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Integrated Nutrient Management for Sustainable Rice-based Cropping Systems and Soil Quality

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ABSTRACT

The real challenge is to keep the pace of sustainable production under condition of natural resources should be used to generate increased output and incomes, especially for low income groups without depleting the natural resource base. Rice is a component of widely varying cropping systems. Rice-based cropping systems form an integral part of agriculture in India. Several intensive rice-based cropping systems have been identified and are being practiced by the farmers in India. Productivity of this soil has remained low and unstable owing to climate and soil-related constraints. Intensive agriculture, involving exhaustive high yielding varieties of rice and other crops, has led to heavy withdrawal of nutrients from the soil. Also imbalanced and indiscriminate use of chemical fertilizers has resulted in deterioration of soil quality or soil health. The basic concept underlying the principle of integrated nutrient management (INM) is to maintain or adjust plant nutrient supply to achieve a given level of sustainable crop production by optimizing the benefits from all possible sources of plant nutrients. It involves utilization of local sources and hence, turned out to be the rational, realistic and economically viable way of supply of nutrients to crops. So that, environmentally benefiting manner without sacrificing soil productivity of future generations. Application of organic manure in conjunction with fertilizer and inclusion of legumes gave higher yield, net income and benefit: cost ratio under rice based cropping system. INM practices also improved the soil quality of the soils to some extent. Integrated nutrient management relies on a number of factors including appropriate nutrient application and conservation and the transfer of knowledge about INM practices to farmers through extension personal. Thus, INM is the only way to restore soil quality and make Indian agriculture sustainable.

Key word: INM, Rice based cropping system, Soil environment, Soil quality, Sustainable crop production

1. INTRODUCTION

Rice is the most important crop in Asia, where more than 90 per cent of rice is grown and consumed. In tropical Asia, rice-rice constitutes an important annual crop rotation. In the subtropical Asia, rice and wheat are grown in rotation in more than 13 million hectares in the Indo-Gangetic plains of South Asia (India, Bangladesh, Nepal, Pakistan) and on similar hectares in the basin of the Yangtze river in China (Timsina and Connor, 2001). In addition to wheat, other crops grown in rotation with rice are barley, oats, maize, sorghum, legumes (mung bean, peanuts, soybean, lentil, and chick pea), oilseeds (mustard, rapeseed), potato, sugarcane, and cotton. Nutrient cycling in the soil-plant ecosystem is an essential component of sustainable productive agricultural enterprise. Rice-based cropping systems form an integral part of agriculture in India. Several intensive rice-based cropping systems (rice-wheat, rice-rice, rice-legumes, Rice-sugarbeet, rice-maize, rice-jute *etc*.) have been identified and are being practiced by the farmers in India. Although during the last three decades fertilizer practices have played a dominant role in the rice based cropping systems. While intensive agriculture, involving exhaustive high yielding varieties of rice and other crops, has led to heavy withdrawal of nutrients from the soil, imbalanced and indiscriminate use of chemical fertilizers has resulted in deterioration of soil quality (John *et al.,* 2001) in the marginal soils. Productivity of this soil has remained low and unstable owing to climate and soil-related constraints. Despite that, it has importance in food production for growing populations. Against the above background, it is imperative to devise ways to sustain and improve the overall productivity of rice-based cropping systems for better livelihood. Sustainable agriculture involves successful management of resources for increased agricultural production to satisfy changing human needs while maintaining or improving the environmental quality and natural resources (Gill *et al.,* 2008). Integrated nutrient management (INM) still play an essential role in the sustainable crop production of rice based cropping system. Thus, INM can provide the right answer for a better livelihood for the resource-poor farmers. INM integrates the use of all natural and man-made sources of plant nutrients, so that productivity and nutrient status of food increases in an efficient and environmentally benefiting manner without sacrificing soil productivity of future generations.

Integrated nutrient management can reduce plant requirements for inorganic nitrogen fertilizer, and reduced use of purchased fertilizer nutrients can result in a significant saving of scarce cash resources for small farmers. It also ensures the conservation and efficient use of native soil nutrients, recycling of organic nutrient flows, enhancing biological nitrogen fixation and soil biological activity, and addition of plant nutrients. There is increased emphasis on the impact on the environmental quality due to continuous use of chemical fertilizers. The INM system is an alternative and is characterized by reduced input of chemical fertilizers as well as combined use of chemical fertilizers with organic materials. For sustainable crop production, integrated use of inorganic and organic fertilizers has proved to be highly beneficial. Moreover, INM reduces erosion, improves water infiltration, soil aeration and plant root growth, Moreover, it minimizes the risk of downstream flooding (Gill *et al.,* 2008). Organic manure along with inorganic fertilizers might be helpful to obtain a good economic return as well as provide favourable conditions for high yield of rice based cropping system. Therefore, this chapter focuses discussion on the impact of INM of organic and inorganic fertilizer sources on sustainability of rice based cropping system and soil quality, so that INM is helpful in sustaining soil quality in rice based cropping system.

2. SOME THOUGHTS ON THE CONCEPT AND RELEVANCE OF INM

In literature at least 3 terminologies are being used often convey same meaning and Goswami (1998) defined these terms as given in Table 1.

Table 1. Basic difference in terminologies in literature

IPNS (Integrated Plant Nutrition System)	IPNS System (Integrated Plant Nutrient Supply System	INM (Integrated Nutrient Management)
It is concept "which aims at the maintenance or adjustment of soil fertility and of plant nutrient supply to an optimum level for sustaining the desired crop productivity through optimization of benefit from all possible sources of plant nutrients in an integrated manner".	Supply of nutrients to the plant from various sources- *(i)* nutrient reserves in the soil, *(ii)* organic source. It is only a method to achieve the objective of IPNS.	It is actually the technical and managerial component of achieving the objective of IPNS under farm situations. It takes into account all factors of soil, crop, water, agro-chemicals etc., besides nutrients.

3. INTEGRATED NUTRIENT MANAGEMENT AND ITS COMPONENTS

Balanced and efficient fertilizer application is essential for the increased yields and for replenishment of the larger removal of soil nutrients. Fertilizer efficiency can be improved by reducing nutrient losses between applications and uptake by the plant. INM is actually the technical and managerial component of achieving the objectives of integrated plant nutrient systems (IPNS) under farm situations.

It takes into account all factors of soil and crop management including management of all other inputs such as water, agrochemicals besides plant nutrients. The basic principle of IPNS is the maintenance of soil fertility, sustaining agricultural productivity and improving farmers' profitability through the judicious and efficient use of mineral fertilizers, organic manures and biofertilizers. Thus, the objectives of INM are to ensure efficient and judicious use of all the major sources of plant nutrients in an integrated manner so as to get maximum economic yield from a specific cropping system. INM includes all possible combinations of organic, inorganic or biological sources to maintain soil chemical, physical and biological properties. The components of INM as given in Figure 1. Among various organic sources, FYM or compost and green manuring are common source. Inclusion of legume in rice based cropping system either as a substitute or biomass to enrich the soil due to their capability to fix atmospheric N_2 and addition of organic matter, respectively. Crop residues on the other hand constitute an important source of organic nutrients. About 80.12 Mt crop residues are available for recycling with a total nutrient potential of 1.61 Mt, which can replace 0.80 Mt chemical fertilizers in India (Gill *et al*., 2008). Use of biofertilizers is an integral part of IPNS as these contain living cells of different types of microorganisms that have ability to mobilize the nutrients from unavailable to available form through biological process. It broadly includes N_2-fixers, both symbiotic and non-symbiotic bacteria, phosphate-solubilizing bacteria and fungi. These approaches ensure the sustainability of rice based cropping system.

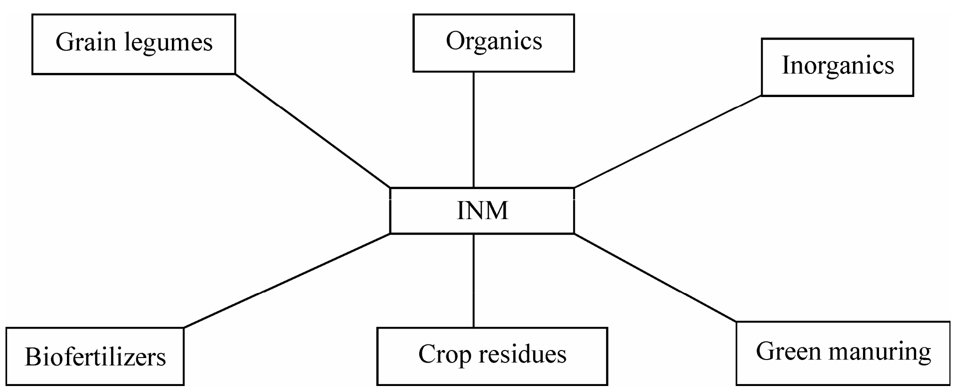

Fig. 1. Components of integrated nutrient management

4. EFFECT OF INM ON SOIL PROPERTIES

4.1 Effect on Soil Chemical and Physical Properties

Soil chemical properties are evaluated under combined use of organic and inorganic fertilizers as their combined effect improves soil organic matter, per centage of organic carbon and total nitrogen. Organic matter in soil is critical for better soil health and higher soil productivity. Addition of organic fertilizer results in increased soil organic carbon (SOC) levels in the soil, while chemical fertilizer result in decreased SOC (Fig. 2) and basic cation contents, and lowering of soil pH. As a result, a positive effect on soil results in modification of soil structure thereby increases the yield in the long term. Organic carbon can be maintained at sustainable manner in 100% NPK + FYM, whereas organic carbon is continuously decreasing in both 100% NPK and control under intensive cultivation (Sarkar, 2000). Along with the evaluation of soil chemical properties, soil physical properties are also enhanced by the use of INM, as it reduces soil erosion and increases cycling of organic residues. Thus it improves both nutrient and water retention capacity of the soil. This management also improves the soil structure, water infiltration, and soil aeration (Das *et al.,* 2014).

4.2 Effect on Soil Biological Properties

The microorganisms perform a key role in nutrient cycling for sustaining the productivity of the soils; because they are the source and sink for mineral nutrition and can carry out biochemical transformations. Moreover, an increase in soil microbial-biomass C and nitrogen (N) is obvious in soils receiving combined application of organic manures and chemical fertilizers compared to soils receiving chemical fertilizers only. Basal and glucose-induced respiration, potentially mineralizable N, and arginine ammonification are higher in soils amended with organic manures with chemical fertilizers, indicating that more active micro-flora is associated with integrated system using organic manures and chemical fertilizers together which are important for nutrient cycling. The use of organic fertilizer together with chemical fertilizers, compared to the addition of organic fertilizers alone, has an higher positive effect on microbial biomass and hence soil health (Hati *et al*., 2008). The INM changes the chemical and biological properties in soils, it improves the soil organic C, total N, phosphorus (P), and potassium (K) status and microbial biomass (C and N), and soil organic matter (OM) content and long-term soil productivity in the tropics where soil OM content is low. Soil biomass is increased by INM as these amendments supply readily decomposable organic matter in addition to increasing root biomass and root exudates due to greater crop growth (Vineela *et al.,* 2008). As for as the enzyme activities are concerned, the urease and alkaline phosphatase activities of soil increase significantly with a combination of inorganic fertilizers and organic amendments as enhanced enzyme activities are always related to soil organic matter content (Goyal *et al.,* 1999) (Table 2).

Table 2. Amounts of microbial biomass C and activities of dehydrogenase, urease and alkaline phosphatase in soils as affected by different fertilizer treatments (*TPF* triphenyl)

Treatment	**Microbial biomass C (mg kg^{-1} soil**	**Biomass C as % of soil C**	**Dehydr-ogenase activity (μg TPF g^{-1} soil 24 h^{-1})**	**Urease activity (μg NH_4^+ -N g^{-1}soil h^{-1})**	**Alkaline phosphatase activity (μg PNP g^{-1} soil h^{-1})**
N_0, P_0	147	3.3	38	42	416
N_{60}, P_{30}	195	3.78	37	55	423
N_{90}, P_{45}	213	3.7	37	60	425
N_{120}, P_{60}	226	3.9	35	64	433
N_{90}, P_{45} + N_{30} (FYM)	273	4.4	39	65	498
N_{90}, P_{45} + N_{30} (wheat straw)	423	6.5	67	88	541
N_{90}, P_{45} + N_{30} (green manure)	317	5.1	34	68	473
LSD (*P* 0.05)	15	0.3	4	5	18

(*Source*: Goyal *et al*., 1999)

4.3 Influence on C : N ratio

Soil organic carbon and nitrogen are the main nutrition used for vegetation growth, and are also used as indexes of soil quality assessment and sustainable land use management. Soil organic carbon and nitrogen not only can reflect the soil fertility level, but can also explain the regional ecological system evolution. The relationship between them can be represented as soil C/N ratio, a sensitive indicator of soil quality and for assessing carbon and nutrient cycling of soils (Zhang *et al*., 2011). Many researchers have shown that soil organic carbon and nitrogen content are not only affected by climate, altitude, terrain, but also land use management. Soil organic C and total N are greater in treatments receiving a combination of inorganic fertilizers and organic amendments compared to soils receiving inorganic fertilizers alone. The greatest amounts of both organic C and total N are observed in soils receiving wheat straw and least organic C and N total were present in unfertilized soils. The C:N ratio of soil decreases with fertilization. The organic amendments show a greater effect in decreasing C:N ratio compared to inorganic fertilizers. Soil organic C and N contents provide a measurement of soil organic matter status. The increase in soil organic matter with the application of inorganic fertilizers is because of greater input of root biomass due to better crop growth. The FYM and crop residue having higher C: N ratio is less resistant to decomposition, addition of inorganic N (50% of recommended dose) along with these materials reduced the C:N ratio and enhanced its decomposability (Nayak *et al.,* 2012). The C:N ratio decrease or increase with organic amendments indicates the build-up of N pool in the soil (Goyal *et al.,* 1999).

5. EFFECT ON YIELD

Targeting high yield with a high cropping intensity is the most logical way to raise the total production from the country's limited resources. Since the nutrient turnover in soil plant system is considerably high in intensive farming, neither the chemical fertilizers nor the organic and biological sources alone can achieve production sustainability of rice based cropping system. Even with balanced use of chemical fertilizers, high yield level could not be maintained over the years because of deterioration in soil physical and biological environments due to low organic matter content in soils. In this context and as a further response to economic recession, and also to conserve and improve soil fertility, the concept of INM system has been adopted. At the same time the integrated use of inorganic fertilizer and organic manure results in important yield attributes (Sharma *et al.,* 2007) (Tables 3).

Table 3. Effect of integrated use of organic and inorganic fertilizers on benefit to cost ratio

Treatment		**Yield**		**B:C ratio**
Rice	**Wheat**	**Rice (q/ha)**	**Wheat (q/ha)**	
Control	Control	18.49	12.79	1.07
50% NPK	75% NPK	36.96	30.64	1.98
100% NPK	100% NPK	42.52	35.89	2.10
50% NPK+ 50% N (FYM)	100% NPK	47.05	37.22	2.20
75% NPK+ 25% N (FYM)	75% NPK	43.08	33.22	2.16
75% NPK+ 50% N (PS)	100% NPK	45.65	34.00	1.92
75% NPK+ 25% N (PS)	75% NPK	41.98	32.82	2.04
75% NPK+ 25% N (GLM)	75% NPK	40.17	33.29	2.06
Farmer's practice	Farmer's practice	28.23	25.40	1.68
CD(P=0.05)		1.86	1.61	0.08

(*Source*: Sharma *et al*., 2007)

6. EFFECT ON ENVIRONMENT

Soil fertility and environment are closely interlinked. Depletion of soil fertility means degradation of the environment and likewise, its improvement also leads to the better environment. The depletion of nutrients (fertility erosion) is wide spread on the earth including in developing countries. The major forms and causes of nutrient depletion include excessive crop nutrient uptake and removal, leaching, gaseous loss, fixation in the soil and immobilization in the trunks and branches of the tree crops. Balance sheet for rice based cropping system indicates that net loss of nitrogen in rice-rice-sesame and rice-rice-okra cropping system occurred, whereas nitrogen gains under rice-rice-groundnut and rice-rice-cowpea (Table 4). Therefore, rice based cropping should be taken with pulse crops as second or third crops for maintaining the good soil environment for crop growth (Pillai *et al*., 2007). Moreover, if an unbalanced organic fertilizer is supplied at levels that satisfy the demands of the limiting nutrient (here S or P), a large surplus of other nutrients, especially nitrogen, would be supplied, with a probable risk for leaching (nitrate, NO_3^-) or volatile losses (ammonia, NH_3), and thereby negative effects on the environment (Heeb *et al.,* 2005). INM practices reduces the emission of greenhouse gases (nitrous and nitric oxides) excessive applications of nitrogen fertilizer results in increased leaching of nitrates into ground water, increasing health risks to new borne infant flows cycled through the return of organic residues as compost, manure and/or mulch have significant implications for conserving soil fauna biodiversity (Prasad, 2008).

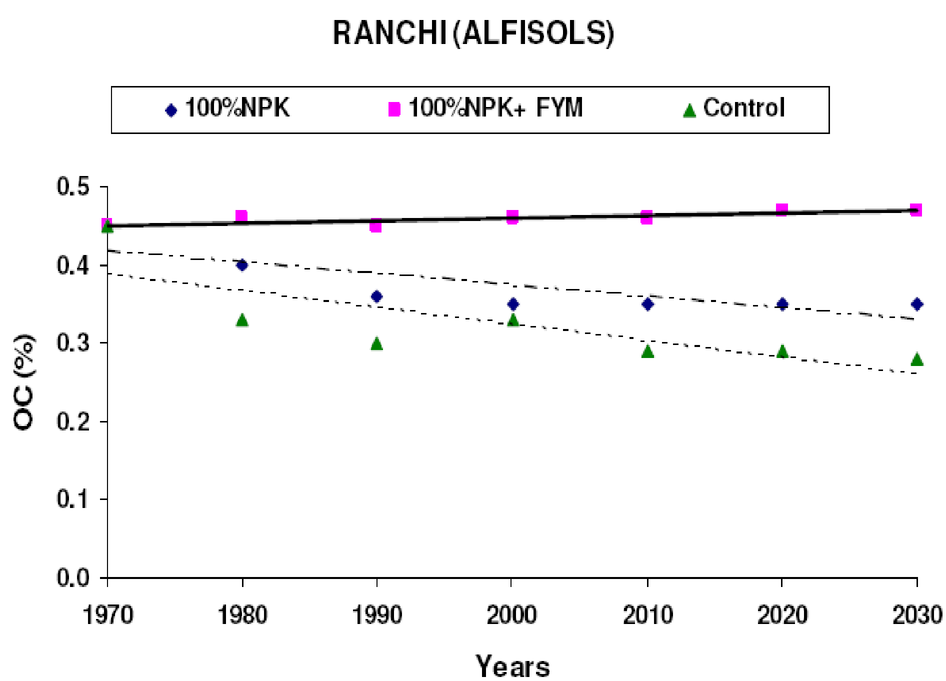

Fig. 2. Long term trend of soil organic carbon status in Alfisol (Ranchi)

Table 4. Balance sheet of nitrogen in soil as influence by INM under different cropping system

Cropping system	Net loss or gain in N (kg ha^{-1})	
	I Year	**II Year**
Rice-Rice-Sesame	-29.7	-9.4
Rice-Rice-Groundnut	+72.2	+86.7
Rice-Rice-Cowpea	+48.3	+22.7
Rice-Rice-*Okra*	-12.6	-28.9

(*Source*: Pillai *et al.,* 2007)

7. SOIL QUALITY EVALUATION UNDER INM

Soil quality is broadly defined as "the capacity of a living soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and promote plant and animal health" (Doran, 2002). Doran and Parkin (1996) proposed a minimum data set called indicators for characterizing and monitoring soil quality. The minimum data set includes soil attributes and properties such as, texture, soil and rooting depth, bulk density, infiltration, water retention characteristics, soil organic matter, electrical conductivity, extractable N,P and K, microbial biomass and soil respiration. The methodology for evaluation of soil quality is described below:

Quantitative evaluation of changes in soil quality: By introducing the concept (Karlen and Stott, 1994) of Relative soil quality index (RSQI), the 9 indicators were combined into an RSQI. The equation for calculating RSQI value is given below:

$$\text{Relative soil quality index (RSQI)} : (SQI/SQI_m) \times 100$$

Where,

SQI = Soil quality index

SQI_m = Maximum value for soil quality index

$SQI = \sum W_i I_i$

W_i = Weights of the indicators

I_i = Marks of the indicators classes

According to the RSQI values, soils were classified into 5 classes from best to worst, represented as follows by I, II, III, IV and V, respectively.

Soil quality increased under INM by 12–19 units as compare to 7–9 unit of farmer's practice (Table 5). In 2001, there was no class I, II and III type soil, and experimental plots were with class IV type soil. After INM practices for 3 years, areas of class IV were improved to class III. This indicates that INM efforts improved low quality soils, but some high quality soils were not maintained. The reason is the INM study only focused on surface soil properties and the soil functions which support plant growth.

Table 5. General soil quality changes in Farmer's Practices and INM

Parameter	Initial			Farmer's practice			INM		
	2001-2002	**2002-2003**	**2003-2004**	**2001-2002**	**2002-2003**	**2003-2004**	**2001-2002**	**2002-2003**	**2003-2004**
SQI	225	221	243	263	244	275	275	283	320
RSQI	57	55	61	66	61	68	69	71	80
Class	IV	V	IV	IV	IV	IV	III	III	III
Δ RSQI		N.A.		9	6	7	12	16	19
Remark		N.A.			Moderate increase			Great increase	

(*Source*: Singh, 2007)

Table 6. Soil quality change (as % over fallow) under different nutrient management practices and cropping systems

Treatment/Cropping system	Rice-wheat	Rice-lentil	Jute-rice-wheat
Control	- 56.0	- 8.0	- 49.0
N only	-	-11.7	- 35.0
NPK only	-10.8	-9.7	19.0
NPK + FYM	18.7	8.6	45.1

(*Source*: Mandal, 2005)

Cultivation without any fertilization (control), only with N caused net degradation of soil quality. Moreover, cultivation even with application of balanced NPK could hardly maintain such quality at the level where no cultivation was practiced. Only integrated use of organic and inorganic sources of nutrient could aggraded the system (Mandal, 2005) (Table 6).

8. ECONOMIC PERFORMANCE

The highest gross return (benefit cost ratio) can be obtained if integrated dose of inorganic fertilizer is applied with organic manure (Table 3). Significantly higher B: C ratio observed under 50 per cent recommended dose of NPK+50% N substitute by FYM among all the treatments (Sharma *et al.,* 2007; Gill *et al.,* 2008).

9. COMMON CONSTRAINTS IN ADOPTION OF INM

As per the feedback of farmers in training, farmers obtained more agricultural knowledge and experience from their neighbours than from the agricultural technology extension technicians. Lack of extension services also contributed to the low adoption of technology. The small-holding farms restricted nutrient management technologies. Small number of staff engaged in soil and fertilizer management in the extension system could not meet the technological demands of farmers. Low levels of education and insufficient trainings to improve agricultural knowledge of farmers in developing countries are another constraint for extension of nutrient management technology.

10. CONCLUSION

On the basis of above chapter on the use of integrated nutrition management (INM) of organic and inorganic fertilizers in agriculture, it can be concluded that it is extremely important combination for sustainable agriculture. It improves the soil organic matter, adds soil macro- and micronutrients, improves soil physical and chemical properties, rejuvenate soil health, and stimulate soil biological and enzyme activities. It has very valuable effect on tomato yield and quality parameters, gives maximum economic benefit and most imperatively, it is environmentally friendly. But if doses of organic and inorganic fertilizers are applied more than the recommended doses according to particular soil type it may affect adversely on the soil and crop. At the same time it is concluded that nitrate fertilizers are better than ammonium fertilizers and poultry manure, FYM or wheat straw are better than any other manure when are combined with inorganic fertilizers. Moreover, governments should take practical steps to promote the implication of INM to enhance the yield of rice based cropping system.

REFERENCES

Das B, Chakraborty D, Singh VK, Aggarwal P, Singh R, Dwivedi BS and Mishra RP (2014) Effect of integrated nutrient management practice on soil aggregate properties, its stability and aggregate-associated carbon content in an intensive rice–wheat system. *Soil and Tillage* **136:** 9–18.

Doran JW (2002) Soil health and global sustainability: translating science into practice. *Agriculture, Ecosystem and Environment* **88:** 119–127.

Doran JW and Parkin TB (1996) Quantitative indicators of soil quality: A minimum data set. In: *Methods for Assessment of Soil Quality* (JW Doran and AJ Jones, Eds). SSSA Special Publication No. 49, Soil Science Society of America, Madison, WI.

Gill MS, Pal SS and Ahlawat IPS (2008) Approaches for sustainability of rice (*Oryza sativa*)-wheat (*Triticum aestivum*) cropping system in Indo-Gangetic plains of India – A review. *Indian Journal of Agronomy* **53:**81–96.

Goswami NN (1998) Some thoughts on the concept, relevance and feasibility of IPNS under Indian conditions. *Bulletin of Indian Institute of Soli Science* **2:** 3–9.

Goyal S, Chander K, Mundra MC and Kapoor KK (1999) Influence of inorganic fertilizers and organic amendments on soil organic matter and soil microbial properties under tropical conditions. *Journal of Biology and Fertility* **29:** 196–200.

Hati Kuntal M, Swarup Anand, Mishra B, Manna MC, Wanjari RH, Mandal KG and Misra AK (2008) Impact of long-term application of fertilizer, manure and lime under intensive cropping on physical properties and organic carbon content of an Alfisol. *Geoderma* **148:**173–179.

Heeb A, Lundegardh B, Ericsson T and Savage GP (2005) Effects of nitrate, ammonium and organic nitrogen based fertilizers on growth and yield of Tomatoes. *Journal of Plant Nutrition and Soil Science* **168:** 123–129.

John PS, George M and Jacob R (2001). Nutrient mining in agro-climatic zones of Kerala. *Fertiliser News* **46:** 45–52, 55–57.

Karlen DL and Stott (1994) A framework for evaluating physical and chemical indicators of soil quality. In: *Defining Soil Quality for a Sustainable Environment* (JW Doran, DC Coleman, DF Bezdicek, and BA Stewart, eds). pp 53–72. SSSA Special Publication. No. 35, Soil Science Society of America, American Society of Agronomy, Madison, WI.

Mandal B (2005) Assessment and improvement of soil quality and resilience for rainfed production system. Completion Report, National Agricultural Technology Project, Indian Council of Agricultural Research, New Delhi, pp. 30.

Nayak AK, Gangwar B, Shukla AK, Mazumdar SP, Kumar A, Raja R, Kumar A, Kumar V, Rai PK and Mohana U (2012) Long-term effect of different integrated nutrient management on soil organic carbon and its fractions and sustainability of rice wheat system in Indo Gangetic Plains of India. *Field Crops Research* **127:**129–139.

Pillai SP, Geetakumari VL and Issac SR (2007) Balance-sheet of soil nitrogen in rice (*Oryza sativa*) - based cropping systems under integrated nutrient management. *Indian Journal of Agronomy* **52:**16–20.

Prasad R (2008) Rice-wheat cropping systems. *Advance in Agronomy* **86:** 255–321.

Sarkar AK (2000) Integrated nutrient management for better livelihood of farmers in rainfed areas. *Journal of the Indian Society of Soil Science* **48:** 690–696.

Sharma AK, Thakur NP, Kour M and Sharma P (2007) Effect of integrated nutrient management on productivity, energy use efficiency and economics of rice-wheat cropping system. *Journal of Farming System Research & Development* **13:** 209–213.

Singh AK (2007) Evaluation of soil quality under integrated nutrient management. *Journal of the Indian Society of Soil Science* **55:** 58–61.

Timsina J and Connor DJ (2001) The productivity and sustainability of rice-wheat production systems: Issues and challenges. *Field Crops Research* **69(2):** 93–132.

Vineela C, Wani SP, Srinivasarao C, Padmaja B and Vittal KPR (2008) Microbial properties of soils as affected by cropping and nutrient management practices in several long-term manurial experiments in the semi-arid tropics of India. *Applied Soil Ecology* **40:** 165–173.

Zhang CH, Wang Z M, Ju WM and Ren CY (2011) Spatial and Temporal Variability of Soil C/N Ratio in Songnen Plain Maize Belt. *Environmental Science* **32:** 1407–1414

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