is required at native soil productivity of 4.0 t/ha, 6 kg P_2O_5 /ton requirement and 25% recovery efficiency.

Potassium (K):

Indian soils though show medium to high K fertility, the outflow of K by crops and cropping systems is very high (at 20-25 kg $K_2$0/ton grain). At the current levels, overall balance of K in the system is negative in majority of the cropping systems needing K application in quantities sufficient to prevent depletion of the nutrient to acute levels.

- Recommended sources of K are MOP (50%) and paddy straw (50%)
- Half of the recommended K should be applied as basal and remaining half at panicle initiation stage especially for hybrid rice.
- Recycling of crop residues rich in K, split application in high productivity systems (eg. Hybrids), additional dose of K in acid soil environments prone to iron, Al, sulfide toxicity etc all benefit the crop system and support high crop production.
- The strategy involves diagnosis and application of deficient nutrients. More important in the management of these nutrients is whether to apply, if so how to apply and the timing rather than how much to apply.

Zinc (Zn): The zinc is widely deficient in Indian rice soils (>8.0 million ha) and is required in initial stages of rice growth for developing aerenchyma tissue, biosynthesis of auxins, protein synthesis and gene expression. Soil application in acutely deficient in high pH soils (@ 30-50 kg/ha) and/or mid season correction by spraying $ZnSO_4$ or chelated zinc (0.50%) are recommended.

Sulphur (S): Being a constituent of important amino acids such as cysteine, cystine, methionine and proteins, and generally required in larger quantum for oil seed crops, the outflow of S even by cereal crops like rice is also high (3-5 kg/ton grain). This suggests for efficient S management considering the total S removal by a cropping system particularly in high rainfall rain fed lowland rice systems where reports of S depletion and response to S application have been reported. Non-use of S fertilizers and increasing cropping intensity are also contributing to the emerging problems of S nutrition. S sources like gypsum, phosphogypsum, ammonium sulphate, elemental S, and organic manures / crop residues as a part of INM are recommended to supply about 30kg S/ha per crop as efficiency of S is relatively low.

The rice yields under different soil fertility management practices are given in Table 3.

Table 3. Rice yields (t/ha) with long term soil fertility management (1989 to 2012) in RBCS

Treatment	Titabar	Mandya	Maruteru	Faizabad
Control 1	2.14	2.39	2.89	1.89
100% PK	3.01	2.91	3.36	1.92
100% N	3.37	3.65	4.05	2.83
100% NP	3.58	4.15	4.48	2.97
100% NPK + Zn + S	4.22	4.84	4.97	3.34
100% NPKZnS + FYM/PM @ 5t/ha	4.71	5.46	4.97	4.36
100% NPK –Zn	3.98	4.70	4.68	3.16
100% NPK – S	4.11	4.65	4.73	3.14
100% N+50% PK	3.67	4.29	4.44	2.97
50% NPK	3.27	3.90	4.28	2.69
50% NPK+ 50% GM-N	3.61	4.84	4.43	2.98
50% NPK+ 50% FYM-N	3.72	4.91	4.69	2.98
50% NPK+25% GM-N+25% FYM-N	3.75	5.47	4.52	3.06
FYM @ 10 t/ha	3.80	4.12	4.40	2.72

DRR (2012)

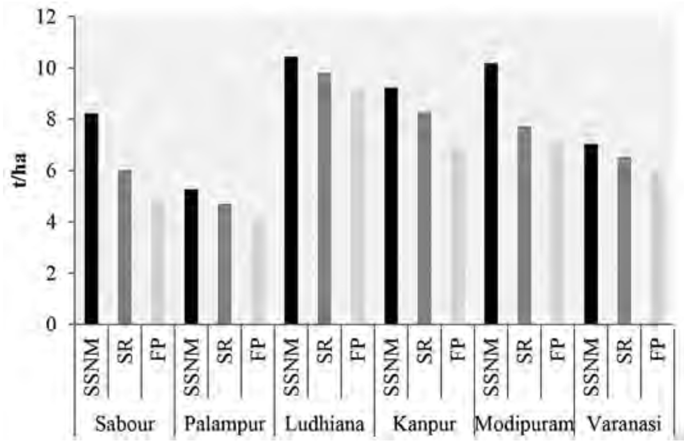

Figure 1. Grain yield of rice with site specific nutrient management (SSNM), state recommendation (SR) and farmers' practice (FP) at selected research centres under PDFSR, Modipuram *(NAAS, 2012)*

Conservation Agriculture Practices

The rice-wheat production system has played an important role in the food security and has remained its cornerstone for rural development and natural resource conservation in Indo-Gangetic plains of not only in India but also across South Asia. But recently second generation problems have started appearing such as

- declining productivity,
- plateauing of crop productivity,
- declining soil organic matter,
- receding ground water table,
- wide spread resource degradation,
- diminishing farm profitability, *etc.*,

These are mainly attributed to intensive conventional production. At present, the challenge is to produce more food from the same land and water resources by alternative systems, while sustaining soil health, environment and improving sustainable farm profitability. A holistic approach is needed to tackle these problems and to improve the sustainability of this cropping system. This necessitates that more attention be given to issues threatening sustainability by adopting various strategies including conservation agriculture.

- Genetic improvement is one of the most efficient approaches to develop rice cultivars suited to conservation agriculture based technologies.
- Conventional crop establishment practice in rice involves manual transplanting of rice in puddled soil which involves excessive tillage, high energy consumption.
- The anaerobic condition of flooded soils in rice crop after transplanted, the imparted soil structure of the puddled layer and compacted layer that strengthens to form a hard pan of increased strength on drying are major impediments to the establishment and growth of ensuing crops.
- Due to these factors, many farmers are shifting from transplanting to direct sowing.
- The varieties developed for conventional tillage system do not necessarily have the same performance and specific genotypes are recommended for no-till system.
- Vigorous modern rice cultivars are increasingly required, which would not only facilitate rapid seedling establishment under a wide range of field conditions but also have increased competitive ability against weeds.
- CA based resource conserving technologies (RCT's) such as zero tillage and bed planting are being promoted in rice-wheat system.
- Direct seeded rice suffers from one or the other stresses such as high pH, micronutrient deficiency, high or low moisture, undulating land, *etc.* For such direct seeded rice (DSR), we need cultivars that do not suffer from iron chlorosis, Zn and P deficiency, and beside these, they should be able to germinate when seeds are placed deeper in moist zones.
- Development of varieties, which can resist moisture stress, is necessary for increasing overall water productivity.
- Rice is the world's most important staple food crop. Conventional flooded rice cultivation in Asia provides more than 75% of the world's rice supply for half the earth's main staple food (Cabangon *et al.,* 2002). However, rice production consumes about 30% of all freshwater used worldwide.
- In Asia, flood-irrigated rice consumes more than 45% of total freshwater available (Barker *et al.*, 1999).
- The global water scarcity analysis has revealed that up to two-third of world population will be affected by water scarcity over the next several decades

(Wallace and Gregory, 2002). By 2025, 15 out of 75 million hectare of Asia's flood-irrigated rice crop will experience water shortage (Tuong and Bouman 2003).

- Decreasing water availability for agriculture threatens the productivity of irrigated rice ecosystem. Therefore, there should be more emphasis on water conservation and improved efficiency of use and reallocation of water from one use to another, presumably shifting to a higher value use.
- Alternatives to the conventional flooded rice cultivation need to be developed world wide to reduce water consumption and produce more rice with less water.
- Rice transplanting is a labour intensive and arduous operation which is about 25 per cent of the total labour requirement for the crop production. Besides, it is time consuming and backbreaking operation.
- Direct sowing of rice by suitable drills is another alternative so as to cater the needs and requirements of farmers. Moreover, increasing energy prices, limited water and labour availability for transplanting, warrant farmers as well as researchers to develop alternate production systems for rice.
- "Conservation agriculture (CA) is a concept for resource saving agricultural crop production that strives to achieve acceptable profits together with high and sustained production levels while concurrently conserving the environment (FAO, 2007)."
- Laser land levelling is an important component of resource conservation technology that can improve water productivity at field level. Lantican *et al.*, (1999) studied the effect of precise land levelling on yield of direct seeded rice in Philippines and found that yield for direct seeded rice was significantly improved with precise land levelling. Yield advantage in both direct seeded as well as puddled transplanted rice with laser land levelling was observed. In India also, it has been experienced in many farmers' participatory trials that a saving of 20-25 per cent of irrigation water can be achieved by laser land levelling (Ravi Gopal *et al.*, 2010). Precise land levelling ensures better crop establishment, improved fertilizer use efficiency as well as easy farm operations.

Conclusion

Sustainable rice production through soil health management in rice based cropping systems in India can be achieved through a proper understanding of the nutrient needs and meeting them through site specific integrated nutrient management and use of conservation agriculture technologies.

References

Barik AK, Arindam das, Giri AK and Chattopadhyay GN. 2006. Effect of organic (Vermicompost, farmyard manure) and Chemical sources of plant nutrients on productivity and soil fertility of *Kharif* rice (*Oryza sativa* L.). *Crop Research* 31(3):339-342.

Barker R, Dawe D, Tuong TP, Bhuiyan SI and Guerra LC. 1999. The outlook for water resources in the year 2020:challenges for research on water management in rice production. *In:*Assessment and Orientation towards the 21st Century. *Proceedings of 19th Session of the International Rice Commission*, Cairo, Egypt, 7–9 September 1998. FAO, Rome, pp. 96–109.

Cabangon RJ, Tuong TP, and Abdullah NB. 2002. Comparing water input and water productivity of transplanted and direct-seeded rice production systems. *Agricultural Water Management* 57:11-31.

Chatterjee BN and Mondal SS. 1996. Potassium nutrition under intensive cropping. *Journal of Potassium Research* 12:358-364.

DRD (Direcrtorate of Rice Development). 2014. Status Paper on Rice. Govt. of India, Patna pp. 151.

DRR (Directorate of Rice Research) 2007. Annual Report.

DRR (Directorate of Rice Research) 2008. Annual Report.

DRR (Directorate of Rice Research) 2012. Annual Progress Report 2012 Vol.3-Soil Science. pp. 5.1-5.89.

FAO 2007, http://www.fao.org/ag/ca

Hegde DM. 1998. Effect of integrated nutrient management on productivity and soil fertility in pearl millet–wheat cropping system. *Indian Journal of Agronomy* 43 (2):580-587.

Janzen HH. 1987. Soil organic matter characteristics after long-term cropping in various spring wheat rotations. *Canadian Journal of Soil Science* 67:845–856.

Karlen DL, Wollenhaupt NC, Erbach D C, Berry EC, Swan JB, Eash NS and Jordahl JL. 1994. Crop residues effect on soil quality following 10 years of no-till corn. *Soil Tillage Research* 31:149-167.

Kumar K and Goh KM. 2000. Crop residues and management practices:effects on soil quality, soil nitrogen dynamics, crop yield and nitrogen recovery. *Advances in Agron*omy 68:269-407.

Lantican MA, Lampayan RM, Bhuiyan SI and Yadav MK. 1999. Determinants of improving productivity of dry-seeded rice in rainfed lowlands. *Experimental Agriculture* 35:127–140.

Mandal KG, Misra AK, Hati KM, Bandyopadhyay KK, Ghosh PK and Mohanty M. 2004. Rice residue management options and effects on soil properties and crop productivity. *Food, Agriculture and Environment, 2:*224–231.

Mishra M.M., Khurana, H.L., Dudeja, S.S. and Kapoor, K.K., 1984. Effect of phosphocompost on the yield and P uptake of redgram. *Tropical Agriculture* 61:174-180.

MNRE (Ministry of New and Renewable Energy Resources). 2009. Govt. of India, New Delhi. www.mnre.gov.in/biomassrsources.

NAAS (National Academy Of Agricultural Sciences) 2012. Value added fertilizers and site specific nutrient management (SSNM). Policy paper 57. NAAS, New Delhi.

NAAS. 2006. Low and declining crop responses to fertilizers. *Policy Paper* 35, 1-8.

Rao KV, Shinde JE and Shantaram MV. 1991. IAEA Symposium on stable isotopes. pp. 317-325.

Rao KV, Shailaja B, Nirmala B and Viraktamath B C. 2013. Important Socio-economic and Ecological Factors Affecting Rice Production in India. pp 117-126 In Innovations in Rice Production (Eds. P K Shetty, M R Hegde, M Mahadevappa). National Institute of Advanced Studies, Bangalore.

Ravi Gopal, Jat RK, Malik RK, Kumar V, Alam MM, Jat ML, Mazid MA, Sahrawat, YS, Mc Donald A and Gupta R. 2010. Direct dry seeded rice production technology and weed management in rice based systems. *Technical bulletin.* International Maize and Wheat Improvement Center, New Delhi India. pp28.

RKMP, http://www.rkmp.co.in/fertimeter.

Sharma PK and Mishra B. 2001. Effect of burning rice and wheat crop residues:Loss of N,P, K and S from soil and changes in nutrient availability. *Journal of the Indian Society of Soil Sci*ence 49:425–429.

Singh S, Prasad R, Singh BV, Goyal SK and Sharma SN. 1990. Effect of green manuring, blue-green algae and neem-cake coated urea on wetland rice. *Biology and Fertility of Soils* 9:235-238.

Stevenson F J.1986. ‘‘Cycles of Soil:Carbon, Nitrogen, Phosphorus, Sulfur, Micronutrients’’. John Wiley and Sons, New York, NY.

Swaup A. 2002. Lessons from long-term fertilizer experiments in improving fertilizer use efficiency and crop yields. *Fertiliser News* 47(12):59-73.

Tandon HLS and Sekhon GS. 1988. Potassium research and agricultural production in India. New Delhi, India:Fertilizer Development and Consultation Organization,New Delhi.

Tiwari K N. 2001. Phosphorus needs of Indian soils and crops. *Better Crops International* 15(2):6-10.

Tiwari KN, Sharma SK, Singh VK, Dwivedi BS and Shukla AK. 2006. Site-specific nutrient management for increasing crop productivity in India. Results with rice-wheat and rice-rice systems. *PDCSR, Modipuram and PPIC-India Programme*, Gurgaon, pp. 112.

Tripathi S, Joshi HC, Sharma DK and Singh JP. 2007. Response of wheat (*Triticum aestivum*) and maize (*Zea mays*) to biocompost prepared from distillery effluent and pressmud. *Indian Journal of Agricultural Sci*ence 77:208-211.

Tuong TP and Bouman BAM. 2003. Rice Production in Water-scarce Environments. *In* J. W. Kijne, R. Barker, & D. Molden, eds. Water Productivity in Agriculture:Limits and Opportunities for Improvement. *CAB International* pp. 53 – 67.

Wallace JS and Gregory PJ. 2002. Water resources and their use in food production. Aquatic Science 64 :363–375

Yadvinder Singh, Bijay Singh, Maskina, MS, Meelu, OP. 1988. Effect of organic manures, crop residues and green manure (Sesbania aculeata) on nitrogen and phosphorus transformations in a sandy loam at field capacity and waterlogged conditions. *Biology and Fertility of Soils* 6:183–187.

Yadvinder Singh and Meelu. 1995. Integrated nutrient management in rice. *Progressive Farming*. May:12, 13 and 27.

Yadvinder Singh, Bijay Singh and Timsina J. 2005. Crop residue management for nutrient cycling and improving soil productivity in rice-based cropping systems in the tropics. *Advances in Agron*omy 85:269-407.

Yadvinder Singh, Bijay Singh, Gupta RK, Khind CS and Ladha JK. 2003 Managing pressmud cake for nitrogen and phosphorus nutrition of crops in a rice-wheat rotation. *International rice research notes* 8:59-61.