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Long-term Effect of Organic Manures and Biofertilizers on Physical and Chemical Properties of Soil and Productivity of Rice-Wheat System

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Abstract

A field experiment was conducted at the research farm of Indian Agricultural Research Institute, New Delhi on a sandy clay-loam soil (*Typic Ustochrept*) starting from *Kharif*-2003 under organic amendments to rice-wheat cropping system. The experiment was laid out in a randomized block design with three replications and six treatments in a set. The treatments consisted of control (T_1), farmyard manure (FYM) (T_2); green manure (GM) (T_3); GM+biofertilizers (B) (T_4); GM+FYM (T_5); and GM+FYM+B (T_6). In this study, the effect of organic amendments were evaluated on some physical soil properties and yield of the respective system by sampling the soil from three depths (0-15, 15-30 and 30-60 cm) at the end of *Rabi* 2011-2012. The results of the study revealed that the plots where, farm yard manure (FYM) was incorporated along with green manure (GM) and biofertilizer (B), the yield of rice and wheat had substantially improved. The combination of B with GM+FYM had not only led to better soil bulk density but even prove superior to FYM alone or GM alone. Soil aggregation was significantly affected by organic amendments; particularly mean weight diameter (MWD) and geometric mean diameter (GMD) were increased to a tune of 73.5% and 34.6% over control in 0-15 cm soil layer. The water stable macroaggregate $(WSMA)_{>0.25mm}$ ranged from 54.60% under control to 71.27% under T_6 in the surface soil (0-15 cm). The combined applications of FYM along with GM and B showed the highest contents of available N, P, K and S in soil. It is thus certain that the cumulative effect of GM+FYM+B proved to be the one that leads to increased productivity as well as increased soil physical properties.

1. Introduction

Nutrient balance is one of the key components to increase crop productivity. Excess and imbalanced use of nutrients has caused nutrient mining from the soil, deteriorated crop productivity and ultimately the soil health. Replenishment of these nutrients through organics and in combination with organics and inorganics has a direct impact on soil health and crop productivity. The production of rice and wheat in a rotation is, however, facing a sustainability problem due to some practices of the modern production system with its indiscriminate use of chemical fertilizers and pesticides (Nambiar, 1994; Duxbury et al., 2000; Ladha et al., 2000; Yadav et al., 2000; Prasad, 2005). The deleterious effects of agro-chemicals are clearly visible on soil structure, microflora, food and fodder. The quality of produce is deteriorated mainly by entry of chemical residues in the plant body and then to the food chain. The concerns such as declining factor productivity (Biswas and Sharma, 2008; Patil, 2008; Yadav, 1998; Yadav, 2008), depletion of soil organic carbon and mineral nutrients (Prakash et al., 2008), waterlogging and salinization, increasing nitrate concentration in well water (Singh et al., 1995), are the consequences of the modern rice-wheat production system with its unbalanced and injudicious use of chemical fertilizers and pesticides. In commercial scale agriculture, the use of chemical fertilizers cannot be ruled out completely. However, there is a need for integrated application for alternate sources of nutrient for sustaining the crop productivity (Tiwari, 2002). In view of great demand of chemical free Basmati rice throughout the world, it is imperative to study the effect of organic sources of nutrients available locally on the yield of rice-wheat cropping system especially in Indo-Gangetic alluvial plains. Nevertheless, it is also essential to study the long-term effect of organic agriculture practiced in rice-wheat cropping system on health of the soil.

The emerging scenario necessitates the need for the adoption of package of practices which maintain soil health, makes the production system more sustainable and provides better food for meeting the nutritional requirements. It has been revealed from the studies on long-term fertilizer experiments that farmyard manure along with chemical fertilizers results in yield improvement and maintenance of soil fertility (Swarup, 1998). The use of organic soil amendments has been associated with desirable soil properties including higher plant available water holding capacity and cation exchange capacity and lower bulk density, and can foster beneficial microorganisms (Doran, 1995; Drinkwater et al., 1995). The role of biofertilizers for enhancing the soil productivity by fixing atmospheric nitrogen, or by solubilising soil phosphorus, or by stimulating plant growth through synthesis of growth promoting substances has special significance in organic farming. Hence the studies with the objectives to assess the impact of different organic amendments on system productivity of rice-wheat cropping system and some physical and chemical properties of soil were undertaken.

2. Materials and Methods

2.1. Site and soil

The field experiment was conducted in the main block 14-C of the research farm of the Indian Agricultural Research Institute, New Delhi-110012. It is situated at 28°4' N Latitude and 77°1' E Longitude at an elevation of 228.6 metres above the mean sea level (Arabian Sea). The climate of New Delhi is sub-tropical semi-arid, with dry hot summers and brief severe winters. The soil of the experimental site was sandy clay loam (*Typic Ustochrept*) of Gangetic alluvial origin, very deep (>2 m), flat and well drained.

2.2. Experimental design and treatments

Details of various treatment combinations were presented in (Table 1). These treatment combinations were applied to both rice (*Oryza sativa* L., cv. Pusa Basmati 1) and wheat (*Triticum aestivum,* cv. HD 2643). The experiment was carried out in a rice-wheat cropping system and the rice crop was taken before the wheat crop. For green manures, *Sesbania aculeata* (SGM) was used for rice, and Leucaena green leaf manuring (LGLM) was used for wheat. For biofertilizers, blue green algae (BGA) were used in rice and *Azotobacter* in wheat. Farmyard manure was well decomposed and used at 10 t ha^{-1}. *Sesbania aculeata* was grown in the field in plots having the SGM treatment and incorporated *in-situ* after about 60 days of sowing, but before transplanting of rice, with the help of a tractor drawn mould board plough followed by heavy disc. The green lopes of *Leucaena leucocephala* (Subabul) were manually collected by pruning of shrubs planted on the side of Nala (Trench), located near the experimental field and applied at 5 t ha^{-1} in the plots having the LGLM treatment. It was incorporated into soil with a tractor drawn heavy disc at 20 days before the sowing of wheat. Multani mitti (Fuller's earth) based BGA culture containing four micro-organisms *Aulosira fertilissima, Nostoc muscorum, Tolypothrix tenuis* and *Anabaena variabilies* was obtained from the National Centre for Conservation and Utilization of Blue Green Algae, IARI, New Delhi and broadcasted uniformly at 2.5 kg ha^{-1} in plots having the BGA treatment after 10 days of transplanting of rice. Strains of *Azotobacter chroococcum* specific to wheat was obtained from the Division of Microbiology, IARI, New Delhi, and used to inoculate the seeds as per the treatments. Sowing of wheat was done by the *pora* method (sowing with the simplest form of drill consisting of a pipe with a funnel and attached with the plough dropping seeds through (*naali* or funnels) with the help of a hand plough in the rows spaced at a spacing of 15 cm using a seed rate of 120 kg ha^{-1}. The *pora* method was used because some plots were sown with *Azotobacter* culture treated seed, whereas other plots were sown with untreated seed.

Table 1: Treatments used in the field experiment

Treatments	Details
T_1	Control
T_2	FYM @ 10 t ha^{-1} to rice and wheat
T_3	SGM for rice and LGLM for wheat
T_4	SGM+BGA for rice and LGLM+*Azotobacter* for wheat
T_5	SGM+FYM for rice and LGLM+FYM for wheat
T_6	SGM+FYM+BGA for rice and LGLM+FYM+*Azotobacter* for wheat

Note: FYM: Farm yard manure; SGM: Sesbania green leaf manuring; LGLM: Leucaena green leaf manuring; BGA: Blue green algae

2.3. Sampling, measurements and data analysis

Sub-samples of soils were drawn by a tube auger from each plot at three respective soil depths, (0-15, 15-30 and 30-60 cm) after the harvest of wheat. These were subsequently processed for further analysis. The soil bulk density was measured from desired depths separately from core samplers and calculated by the method prescribed by Veihmeyer and Hendrickson (1948). Subsequently, soil aggregates were separated using weight sieving technique (Yoder, 1936). After wet-sieving, aggregates from each sieve were transferred to a set of pre-weighed beakers, oven-dried at 60 °C until water evaporated and weighed. The mean weight diameter (MWD), geometric mean diameter (GMD) and water stable macroaggregate $(WSMA)_{>0.25mm}$ were calculated as an index of aggregation (Van Bavel, 1949; Kemper and Roseneau, 1986) using following formula:

$MWD = \sum xi\ wi$ .... (1)

Where wi is the proportion of each aggregate class in relation to whole, and xi the mean diameter of the class (mm).

GMD=exp ∑ (wi log xi) / (∑ wi).................... (2)

Where, wi is the weight of aggregates (g) in a size class with an average diameter xi.

The oven dry soil samples (<2 mm) were analysed for available N (alkaline $KMnO_4$ method by Subbiah and Asija, 1956), 0.5 M $NaHCO_3$ (pH 8.5) extractable P (Olsen et al., 1984) and 1N NH_4OAc extractable K (Knudsen et al., 1984) following Page et al. (1982) and available S by turbidmetric method (Chesnin and Yien, 1950).

Statistical analysis was performed by the Windows-based SPSS program (Version 16.0, SPSS, 2007, Chicago, IL). The SPSS procedure was used for analysis of variance to determine the statistical significance of treatment effects. Duncan's multiple-range test was used to compare treatment means at 5% probability.

3. Results and Discussion

3.1. Grain yield of rice

Different combinations of organic amendments and biofertilizers significantly influenced the grain yield of rice (Table 2). The treatment combinations of GM+FYM and GM+FYM+B producing grain yields of 4.95 and 5.01 t ha^{-1}, respectively were statistically at par and these were significantly higher over that obtained with FYM or GM alone. Maskina et al. (1988) reported beneficial effect of FYM @ 12 t ha^{-1} in the absence of fertilizers increased the yield of wetland rice by 32%. Previously it was also reported that cumulative effects of organic manures were higher as compared to their direct effects (Sharma et al., 1995; Dwivedi and Thakur, 2000). Further, Chinnusamy et al. (2006) reported that the combination of BGA+phosphate solubilising bacteria (PSB)+vesicular arbuscular mycorrhizae (VAM)+*Azospirillum* was best for improvement in growth and yield traits and nutritional status of rice. These findings are in accordance with higher nutrient supply through GM+FYM and GM+FYM+B than GM alone or FYM alone.

3.2. Grain yield of wheat

The data on grain yield of wheat as influenced by different combinations of organic amendments and biofertilizers are presented in (Table 2). Inoculation of B with GM+FYM *i.e.*, T_6 led to a yield of 4.86 t ha^{-1} which was 73.57% higher over the control. Further, the combination of FYM and B with GM improved yield over FYM or GM alone. This may be due to the fact that, the application of B in wheat resulted in addition of nutrients and some amounts of them can be expected from the residual effect of B applied to the preceding rice crop. Thus the cumulative effect of GM+B proved more effective than GM alone. Rathore et al. (1995) reported a residual effect of BGA inoculated in rice on yields of the succeeding wheat crop. The combination of GM+FYM was significantly better than GM and FYM alone in increasing grain yield.

3.3. Soil bulk density

Incorporation of organic manures and biofertilizers reduced bulk density of soil (Figure 1) which is an important soil characteristic for successful root development (Kuchenbuch and Ingram, 2004). Bulk density was lowest in T_6 with 1.55 Mg m^{-3} followed by T_5 and T_4 over the control, though the change was non-significant. A higher bulk density value with similar trend was observed in 15-30 cm and 30-60 cm soil depths. This might be due to increased compaction with increase in soil depth.

3.4. Mean weight diameter (MWD) and geometric mean diameter (GMD)

Soil aggregation as represented by mean weight diameter (MWD) and geometric mean diameter (GMD) were significantly affected by different combinations of organic amendment practices (Table 3). The MWD in 0-15 cm soil layer ranged from 0.49 mm to 0.85 mm among different treatment combinations, with highest value in T_6. The value in T_6 was 73.5% higher than control T_1, followed by T_5, T_4 and T_2. As far as, GMD is concerned, T_6 and T_5 had registered an increment of 34.6% and 27.7% over T_1 in 0-15 cm soil layer. Similar trends were observed in 15-30 and 30-60 cm soil depth. It has been observed that, the treatments where FYM was applied alone or in combinations performed well or had better soil aggregation. This might be ascribed due to close relationship between soil aggregation and organic matter status of the soil. There was application of organic matter where FYM was applied in conjunction with GM or B. The organic matter stabilizes clay domains and between quartz particles and clay domains (Emerson, 1977). The beneficial effect of FYM could be attributed to the marked effect on certain polysaccharides formed during decomposition of organic residues by microbial activity (Martin, 1945).

Table 2: Grain yield (t ha^{-1}) of rice and wheat during 2011-2012 as influenced by long-term application of organic manures and biofertilizers

Treatments	Grain yield (t ha^{-1})	
	Rice	Wheat
T_1	2.95^e	2.80^d
T_2	4.81^c	3.94^c
T_3	4.74^d	3.84^c
T_4	4.82^c	4.40^b
T_5	4.95^b	4.42^b
T_6	5.01^a	4.86^a

Columns with different lower case letters are significant according to Duncan's Multiple Range Test (p=0.05)

3.5. Water stable macroaggregate (WSMA)$_{>0.25mm}$

The water stable macroaggregate (WSMA)$_{>0.25mm}$ ranged from 54.60% under control to 71.27% under T_6 in 0-15 cm soil depth (Table 3). A lower % of WSMA$_{>0.25mm}$ with non-significant difference across the treatments was observed at 30-60 cm soil layer compared to 0-15 and 15-30 cm soil layers and maintains the similar trend across the treatments. Differences in aggregation between the treatments might be due to the differences in C inputs returned to the soil. The added organics could supply additional fresh organic residues and C to the soil resulting in production of microbial polysaccharides that increase aggregate cohesion which could explain the observed progressive increase in aggregate stability. Positive effects of manure and straw application on aggregate stability have been reported in a number of studies (Tripathy and Singh, 2004; Singh et al., 2007).

3.6. Available nutrients

The available nitrogen (N) content in 0-15 cm soil varied from 138.6 kg ha^{-1} in control (T_1) to 167.58 kg ha^{-1} in T_6 treatment (Table 4). The lowest value of available N in T_1 was inferior over all the other treatments except T_2, T_3 and T_4. In general the application of organic amendments had led to increase in the content of available N in soil. In T_6 and T_5 treatments, the increments were 21% and 8.5%, respectively over the control treatment. The beneficial effects of manuring on available N content in soil have been widely reported. The data pertaining to available phosphorus (P) content in 0-15 cm depth of soil after harvest of wheat varied from 31.74 kg ha^{-1} in T_1 to 62.43 kg ha^{-1} in T_6 with an increment of 96.7% over T_1. Further, FYM amended plots improved the content of available P over other treatments. The increased in content of P might be due to the fact that the organic anions compete with the phosphate ions for binding sites on soil particles thereby reducing the P fixation (Panneerselvam et al., 2000). Long-term studies on rice-wheat system revealed that integrated application of organic manures and chemical fertilizers significantly improved available N and P contents of soil (Kumar and Yadav, 1995). The data on available potassium (K) content of soil for 0-15 cm depth varied from a minimum of 396.48 kg ha^{-1} under T_1 to 475.66 kg ha^{-1} under T_5 and 462.73 kg ha^{-1} under T_6. The application of FYM in conjunction with GM and GM+B i.e., T_5 and T_6 were at par to each other but these treatments were superior over T_1. The beneficial effects of FYM on the availability of K may be ascribed to the reduction in K fixation and release of K due to the interaction of organic matter with clay (Tolanur and Badanur, 2003). The available sulphur (S) content in soil was increased significantly due to application of different combinations of organic sources. The available sulphur (S) content in top layer varied markedly from 51.44 kg ha^{-1} under control to 89.86 kg ha^{-1} under T_6 after 9 years of

Table 3: Impact of organic manuring and biofertilizer amendments on mean weight diameter (MWD), geometric mean diameter (GMD) and water stable macroaggregate (WSMA)$_{>0.25mm}$ in the 0-15, 15-30 and 30-60 cm soil layer after 9 years of rice-wheat cropping

Treatments	Mean weight diameter (mm)			Geometric mean diameter (mm)			% (WSMA)$_{>0.25mm}$		
	0-15 cm	15-30 cm	30-60 cm	0-15 cm	15-30 cm	30-60 cm	0-15 cm	15-30 cm	30-60 cm
T_1	0.49^b	0.23^e	0.07^b	1.59^c	2.08^d	2.54^b	54.60^d	50.50^d	45.23^a
T_2	0.79^a	0.27^c	0.08^b	1.63^{bc}	2.31^b	2.63^b	64.03^{bc}	56.37^c	50.13^a
T_3	0.50^b	0.24^d	0.07^b	1.64^{bc}	2.22^c	2.59^b	59.43^{cd}	52.00^{cd}	48.60^a
T_4	0.82^a	0.29^b	0.15^a	1.71^b	2.33^b	3.35^a	67.90^{ab}	62.40^b	50.30^a
T_5	0.83^a	0.32^a	0.16^a	2.03^a	2.35^b	3.38^a	68.57^{ab}	63.97^b	51.17^a
T_6	0.85^a	0.33^a	0.16^a	2.14^a	2.48^a	3.44^a	71.27^a	72.33^a	52.10^a

Table 4: Long-term effect of organic manures and biofertilizers on distribution of soil available N, P, K and S in 0-15 cm, 15-30 and 30-60 cm soil layer under rice-wheat cropping system

	Available nutrients (kg ha^{-1})											
Treatment	0-15 cm				15-30 cm				30-60 cm			
	N	P	K	S	N	P	K	S	N	P	K	S
T_1	138.60^c	31.74^d	396.48^b	51.44^d	82.74^{bc}	7.36^e	269.42^b	22.14^c	37.80^b	2.52^c	145.66^c	16.93^a
T_2	139.86^{bc}	53.92^b	422.41^b	73.58^{abc}	83.16^{bc}	11.35^c	272.05^b	32.56^{ab}	39.06^b	3.57^{abc}	157.42^{bc}	21.70^a
T_3	139.86^{bc}	27.33^d	409.30^b	56.65^{cd}	76.02^c	9.25^d	282.74^{ab}	40.37^a	50.40^a	3.57^{abc}	158.26^{bc}	22.14^a
T_4	138.60^c	29.22^d	422.13^b	80.74^{ab}	93.24^a	11.35^c	298.54^a	36.90^a	48.30^a	3.36^{bc}	153.05^{bc}	24.74^a
T_5	150.36^b	42.25^c	475.66^a	65.12^{bcd}	89.46^{ab}	14.92^b	280.50^{ab}	24.74^{bc}	49.14^a	4.20^{ab}	181.16^a	17.36^a
T_6	167.58^a	62.43^a	462.73^a	89.86^a	95.76^a	18.92^a	284.20^{ab}	32.56^{ab}	46.20^a	5.05^a	162.46^b	26.05^a

N: Nitrogen; P: Phosphorus; K: Potassium; S: Sulphur

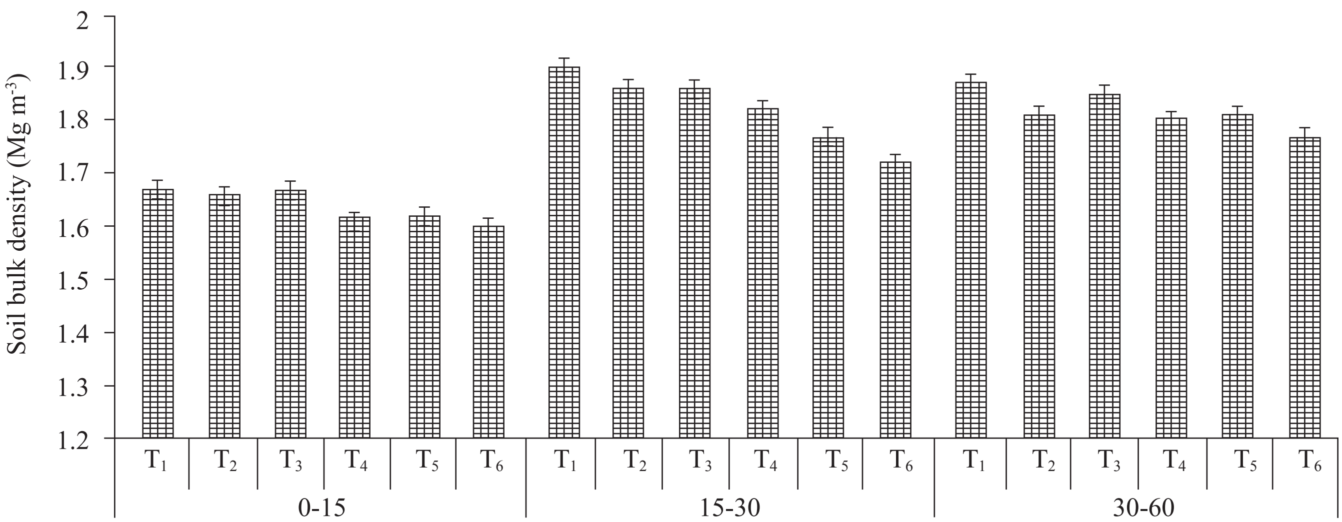

Figure 1: Soil bulk density (Mg m-3) at 0-15, 15-30 and 30-60 cm soil layer as influenced by organic manure and biofertilizers under rice-wheat cropping system. Error bars indicate SE(m).

continuous addition of organic amendments to both rice and wheat. The application of FYM alone, GM+B treated soil and GM+FYM+B i.e., (T2, T4 and T6) showed highest content of available sulphur in soil. Moreover, the subsurface layers of soil almost showed similar trends in available N, P, K and S content, with decline in content with depth.

4. Conclusion

The combined application of farm yard manure along with either green manures or green manures with biofertilizers consecutively for nine years significantly increased the grain yield of rice and wheat in Inceptisol of subtropical India. The above treatments could be promoted in rice-wheat system as an alternative source of nutrients to further improve the physical properties of soil. Nevertheless, organic manuring treatments also invariably increased the available N, P, K and S contents in soil.

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6. References

Biswas, P.P., Sharma, P.D., 2008. A new approach for estimating fertilizer response ratio-the Indian scenario. Indian Journal of Fertilizers 4(7), 59-62.

Chesnin, L., Yien, C.H., 1950. Turbidimetric determinations of available sulphates. Soil Science of America Proceedings 15, 149-151.

Chinnusamy, M., Kaushik, B.D., Prasanna, R., 2006. Growth, nutritional and yield parameters of wetland rice as influenced by microbial constria under controlled conditions. Journal of Plant Nutrition 29(5), 857-871.

Doran, J., 1995. Building soil quality. In: Proceedings of the 1995 Conservation Workshop on Opportunities and Challenges in Sustainable Agriculture. Red Dear, Alta, Canada, Alberta Tillage Conservation Society and Alberta Agriculture Conservation, development Branch, 151-158.

Drinkwater, L.E., Letournean, D.K., Workneh, F., van Bruggen, A.H.C., Shennan, C., 1995. Fundamental differences between conventional and organic tomato agroecosystems in California. Ecological Applications 5, 1098-1112.

Duxbury, J.M., Abrol, I.P., Gupta, R.K., Bronson, K., 2000. Analysis of long-term soil fertility experiments with rice-wheat rotation in South Asia. In: Abrol, I.P., Bronson, K., Duxbury, J.M., Gupta, R.K. (Eds.), Long-Term Soil Fertility Experiments in Rice-Wheat Cropping System. Rice-Wheat Consortium Res. Ser. No. 6, Rice-Wheat Consortium for the Indo-Gangetic Plains, New Delhi, India, 7-22.

Dwivedi, D.K., Thakur, S.S., 2000. Effect of organic and inorganic fertility levels on productivity of rice (*Oryza sativa*). Indian Journal of Agronomy 45(3), 568-574.

Emerson, W.W., 1977. Physical properties and structure. In: Russell, J.S., Graecen, E.L. (Eds.), Soil Factors in Crop Production in a Semi-arid Environment, St.Lucia, Australia: University of Queensland press, 78-104.

Kemper, W.D., Rosenau, R.C., 1986. Aggregate stability and size distribution. In: Methods of Soil Analysis. Klute, A. (Ed.), Part I. American Society of Agronomy Monograph 9, 425-442.

Kuchenbuch, R.O., Ingram, K.T., 2004. Effects of soil bulk density on seminal and lateral roots of young maize plants (*Zea mays* L). Journal of Plant Nutrition and Soil Science 167, 229-235.

Kumar, A., Yadav, D.S., 1995. Use of organic manure and fertilizer in rice (*Oryza sativa*)-wheat (*Triticum aestivum*) cropping system for sustainability. Indian Journal of Agricultural Sciences 65(10), 703-707.

Knudsen, D., Peterson, G.A., Pratt, P.F., 1982. Lithium, sodium and potassium. In: Page, A.L., Miller, R.H., Keeney, D.R. (Eds.), Methods of soil analysis, part 2, Chemical and microbiological properties. American Society of Agronomy, Soil Science Society of America, Madison, Wisconsin, 225-246.

Ladha, J.K., Fisher, K.S., Hossain, M., Hobbs, P.R., Hardy, B., 2000. Improving the productivity and sustainability of rice-wheat systems of the Indo-Gangetic Plains: A synthesis of NARS-IRRI partnership research. Discussion paper no. 40. IRRI, Los Banos, Philippines, 1-31.

Martin, J.P., 1945. Microorganisms and soil aggregates, I: origin and nature of some of the aggregating substances. Soil Science 59, 163-174.

Maskina, M.S., Singh, B., Singh, Y., Baddesha, H.S., Meelu, O.P., 1988. Fertilizer requirement of rice-wheat and maize-wheat rotations on coarse textures soils amended with farm yard manure. Fertilizer Research 17, 153-164.

Nambiar, K.K.M., 1994. Soil fertility and crop productivity under long-term fertilizer use in India. Indian Council for Agricultural Research, New Delhi, India.

Olsen, S.R., Cole, C.V., Watanabe, F.S., Dean, L.A., 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. Circular U.S. Department of Agriculture 939.

Panneerselvam, S., Christopher, L.A., Balasubramanian, N., 2000. Soil available phosphorus and its uptake by soybean (*Glycine max*, L. Merrill) as influenced by organic manures, inorganic fertilisers and weed management practices. Indian Journal of Agricultural Research 34(1), 9-16.

Patil, V.C., 2008. Declining factor productivity and improving nutrient use efficiency. In: National Symposium on New Paradigms in Agronomic Research. November 19-21, 2008. Navsari, Gujarat.

Prakash, A., Singh, V.P., Kumar, R., Singh, I.P., 2008. Effect of organics and micronutrient fertilization in rice (*Oryza sativa*)-wheat (*Triticum aestivum*) cropping system. In: National Symposium on New Paradigms in Agronomic Research. November 19-21, 2008. Navsari, Gujarat.

Prasad, R., 2005. Rice-wheat cropping systems. Advances in Agronomy 86, 255-339.

Rathore, A.L., Chipde, S.J., Pal, A.R., 1995. Direct and residual effects of bio-organic and inorganic fertilizers in rice (*Oryza sativa*)-wheat (*Triticum aestivum*) cropping system. Indian Journal of Agronomy 40(1), 14-19.

Sharma, S.N., Prasad, R., Singh, S., 1995. The role of mungbean residue incorporation on productivity and nitrogen uptake of a rice-wheat cropping system. Bioresource Technology 67, 171-175.

Singh, G., Jalota, S.K., Singh, Y., 2007. Manuring and residue management effects on physical properties of a soil under the rice-wheat system in Punjab, India. Soil and Tillage Research 94, 229-238.

Singh, S., Prasad, R., Sharma, S.N., 1995. Effect of blue green algae, nitrogen levels and modified urea materials on yield attributes and yield of wet land rice (*Oryza sativa*). Indian Journal of Agronomy 40(4), 594-597.

Subbaiah, B.V., Asija, G.L., 1956. A rapid procedure for assessment of available nitrogen. Current Science, 259-260.

Swarup, A., 1998. Emerging soil fertility management issues for sustainable crop productivity in irrigated systems. In: Swarup, A., Reddy, Damodar., Prasad, R.N. (Eds.), Long-term Soil Fertility Management through Integrated Plant Nutrient Supply, Indian Institute of Soil Science, Bhopal, India, 54-67.

Tiwari, K.N., 2002. Nutrient management for sustainable agriculture. Journal of Indian Society of Soil Science 50(4), 374-397.

Tolanur, S.I., Badanur, V.P., 2003. Changes in organic carbon, available N, P and K under integrated use of organic manure, green manure and fertiliser on sustaining productivity of pearlmillet-pigeonpea system and fertility of an Inceptisol. Journal of Indian Society of Soil Science 51, 37-41.

Tripathy, R., Singh, A.K., 2004. Effect of water and nitrogen management on aggregate size and carbon enrichment of soil in rice–wheat cropping system. Journal of Plant Nutrition and Soil Science 167, 216–228.

Van Bavel, C.H.M., 1949. Mean weight diameter of soil aggregates as a statistical index of aggregation. Soil Science Society of America Proceedings 14, 20–23.

Veihmeyer, J., Hendrickson, A.H., 1948. Soil density and root penetration. Soil Science 65, 487-493.

Yadav, D.S., 2008. Long-term effect of nutrient management on soil health and productivity of rice (*Oryza sativa*)-wheat (*Triticum aestivum*) system. In: National Symposium on New Paradigms in Agronomic Research, November 19-21, 2008. Navsari, Gujarat.

Yadav, R.L., 1998. Factor productivity trends in a rice-wheat cropping system under long-term use of chemical fertilizers. Experimental Agriculture 34, 1-8.

Yadav, R.L., Dwivedi, B.S., Pandey, P.S., 2000. Rice-wheat cropping system: assessment of sustainability under green manuring and chemical fertilizer inputs. Field Crops Research 65, 15-30.

Yoder, R.E., 1936. A Direct Method of Aggregate Analysis and Study of the Physical Nature of Erosion Losses. Journal of American Society of Agronomy 28, 337-351.