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Productivity of soils amended with different organic manures and tillage practices in rice-wheat system

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ABSTRACT

A field experiment was conducted with rice-wheat cropping system at IARI, New Delhi for two Kharif (rainy) and Rabi (winter) seasons during 2006-08. The main plots comprised two tillage treatments viz. puddled and non-puddled in rice and conventional tillage and no-tillage in wheat. The sub-plots included seven fertilizer treatments including recommended doses of urea (120 kg N ha^{-1}), urea + FYM, urea + green manure (GM), urea + municipal solid waste (MSW) compost. Results showed that the growth and yield of rice and wheat were higher under puddled/ conventional tillage condition compared to non-puddled/ no-tillage conditions. Application of organic matter with recommended dose of mineral fertilizer gave the higher plant growth, yield attributes, grain and straw yield compared to other treatments.

***Key words**: Grain yield, organic amendments, rice-wheat system, tillage, yield attributes*

The rice-wheat cropping system of the Indo-Gangetic Plains (IGP) covering an area of about 10 million ha in South Asia is vital for food security and livelihood for millions of rural and urban people. Long-term experiments conducted in IGP showed that there is a stagnating or declining trend in productivity at several locations even with application of N, P and K fertilizers under modern intensive farming (Sinha *et al.,* 1998). Over time more nutrients are removed than the amount externally added through fertilizers and manures. Farmers, therefore, have to apply more fertilizers to get the yield as they were getting with less fertilizer 20-30 years ago. Adequate supply of nutrients in soil can enhance biomass production and soil organic carbon (SOC) content (Van Kessel and Hartley, 2000). Use of organic manure and compost enhances the SOC pool more than application of the same amount of nutrients as mineral fertilizers (Gregorich *et al.,* 2001). For sustainable rice productivity, application of organic residues plays a very significant role in the Red and Laterite soil of West Bengal when the inherent organic matter content of the soil in very low (Patra and Bhattacharya, 2008). Long-term manure application increases the SOC pool (Gilley and Risse, 2000), which not only sequester CO_2 but also enhances productivity of soil (Manna *et al.,* 2005). Indian cities generate 4.1 Mt C yr^{-1} municipal solid waste (MSW) and it can be an important source of organic C (Pathak *et al.,* 2009). Cultivation practices such as tillage can also enhance soil aeration, mineralization of SOC and the flux of CO_2 from soils. In long-term rice-wheat systems increased yield with addition of organic matter was due to correction of unrecognized nutrient deficiency, indirect effect of nutrient addition such as effect of potassium on resistance to lodging (Swarup *et al.,* 2000; Manna *et al.,* 2005). So we need to identify nutrient management strategies for sustainable rice-wheat production. With this background a field experiment was conducted to determine the effect of nutrient management and tillage practices on productivity of soils in rice-wheat system.

MATERIALS AND METHODS

The field experiments growing rice and wheat in *Kharif* (Rainy) and *Rabi* (Winter) seasons for two years were conducted at the farm of Indian Agricultural Research Institute, New Delhi situated at a latitude of 28º40' N and longitude of 77º12' E, altitude of 228.6 meters above the mean sea level. The area receives 750 mm annual rainfall, about 80% of which occurs from June to September. The mean annual maximum temperature is 35ºC while the mean annual minimum temperature is 18ºC. The alluvial soil of experimental site had 7.82 pH and sandy clay loam texture. At the beginning of experiment, composite soil sample had 250.0 kg ha^{-1} total N, 13.2 mg kg^{-1} NH_4-N, 31.0 mg kg^{-1} NO_3-N, 56.5 kg^{-1} available P and 406.0 kg^{-1} available K.

The field experiment laid out in a split plot design was conducted with rice (*Oryza sativa* L.) variety 'Pusa Sugandh-5'. The main plots comprised two tillage treatment *viz.*, puddled and non-puddled. The sub-plots included seven treatments including recommended doses of urea (120 kg N ha^{-1}), urea +

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FYM, urea + green manure (GM), urea + municipal solid waste (MSW) compost. On dry weight basis FYM, GM (*Sesbania aculeata*) and MSW compost contained 318, 410 and 35 g C kg^{-1}; 9.6, 20.7 and 2.5 g N kg^{-1}; 2.9, 1.9 and 4.0 g P kg^{-1} and 4.8, 18.5 and 1.6 g K kg^{-1}, respectively. In puddling treatments, cross ploughing was done with disc plough and then water was filled 12 hours before puddling. Transplanting was done 8 hours after puddling. In non-puddled treatments water was filled after cross ploughing of field and then transplanting was done. The C, N, P and K content of the applied organic manures is given in table 1. In the first and second year, transplanting was carried out on 22 and 18 July, respectively and a row to row spacing of 20 cm and plant to plant spacing of 15 cm was maintained. Details of the treatments are given in table 2. Urea was used as a source of mineral nitrogen and applied in 3 equal splits as per the treatment. Phosphorus (60 kg P ha^{-1}) and potassium (50 kg N ha^{-1}) were applied as basal. Irrigations were provided at every two days throughout the cropping period to maintain the saturation moisture regime. FYM was incorporated in soil two weeks before transplanting at the rate 6 t ha^{-1}. Green manuring crop *(Sesbania aculeata)* was incorporated (3 t ha^{-1}) in soil before transplanting. MSW compost was incorporated at the rate of 60 kg N ha^{-1} two weeks before transplanting. The rice crop was harvested in last week of October. Wheat (*Triticum aestivum*) variety 'PBW-343' was sown on last week of November at a row spacing of 22.5 cm. Urea was applied as per the treatment in three splits, half at 24 days after sowing(DAS) and the remaining half in two equal splits at 40 and 90 DAS. Phosphorus (60 kg P ha^{-1}) and potassium (50 kg N ha^{-1}) were applied basally. Five irrigations were applied at 20, 41, 63, 83 and 107 DAS. In wheat FYM, green manure and MSW compost were applied in the same way as in rice. In wheat also, two tillage practices *viz*. conventional tillage and no-tillage were taken in main plots. In conventional tillage treatments, two times cross ploughing done with disc plough was followed by one time ploughing with cultivator. In no-tillage treatments sowing was done with no-tillage seed drill. The sub-plots included seven treatments as done in rice crop. Treatments were replicated thrice and plot size of 7.5 m x 7.00 m was maintained with same layout used for two years in both the crops. Wheat crop was harvested in third week of April.

Observations on plant growth, yield attributes and yield were recorded as per standard procedures. After harvesting, threshing, cleaning and drying the grain yield was recorded at 14% moisture. Straw yield was obtained by subtracting grain yield from the total biomass yield. The data on various attributes were analyzed statistically using MSTAT-C (version 1.41), developed by Crop and Soil Science Division, Michigan State University, USA. LSD values at P=0.05 were used to determine the significance of difference between treatment means.

RESULTS AND DISCUSSION

Yield attributes of rice and wheat

The yield attributing characters of rice and wheat viz., total number of tillers, number of effective tillers, number of panicles and test weight were positively influenced by the addition of organic amendments viz. FYM, GM and MSW compost along with the mineral N in rice over sole mineral N (Table 1 and 2). In non-puddled rice on an average 9% less number of panicles $hill^{-1}$ were recorded in control treatment over puddled rice. In other treatments also all the yield attributes were lower in non-puddled rice treatments compared to puddled rice. In wheat also all the yield attributes were lower in non-tillage condition compared to conventionally tilled wheat. Yield attributes of rice and wheat showed higher values when FYM, GM and MSW compost were added with recommended dose of mineral nitrogen. However, same attributes of rice and wheat declined when 50% of mineral nitrogen was substituted with organic sources i.e., FYM, GM and MSW. 50% substitution of mineral nitrogen with organic sources i.e., FYM, GM and MSW showed statistically significant reduction in tiller numbers compared with organic manure addition treatments over mineral N. This might be due to slow release of nutrients from these sources. The numbers of tillers of wheat increased by 17% in mineral N in tilled plots over the no-tilled plots. Similarly there was 8.3% and 12.6% decline in number of spikelets $spike^{-1}$ in wheat in the control treatment under no-tillage over conventional tilled conditions in the year 2006-2007. In rice crop there was reduction in no. of productive tiller by 16.4 to 16.5% in treatments T_7 and T_3 over T_2. The substitution of organic amendments also reduced the number of tillers as compared to mineral fertilizer alone in both rice and wheat crops which might be due to slow release of nutrients from these sources. Test weight of rice as well as wheat was lower in rice and wheat under non-puddled/no-tillage as compared to conventionally puddled/ tilled conditions. Improvement in yield attributes of rice due to application of manures was reported by Singh *et al.*

(2011). Karmakar *et al.* (2011) also reported enhanced effective tillers, panicle length and numbers of grains/ panicle due to the application of 50% recommended dose of chemical fertilizers and 25% N through FYM, green manuring and BGA.

Yield of rice and wheat

Grain and straw yield of rice as well as wheat were significantly affected by organic amendment treatments in both the tillage conditions. In puddled conditions, grain yield of rice ranged from 4.60 to 5.96 t ha^{-1} and 4.8 to 5.89 t ha^{-1} and in non-puddled conditions from 3.91 to 4.85 t ha^{-1} and 3.85 to 4.80 t ha^{-1} in wet seasons of 2006 and 2007, respectively (Table 3). Tomar *et al.* (2006) also found considerable higher grain yield of rice under puddled conditions compared to direct seeded condition which might be due to reduced percolation losses of water and nutrients in puddled rice. In conventionally tilled conditions, grain yield of wheat ranged from 4.42 to 5.87 78 t ha^{-1} and 4.63 to 5.78 t ha^{-1} and in no tillage condition from 3.75 to 5.02 t ha^{-1} and 3.82 to 4.95 t ha^{-1} in dry seasons of 2006-07 and 2007-08, respectively (Table 4). Grain and straw yield of rice and wheat were increased when FYM, GM and MSW compost were added with recommended dose of mineral nitrogen. However, same yields of rice and wheat declined when 50% of mineral nitrogen was substituted with organic sources i.e., FYM, GM and MSW which might be due to slow release of nutrients from these sources that caused lower plant growth and yield attributes.

Table 1: Effect of different treatments on yield attributes of rice

Treatment	Puddled rice									Non-puddled rice								
	No. of tillers $hill^{-1}$			No. of effective tillers $hill^{-1}$			1000- grain weight (g)			No. of tillers $hill^{-1}$			No. of effective tillers $hill^{-1}$			1000- grain weight (g)		
	1st Yr	2nd Yr	Pooled	1st Yr	2nd Yr	Pooled	1st Yr	2nd Yr	Pooled	1st Yr	2nd Yr	Pooled	1st Yr	2nd Yr	Pooled	1st Yr	2nd Yr	Pooled
T_1	21.3	22.1	21.7	18.1	19.2	18.7	23.9	24.1	24.0	20.3	20.1	20.2	16.1	18.1	17.1	22.9	23.0	23.0
T_2	24.8	23.3	24.1	23.0	20.2	21.6	24.1	25.2	24.7	22.6	21.2	21.9	20.6	20.0	20.3	24.2	24.1	24.2
T_3	19.9	20.2	20.1	18.0	17.1	17.6	23.2	24.1	23.7	18.4	19.2	18.8	16.4	18.5	17.5	22.0	23.5	22.8
T_4	23.3	25.9	24.6	21.4	24.2	22.8	24.8	25.0	24.9	21.3	22.5	21.9	19.4	19.3	19.4	24.1	25.2	24.7
T_5	18.4	19.2	18.8	17.1	18.2	17.7	19.5	20.2	19.9	18.4	19.1	18.8	15.1	18.2	16.7	19.2	21.2	20.2
T_6	22.7	21.1	21.9	19.9	19.5	19.7	24.2	25.1	24.7	22.4	20.1	21.3	18.1	18.2	18.2	23.9	24.0	24.0
T_7	19.8	17.4	18.6	16.5	18.9	17.7	22.1	20.2	21.2	16.4	16.5	16.5	14.2	17.2	15.7	21.9	21.6	21.8
LSD (0.05)	**2.5**	**2.2**	**2.4**	**3.0**	**4.1**	**3.9**	**3.4**	**2.9**	**3.6**	**2.5**	**2.2**	**2.1**	**3.0**	**4.1**	**3.3**	**3.4**	**2.9**	**3.1**

Table 2: Effect of different treatments on yield attributes of wheat

Treatment	Conventional tillage									No-tillage								
	No. of tillers $hill^{-1}$			No. of effective tillers $hill^{-1}$			1000- grain weight(g)			No. of tillers $hill^{-1}$			No. of effective tillers $hill^{-1}$			1000- grain weight (g)		
	1st Yr	2nd Yr	Pooled	1st Yr	2nd Yr	Pooled	1st Yr	2nd Yr	Pooled	1st Yr	2nd Yr	Pooled	1st Yr	2nd Yr	Pooled	1st Yr	2nd Yr	Pooled
T_1	12.14	14.97	13.56	12.33	12.87	12.60	29.7	32.1	30.9	12.0	12.7	12.4	11.9	12.1	12.0	26.0	30.0	28.0
T_2	14.41	15.32	14.87	13.02	13.24	13.13	31.3	32.2	31.7	14.4	13.7	14.1	12.7	12.5	12.6	31.3	30.8	31.1
T_3	12.94	12.89	12.92	12.04	12.21	12.13	26.6	31.0	28.8	11.7	11.3	11.5	11.6	10.2	10.9	31.3	28.1	29.7
T_4	15.03	15.48	15.26	13.22	13.54	13.38	32.7	32.2	32.5	14.9	13.8	14.4	12.9	12.5	12.7	32.5	31.0	31.8
T_5	13.61	14.05	13.83	12.71	12.23	12.47	27.9	31.4	29.7	11.7	12.5	12.1	11.6	11.3	11.5	27.8	29.2	28.5
T_6	14.14	15.12	14.63	12.44	13.15	12.80	30.1	32.1	31.1	13.9	13.5	13.7	12.1	12.3	12.2	28.4	30.6	29.5
T_7	10.14	12.33	11.24	11.53	11.12	11.33	24.5	28.6	26.6	10.8	11	10.9	9.2	9.8	9.5	23.2	27.6	25.4
LSD (0.05)	**2.73**	**2.15**	**1.96**	**1.74**	**1.45**	**1.73**	**2.2**	**1.7**	**1.4**	**2.7**	**2.15**	**1.8**	**1.7**	**1.5**	**1.5**	**2.2**	**1.7**	**2.0**

T_1: 120 kg mineral N ha^{-1} (control); T_2: 120 kg mineral N ha^{-1} + 6000 kg FYM ha^{-1}; T_3: 60 kg mineral N ha^{-1} + 6000 kg FYM ha^{-1}; T_4: 120 kg mineral N ha^{-1} + 3000 kg GM ha^{-1}; T_5: 60 kg mineral N ha^{-1} + 3000 kg GM ha^{-1}; T_6: 120 kg mineral N ha^{-1} + 60 kg N ha^{-1} (MSW compost); T_7: 60 kg mineral N ha^{-1} + 60 kg N ha^{-1} (MSW compost)

Treatments with addition of organic manures along with mineral N gave higher yields in both rice and wheat due to rapid and higher nutrient availability as compared with the mineral fertilizer alone. Positive effects due to the addition of organic manures along with urea on the yield of rice and wheat were reported earlier also (Goyal *et al.,* 1997, Singh *et al.,* 1999, Singh and Dhar, 2011). The yield attributes and yields in the MSW compost treatments were at par with the FYM and green manure treatments in both rice and

Table 3: Effect of different treatments on grain and straw yield of rice

Treatment	Puddled rice									Non-puddled rice								
	Grain yield (t ha^{-1})			Straw yield (t ha^{-1})			Harvest Index (%)			Grain yield(t ha^{-1})			Straw yield (t ha^{-1})			Harvest Index (%)		
	1st Yr	2nd Yr	Pooled	1st Yr	2nd Yr	Pooled	1st Yr	2nd Yr	Pooled	1st Yr	2nd Yr	Pooled	1st Yr	2nd Yr	Pooled	1st Yr	2nd Yr	Pooled
T_1	5.18	5.30	5.24	11.86	12.4	12.13	44	43	43.5	4.21	4.10	4.16	9.87	10.76	10.32	43	38	40.5
T_2	5.96	5.89	5.93	12.75	13.9	13.33	47	42	44.5	4.76	4.80	4.78	10.93	11.9	11.42	44	40	42.0
T_3	4.95	4.90	4.93	11.89	11.6	11.75	42	42	42.0	4.08	4.20	4.14	10.56	11.1	10.83	39	38	38.5
T_4	5.58	5.70	5.64	12.02	13.5	12.76	46	42	44.0	4.85	4.80	4.83	10.95	11.5	11.23	44	42	43.0
T_5	4.78	4.80	4.79	10.80	12.5	11.65	44	38	41.0	4.23	4.07	4.15	10.12	10.5	10.31	42	39	40.5
T_6	5.65	5.80	5.73	12.58	13.8	13.19	45	42	43.5	4.62	4.55	4.59	10.70	11.2	10.95	43	41	42.0
T_7	4.60	4.95	4.78	10.86	11.7	11.28	42	42	42.0	3.91	3.85	3.88	10.35	10.15	10.25	38	38	38.0
LSD (0.05)	**0.35**	**0.26**	**0.28**	**1.59**	**2.2**	**1.78**	**3**	**4**	**3.2**	**0.35**	**0.26**	**0.40**	**1.59**	**2.21**	**2.07**	**3**	**4**	**3.2**

Table 4: Effect of different treatments on yield of wheat

Treatment	Conventional tillage									No-tillage								
	Grain yield (t ha^{-1})			Straw yield (t ha^{-1})			Harvest Index (%)			Grain yield(t ha^{-1})			Straw yield (t ha^{-1})			Harvest Index (%)		
	1st Yr	2nd Yr	Pooled	1st Yr	2nd Yr	Pooled	1st Yr	2nd Yr	Pooled	1st Yr	2nd Yr	Pooled	1st Yr	2nd Yr	Pooled	1st Yr	2nd Yr	Pooled
T_1	5.11	5.59	5.35	11.59	13.50	12.55	44	39	41.5	4.19	3.97	4.08	10.86	10.90	10.88	39	36	37.5
T_2	5.87	5.59	5.73	13.12	13.50	13.31	45	41	43.0	4.92	4.59	4.76	11.75	11.46	11.61	42	40	41.0
T_3	4.42	4.67	4.55	11.42	10.85	11.14	39	43	41.0	3.75	3.86	3.81	10.89	9.77	10.33	34	40	37.0
T_4	5.62	5.78	5.73	13.60	13.12	13.36	41	44	42.5	4.56	4.40	4.48	11.02	11.06	11.04	41	40	40.5
T_5	4.73	4.86	4.80	10.97	10.90	10.94	43	45	44.0	4.03	3.97	4.00	10.30	10.08	10.19	39	39	39.0
T_6	5.37	5.47	5.42	12.86	12.85	12.86	42	43	42.5	5.02	4.38	4.70	11.98	10.99	11.49	42	40	41.0
T_7	4.63	4.63	4.63	10.76	10.37	10.57	43	45	44.0	3.98	3.82	3.90	10.86	9.86	10.36	37	39	38.0
LSD (0.05)	**0.26**	**1.16**	**0.94**	**1.26**	**1.34**	**1.12**	**3**	**3**	**2.8**	**0.26**	**1.16**	**0.82**	**1.26**	**1.34**	**1.19**	**3**	**3**	**2.6**

T_1: 120 kg mineral N ha^{-1} (control); T_2: 120 kg mineral N ha^{-1} + 6000 kg FYM ha^{-1}; T_3: 60 kg mineral N ha^{-1} + 6000 kg FYM ha^{-1}; T_4:120 kg mineral N ha^{-1} + 3000 kg GM ha^{-1}; T_5:60 kg mineral N ha^{-1} + 3000 kg GM ha^{-1}; T_6:120 kg mineral N ha^{-1} + 60 kg N ha^{-1} (MSW compost); T_7: 60 kg mineral N ha^{-1} + 60 kg N ha^{-1} (MSW compost)

wheat. The yield data obtained clearly demonstrate the superiority of the integrated use of FYM, GM, compost and chemical fertilizers, which provided greater stability in crop production in comparison to sole mineral N application. This could be associated with other benefits of organics apart from N supply, such as improvements in microbial activities; better supply of macro- and micronutrients such as S, Zn, Cu and B which are not supplied by mineral fertilizers and less losses of nutrients from the soil (Yadav *et al.,* 2000, Singh *et al.,* 2011). The higher wheat yields obtained on FYM, GM and compost amended plots in both conventionally tilled and no-tilled wheat were possibly caused by the better supply pattern of N, P and K and improved soil physical conditions (Singh *et al.,* 2004, Hati *et al.,* 2006). Harvest index also showed the same trend as grain and straw yield. Harvest index ranged from 39 to 47% in rice and from 37 to 45% in wheat in the different treatments under both the tillage practices. The decline in harvest index was more in case of non-puddled rice and no-tilled wheat compared to conventional tillage which might be due to reduced percolation losses of water and nutrients in puddled rice and better nutrient availability in conventionally tilled wheat.

It was concluded that for nutrient management in rice-wheat system, 100% replacement of mineral nutrients with FYM, GM or MSW compost has good potential in sustaining yield. However, integrated nutrient management was more appropriate technology for enhancing growth and productivity in intensive rice-wheat cropping system.

REFERENCES

Gilley, J. E. and Risse, L. M. 2000. Runoff and soil loss as affected by the application of manure. *Trans. Am. Soc. Agric. Biol. Eng.* **43:** 1583–88.

Goyal, S., Mishra, M. M., Hooda, I.S. and Singh, R. 1997. Organic matter–microbial biomass relationships in field experiments under tropical conditions: effects of inorganic fertilization and organic amendments. *Soil Biol. Biochem.* **24:** 1081–84.

Gregorich, E.G., Drury, C.F. and Baldock, J.A. 2001. Changes in soil carbon under long-term maize in monoculture and legume-based rotation. *Canadian J. Soil Sci.* **81**: 21-31.

Hati, K.M., Mandal, K.G., Misra, A.K., Ghosh, P.K. and Bandyopadhyay, K.K. 2006. Effect of mineral fertilizer and farmyard manure on soil properties, root distribution, and water-use efficiency of soyabean in Vertisols of central India. *Bioresource Technol.* **97:** 2182–88.

Karmakar, S., Prakash, S., Kumar, R., Agrawal, B.K., Prasad, D. and Kumar, R. 2011. Effect of green manuring and biofertilizers on rice production. *Oryza*. **48**: 339-42.

Manna, M. C., Swarup, A. and Wajari, R. H. 2005. Long-term effect of fertilizer and manure application on soil organic carbon storage, soil quality and yield sustainability under sub-humid and semi-arid tropical India. *Field Crops Res.* **93:** 264–80.

Pathak, H., Jain, N., Bhatia, A. and Gupta, N. 2009. Global warming mitigation potential of biogas plants in India. *Environ. Monit. Assess.* **157:** 407–18.

Patra, P. K. and Bhattacharya, C. 2008. Efficacy of different organic residues and inorganic fertilizer on growth and yield of two varieties of rice in red and laterite zone of West Bengal. *J. Crop. Weed* **4**:31-37.

Singh, S., Kumar, S. and Jain, M. C. 1997. Effect of rice cultivators on methane emission. *Biol. Fert. Soils* **25:** 285-89.

Singh, Y., Singh, B., Meelu, O. P. and Khind, C. S. 2000. Long term effects of organic manuring and crop residues on the productivity and sustainability of rice-wheat cropping system of North-West India.

Singh, Y.V. and Dhar, D.W. 2011. Influence of organic farming on soil microbial diversity and grain yield under rice-wheat-green gram cropping sequence. *Oryza.* **48**: 40-45.

Singh, Y.V., Dhar, D.W. and Agarwal, B. 2011. Influence of organic nutrient management on basmati rice (*Oryza sativa*)-wheat (*Triticum aestivum*)-green gram (*Vigna radiata*) cropping system. *Indian J. Agron.* **56**: 169-75.

Sinha, S. K., Singh, G.B. and Rai. M.1998. *Decline in crop Productivity in Haryana and Punjab: Myth or reality?* Indian ICAR., New Delhi. pp. 89.

Swarup, A., Manna, M.C. and Singh, G. B. 2000. Impact of land use and management practices on organic dynamics in soils of India. In: Global Climatic Change and Tropical Ecosystem, Lal *et al.* (eds) *Advance in Soil Sci. CRC/Press,* Boca Raton, New York, pp. 261-81.

Tomar, R.K., Singh, D., Gangwar, K.S., Garg, R.N., Gupta, V.K., Sahoo, R.N., Chakraborty, D and Kalra, Naveen. 2006. Influence of tillage systems and moisture regimes on soil physical environment, growth and productivity of rice-wheat system in upper gangetic plains of Western Uttar Pradesh. *Indian J. Crop Sci*. **1**:146-50

Van Kessel, C. and Hartley, C. 2000. Agricultural management of grain legumes: has it led to an increase in nitrogen ûxation? *Field Crops Res.* **65:** 165–81.

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

Yadvinder Singh, Singh, Bijay., Ladha, J.K., Khind, C.S., Gupta, R.K., Meelu, O.P. and Pasuquin, E. 2004. Long-term effects of organic inputs on yield and soil fertility in rice–wheat rotation. *Soil Sci Soc Am. J.* **68:** 845–53