Yield trends and nutrient budgeting under a long-term (28 years) nutrient management in rice-wheat cropping system under subtropical climatic condition

A. Das[1], R.P. Sharma[2], N. Chattopadhyaya[1], R. Rakshit[1]

[1]*Department of Soil Science and Agricultural Chemistry, Bihar Agricultural University, Bhagalpur, Bihar, India*
[2]*Department of Agronomy, Bihar Agricultural University, Bhagalpur, Bihar, India*

ABSTRACT

We measured the long-term (28 years) sustainability of rice-wheat cropping system under integrated nutrient management practices emphasizing the trends in grain yields, sustainable yield index (SYI) and nutrient budgeting. The data of long-term experiment revealed that grain yield of both rice and wheat declined under control and sub-optimal fertilizer inputs (50% or 75% recommended fertilizer NPK). Negative yield trend (slope) was observed in control plots for rice (–0.0296) and wheat (–0.0070); whereas positive yield trend was observed under treatments receiving organic supplements. The SYI values indicate that rice yields are more sustainable than wheat. Data on apparent nutrient balance showed a deficit of N (–42.2 kg/ha/year), P (–9.1 kg/ha/year) and K (–52.2 kg/ha/year) under control plots. Surprisingly, there was net depletion of K under the organic supplemented plots. Correlation study revealed that apparent balance of K was negatively correlated with SYI (r = –0.921 for rice; r = –0.914 for wheat) and yield slope (r = –0.870 for rice; r = –0.896 for wheat). If the trend of K imbalance is not reversed, the potential to improve N and P fertilizer use efficiency and crop yields will be limited.

Keywords: apparent nutrient balance; K imbalance; sustainable yield index; organics; ustochrept

Rice and wheat are the world's most important cereal crops, contributing 45% of the digestible energy and 30% of total protein in the human diet, as well as a substantial contribution to feeding livestock (Timsina and Connor 2001). In South Asia, the rice-wheat cropping system is a central agricultural production system to meet the increasing food demand and thus this production system was accepted with a massive expansion of irrigation facilities along with the availability of high yielding, short duration crop cultivars, leading to the first 'Green Revolution' in India (Yadav et al. 2000). Rice and wheat are grown in succession on about 12.5 million ha in Pakistan, India, Nepal, and Bangladesh with an additional 10 million ha in China (Mann and Garrity 1994). Currently, a third of the rice area and half of the wheat area in the Indo-Gangetic Plain is managed under this system, providing food, income and employment to hundreds of millions of rural and urban producers and consumers (Hobbs and Morris 1996). In recent times, a plateauing in productivity of this system appeared in this region, possibly due to fatigued exploitation of natural resource base (Ladha et al. 2003). In many areas, yields started declining because of a decrease in factor productivity (Yadav 1998), and farmers have resorted to using higher than the recommended doses of mineral fertilisers to maintain previously attained yield levels. Therefore, one of the most promising means for increasing yield in the rice-wheat system is to develop alternative nutrient management practices, which may increase factor productivity and crop yields. In this direction, integrated management of organic manures and mineral fertilisers can be a useful practice to increase crop yields along with soil fertility. Thus, we analysed data from a long-term (28 years) field experiment on rice-wheat system with the objectives to recognize the yield trends and to assess the N, P, K budget as influenced by application of organic manures in combination with or without mineral fertilisers over the years.

MATERIAL AND METHODS

Site description. This field experiment was established in 1984 at the Bihar Agricultural College Research Farm (25°23'N, 87°07'E, 37.19 m a.s.l.), Bhagalpur, Bihar, India under the network project research program of the Project Directorate on Farming System Research, Modipuram. The soil is Ustochrept clayey soil with general properties: pH 7.40, organic carbon 0.46%, available N 194 kg/ha, available P 10.12 kg/ha and available K 128.65 kg/ha.

Experimental details. The experiment was laid out in randomized block design with 4 replications consisting of 12 treatment combinations *viz*; control (T_1) (no fertilizer no organic manure); 50% recommended dose of fertilizers (RDF) to both rice and wheat (T_2); 50% RDF to rice and 100% RDF to wheat (T_3); 75% RDF to both rice and wheat (T_4); 100% RDF to both rice and wheat (T_5); 50% RDF + 50% N through farm yard manure (FYM) to rice and 100% RDF to wheat (T_6); 75% RDF + 25% N through FYM to rice and 75% RDF to wheat (T_7); 50% RDF + 50% N through wheat straw to rice and 100% RDF to wheat (T_8); 75% RDF + 25% N through wheat straw to rice and 75% RDF to wheat (T_9); 50% RDF + 50% N through green leaf manure (GLM) (*Sesbania aculeata*) to rice and 100% RDF to wheat (T_{10}); 75% RDF + 25% N through (GLM) to rice and 75% RDF to wheat (T_{11}); farmer's fertilizers practice to rice and wheat (70 kg N + 13.2 kg P + 8.3 kg K/ha) (T_{12}). The recommended dose of fertilizers (N: P: K) for rice (cv. Sita) and wheat (cv. UP-262) is 80:17.6:33.2 kg/ha and 120:26.4:33.2 kg/ha, respectively. The required amount of FYM, wheat straw and *Sesbania* was applied 3 weeks before rice transplanting as per treatment to substitute a specified amount of N. The FYM, wheat straw and *Sesbania* used in this experiment contain 0.5, 0.65 and 0.53% N, respectively.

Analytical methods. Grain yield and straw yield were recorded from a harvest area of 12 m^2. Dried plant samples were analysed for total N content using Kel-Plus analyser (Pelican Equipments, Chennai, Tamilnadu, India). The total P and K contents were determined in aqueous extracts prepared after wet-digestion of the organic material samples in a di-acid mixture of HNO_3 and $HClO_4$ as outlined by Page et al. (1982). The N, P and K uptake was calculated from the nutrient concentration in straw, grain and yield data.

Yield trends and nutrient balance. The grain yield data of rice and wheat for all previous years were averaged for every 7 years to examine the yield trends from the beginning of experiment. Apparent nutrient balance for N, P and K was calculated as:

$$N_{ab} = N_{inp} - (N_{up} - N_{rec})$$

Where: N_{ab} – apparent nutrient balance; N_{inp} – nutrient input through fertilizer, manure (FYM, green manure); N_{up} – nutrient uptake by straw and grain; N_{rec} – nutrient recycled through the left-over straw as done by Saleque et al. (2004).

Table 1. Grain and straw yield (t/ha) of rice and wheat (average over 10 years)

Treatment	Rice		Wheat	
	grain	straw	grain	straw
T_1	1.11^{i}	1.95^{d}	0.77^{g}	1.32^{e}
T_2	2.65^{h}	3.78^{c}	1.95^{f}	2.87^{d}
T_3	2.79^{h}	3.98^{bc}	3.48^{d}	4.79^{b}
T_4	3.50^{f}	4.75^{b}	2.78^{e}	3.89^{c}
T_5	4.59^{e}	6.01^{a}	3.76^{cd}	5.02^{ab}
T_6	5.28^{a}	6.83^{a}	4.36^{a}	5.79^{a}
T_7	4.91^{bcd}	6.43^{a}	3.97^{abcd}	5.25^{ab}
T_8	5.08^{abc}	6.63^{a}	4.19^{abc}	5.51^{ab}
T_9	4.73^{de}	6.20^{a}	3.81^{bcd}	5.13^{ab}
T_{10}	5.18^{ab}	6.77^{a}	4.29^{ab}	5.62^{ab}
T_{11}	4.83^{cde}	6.34^{a}	3.89^{abcd}	5.19^{ab}
T_{12}	3.17^{g}	4.37^{bc}	2.73^{e}	3.80^{c}
$LSD_{0.05}$	0.28	0.89	0.45	0.85

Values with the same letter are not significantly different at $P < 0.05$. T_1 – control (no fertilizer no organic manure); T_2 – 50% recommended dose of fertilizers (RDF) to both rice and wheat; T_3 – 50% RDF to rice and 100% RDF to wheat; T_4 – 75% RDF to both rice and wheat; T_5 – 100% RDF to both rice and wheat; T_6 – 50% RDF + 50% N through farm yard manure (FYM) to rice and 100% RDF to wheat; T_7 – 75% RDF + 25% N through FYM to rice and 75% RDF to wheat; T_8 – 50% RDF + 50% N through wheat straw to rice and 100% RDF to wheat; T_9 – 75% RDF + 25% N through wheat straw to rice and 75% RDF to wheat; T_{10} – 50% RDF + 50% N through green leaf manure (GLM) (*Sesbania aculeata*) to rice and 100% RDF to wheat; T_{11} – 75% RDF + 25% N through (GLM) to rice and 75% RDF to wheat; T_{12} – farmer's fertilizers practice to rice and wheat (70 kg N + 13.2 kg P + 8.3 kg K/ha)

Table 2. Yield trends during 1984–1985 to 2011–2012 as affected by different nutrient management practices

Treatment	Rice				Wheat			
	a	*b*	R^2	initial yield (t/ha)	*a*	*b*	R^2	initial yield (t/ha)
T_1	1.643	–0.0296	0.989	1.67	0.896	–0.0070	0.853	0.92
T_2	2.756	–0.0091	0.397	2.85	1.748	0.0111	0.820	1.78
T_3	2.832	0.0047	0.323	2.88	2.797	0.0181	0.671	2.90
T_4	3.310	0.0057	0.460	3.36	2.559	0.0099	0.582	2.63
T_5	3.985	0.0193	0.931	4.03	3.139	0.0206	0.922	3.19
T_6	3.837	0.0589	0.983	3.78	3.130	0.0421	0.988	3.12
T_7	3.831	0.0466	0.994	3.82	2.834	0.0420	0.998	2.84
T_8	3.597	0.0603	0.992	3.56	2.985	0.0400	0.988	2.96
T_9	3.730	0.0436	0.993	3.75	2.733	0.0447	0.996	2.71
T_{10}	3.650	0.0621	0.986	3.59	3.001	0.0444	0.986	2.98
T_{11}	3.692	0.0467	0.974	3.75	2.755	0.0490	0.972	2.77
T_{12}	2.876	0.0037	0.573	2.87	2.023	0.0254	0.956	2.02

Initial grain yield is an average of first years; *a*, *b* – intercept and slope of regression equation $Y = a + b_t$, respectively. T_1 – control (no fertilizer no organic manure); T_2 – 50% recommended dose of fertilizers (RDF) to both rice and wheat; T_3 – 50% RDF to rice and 100% RDF to wheat; T_4 – 75% RDF to both rice and wheat; T_5 – 100% RDF to both rice and wheat; T_6 – 50% RDF + 50% N through farm yard manure (FYM) to rice and 100% RDF to wheat; T_7 – 75% RDF + 25% N through FYM to rice and 75% RDF to wheat; T_8 – 50% RDF + 50% N through wheat straw to rice and 100% RDF to wheat; T_9 – 75% RDF + 25% N through wheat straw to rice and 75% RDF to wheat; T_{10} – 50% RDF + 50% N through green leaf manure (GLM) (*Sesbania aculeata*) to rice and 100% RDF to wheat; T_{11} – 75% RDF + 25% N through (GLM) to rice and 75% RDF to wheat; T_{12} – farmer's fertilizers practice to rice and wheat (70 kg N + 13.2 kg P + 8.3 kg K/ha)

Statistical analysis. ANOVA of the measured parameters was performed for 10 year average basis and the treatment means were compared using the Duncan's multiple range test (DMRT) at the 5% level of probability. The yield trends of rice and wheat were analysed separately by ordinary least squares linear regression of yields against a time (years) trend variable over the period of 7 years average as done by Dawe et al. (2000). The form of the linear regression was:

$$Y = a + b_t$$

Where: Y – grain yield (t/ha); *a* – constant; t – year; *b* – slope of the yield trend.

RESULTS AND DISCUSSION

Crop yields. The grain yields of rice and wheat were significantly greater with the application of 50% mineral NPK fertilizer supplemented with 50% N through FYM (T_6) as compared to the recommended level of NPK fertiliser (T_5), whereas straw yields of both crops were similar under combined application of manure with sub-optimal doses (below 100% of fertiliser NPK). The results revealed that balanced fertilisation improves the grain yield (Gu et al. 2009, Li et al. 2010). Balance nutrition facilitates the translocation of nutrients to the economic part of the crop (Yang et al. 2004); the residual effect of organic manures applied to rice on the grain yield of succeeding wheat was statistically significant (Bi et al. 2009); but the straw yield was found to be non significant.

Yield trends. The 28-year yield trend of rice and wheat differs significantly with different management treatments. The rice and wheat crop do not exhibit any significant changes in yield with time under T_1 and T_2 treatments, but significant positive yield trends were observed in T_3–T_{12} treatments (Table 2). Higher dose of mineral fertilizer (T_3–T_5) in rice increased the yield slope (0.0047–0.0193 t/ha/year), the magnitude of slope under mineral fertilization

Table 3. Sustainable yield index of rice and wheat under various management practices

Treatment	Sustainable yield index	
	rice	wheat
T_1	0.18	0.14
T_2	0.47	0.35
T_3	0.49	0.57
T_4	0.62	0.48
T_5	0.82	0.63
T_6	0.95	0.74
T_7	0.89	0.67
T_8	0.92	0.71
T_9	0.85	0.64
T_{10}	0.94	0.72
T_{11}	0.87	0.65
T_{12}	0.55	0.47
$LSD_{0.05}$	0.14	0.17

T_1 – control (no fertilizer no organic manure); T_2 – 50% recommended dose of fertilizers (RDF) to both rice and wheat; T_3 – 50% RDF to rice and 100% RDF to wheat; T_4 – 75% RDF to both rice and wheat; T_5 – 100% RDF to both rice and wheat; T_6 – 50% RDF + 50% N through farm yard manure (FYM) to rice and 100% RDF to wheat; T_7 – 75% RDF + 25% N through FYM to rice and 75% RDF to wheat; T_8 – 50% RDF + 50% N through wheat straw to rice and 100% RDF to wheat; T_9 – 75% RDF + 25% N through wheat straw to rice and 75% RDF to wheat; T_{10} – 50% RDF + 50% N through green leaf manure (GLM) (*Sesbania aculeata*) to rice and 100% RDF to wheat; T_{11} – 75% RDF + 25% N through (GLM) to rice and 75% RDF to wheat; T_{12} – farmer's fertilizers practice to rice and wheat (70 kg N + 13.2 kg P + 8.3 kg K/ha)

was found to be lower as compared to the integrated sources i.e. T_6–T_{11} (0.0436–0.0621 t/ha/year) and the residual effect of organic manures applied to rice on the yield slope of succeeding wheat crop was statistically significant. The higher yield slope was due to more conducive plant growth environment under the application of organics as reported by Herencia et al. (2007). Efthimiadou et al. (2010) enumerated that combined application of mineral and organic source of nutrients enhances the photosynthetic rate and stomatal conductance which are the primary physiological processes responsible for plant dry matter production.

Yield sustainability. Sustainable yield index for rice was found to be greater than wheat (Table 3), indicating that rice yields are more sustainable than those of wheat. Among various treatments analysed, application of recommended fertilizers alone (T_5) or partial substitution of fertilizer NPK with organics (T_6, T_8 and T_{10}) sustained more yield than other treatments in both the crops. Our results confirm the study carried out by Yadav et al. (2000).

Nutrient budgeting. The total nitrogen (N) input for the control plots was nil over a period of 28-years (Table 4) but the total N uptake from the control plots was 42.2 kg/ha/year; however, no supplement was given to the soil. Thus, the apparent balance of N for the control plot was –42.2 kg/ha/year. The treatments T_3, T_4 and T_5 show negative apparent N, whereas T_6, T_8 and T_{10} show positive apparent balance of 8.2, 16.9 and 10.1 N kg/ha/year, respectively, where N is recycled through organic supplements to sustain a positive N balance. However, T_{12} also shows positive apparent N balance because of the reduced N uptake.

A net P loss of 9.1 kg P/ha/year from soil without P fertilization (T_1) was found due to plant uptake but a net gain of 22.8–46.5 kg P/ha/year occurred in soil with P fertilization either alone or in combination with organics. Positive linear relation between the Olsen-P level in soil and P surplus might be the cause of P fertiliser accumulation (Tang et al. 2008).

Potassium showed the negative apparent balance ranging from 52.2–181.5 kg K/ha/year with a mean of 134.52 kg K/ha/year, although 50% N substituted through wheat straw (T_8) showed the lowest K balance rather than 100% RDF (Zhang et al. 2006) because wheat straw is a potential source of K (Cao et al. 2004). The negative K balance is a serious issue to address because of the role of non-exchangeable K in plant nutrition. This phenomenon triggered a potential threat against yield sustainability (Miao et al. 2011). Pearson's correlation study also confirmed that K is the sole nutrient that governs the long term yield sustainability as well as yield slope (Table 5). The surpluses of N and P and deficiency of K were confirmed in different farming systems by many other researchers (Lin et al. 2008).

We recommend the combined use of organic manure, if available, with inorganic fertilizers should be considered based on the balance between crop demand and supply of available nutrients. If the

Table 4. Apparent balance of nitrogen, phosphorus and potassium in rice-wheat cropping system

Nutrient	Treatment	Nutrients added (kg/ha/year)				Nutrients (kg/ha/year)		
		fertilizer	FYM	GM	total	uptake	recycled	apparent balance
Nitrogen	T_1	0.0	–	–	0.0	42.2	–	–42.2
	T_2	90.0	–	–	90.0	99.6	–	–9.6
	T_3	140.0	–	–	140.0	140.5	–	–0.5
	T_4	135.0	–	–	135.0	137.5	–	–2.5
	T_5	180.0	–	–	180.0	187.8	–	–7.8
	T_6	180.0	40.0	–	220.0	211.8	–	8.2
	T_7	135.0	20.0	–	155.0	195.6	–	–40.6
	T_8	180.0	–	–	180.0	203.1	40.0	16.9
	T_9	135.0	–	–	135.0	189.2	20.0	–34.2
	T_{10}	180.0	–	40.0	220.0	209.9	–	10.1
	T_{11}	135.0	–	20.0	155.0	194.0	–	–39.0
	T_{12}	150.0	–	–	150.0	128.1	–	21.9
Phosphorus	T_1	0.0	–	–	0.0	9.1	–	–9.1
	T_2	45.0	–	–	45.0	22.2	–	22.8
	T_3	70.0	–	–	70.0	32.1	–	37.9
	T_4	67.5	–	–	67.5	31.7	–	35.8
	T_5	90.0	–	–	90.0	43.5	–	46.5
	T_6	70.0	24.0	–	94.0	51.2	–	42.8
	T_7	67.5	12.0	–	79.5	45.6	–	33.9
	T_8	80.0	–	–	80.0	48.2	6.2	38.0
	T_9	67.5	–	–	67.5	41.9	3.1	28.7
	T_{10}	70.0	–	7.6	77.6	50.4	–	27.2
	T_{11}	67.5	–	3.8	71.3	46.8	–	24.5
	T_{12}	60.0	–	–	60.0	27.4	–	32.6
Potassium	T_1	0.0	–	–	0.0	52.2	–	–52.2
	T_2	22.5	–	–	22.5	105.6	–	–83.1
	T_3	35.0	–	–	35.0	153.0	–	–118.0
	T_4	33.8	–	–	33.8	146.6	–	–112.8
	T_5	45.0	–	–	45.0	200.0	–	–155.0
	T_6	35.0	32.0	–	67.0	235.6	–	–168.6
	T_7	33.8	16.0	–	49.8	213.4	–	–163.6
	T_8	35.0	–	–	35.0	229.4	68.2	–126.2
	T_9	6.5	–	–	6.5	211.6	34.1	–171.0
	T_{10}	35.0	–	13.6	48.6	230.1	–	–181.5
	T_{11}	33.8	–	6.8	40.6	210.6	–	–170.0
	T_{12}	25.0	–	–	25.0	137.2	–	–112.2

FYM – farm yard manure; GM – green manure. T_1 – control (no fertilizer no organic manure); T_2 – 50% recommended dose of fertilizers (RDF) to both rice and wheat; T_3 – 50% RDF to rice and 100% RDF to wheat; T_4 – 75% RDF to both rice and wheat; T_5 – 100% RDF to both rice and wheat; T_6 – 50% RDF + 50% N through FYM to rice and 100% RDF to wheat; T_7 – 75% RDF + 25% N through FYM to rice and 75% RDF to wheat; T_8 – 50% RDF + 50% N through wheat straw to rice and 100% RDF to wheat; T_9 – 75% RDF + 25% N through wheat straw to rice and 75% RDF to wheat; T_{10} – 50% RDF + 50% N through green leaf manure (GLM) (*Sesbania aculeata*) to rice and 100% RDF to wheat; T_{11} – 75% RDF + 25% N through (GLM) to rice and 75% RDF to wheat; T_{12} – farmer's fertilizers practice to rice and wheat (70 kg N + 13.2 kg P + 8.3 kg K/ha)

Table 5. Pearson's correlation matrix among sustainable yield index (SYI), yield slope and apparent nutrient balance

		SYI		Yield slope		Apparent nutrient balance		
		rice	wheat	rice	wheat	N	P	K
SYI	rice	1						
	wheat	0.951**	1					
Yield slope	rice	0.964**	0.909**	1				
	wheat	0.907**	0.887**	0.935**	1			
Apparent nutrient balance	N	0.408	0.517	0.387	0.358	1		
	P	0.657*	0.766**	0.493	0.472	0.669*	1	
	K	–0.921**	–0.914**	–0.870**	–0.896**	–0.275	–0.587*	1

*$P \leq 0.05$; **$P \leq 0.01$

trend of K imbalance is not reversed, the potential to improve N and P fertilizer-use efficiency and increase crop yield will be limited.

Acknowledgement

Authors are thankful to the Vice Chancellor, Bihar Agricultural University (BAU), Bhagalpur, Bihar, India for providing necessary facilities, Director Research, BAU for his support and critical suggestions. Special thanks to the scientists associated with AICRP-IFS, Sabour unit. Finally, the financial support from AICRP-IFS (ICAR) is gratefully acknowledged.

REFERENCES

Bi L., Zhang B., Liu G., Li Z., Liu Y., Ye C., Yu X., Lai T., Zhang J., Yin J., Yin L. (2009): Long-term effects of organic amendments on the rice yields for double rice cropping systems in subtropical China. Agriculture, Ecosystems and Environment, *129*: 534–541.

Cao R.X., Wang Z.M., Tong X.L., Li G.H., Zhao H.J. (2004): Study on the utilization of straw potassium and chemical potassium in rice-wheat rotation system. Soils and Fertilizers, *4*: 23–26.

Dawe D., Dobermann A., Moya P., Abulrachman S., Singh B., Lal P., Li S.Y., Lin B., Panuallah G., Sariam O., Singh Y., Swarup A., Tan P.S., Zhen Q.X. (2000): How widespread are yield declines in long-term rice experiments in Asia? Field Crops Research, *66*: 175–193.

Efthimiadou A., Bilalis D., Karkanis A., Froud-Williams B. (2010): Combined organic/inorganic fertilization enhance soil quality and increased yield, photosynthesis and sustainability of sweet maize crop. Australian Journal of Crop Science, *4*: 722–729.

Gu Y.F., Zhang X.P., Tu S.H., Lindström K. (2009): Soil microbial biomass, crop yields, and bacterial community structure as affected by long-term fertilizer treatments under wheat-rice cropping. European Journal of Soil Biology, *45*: 239–246.

Herencia J.F., Ruiz-Porras J.C., Melero S., Garcia-Galavis P.A., Morillo E., Maqueda C. (2007): Comparison between organic and mineral fertilization for soil fertility levels, crop macronutrient concentrations, and yield. Agronomy Journal, *99*: 973–983.

Hobbs P., Morris M. (1996): Meeting South Asia's Future Food Requirements from Rice-Wheat Cropping Systems: Priority Issues Facing Researchers in the Post-Green Revolution Era. International Maize and Wheat Improvement Center, Mexico.

Ladha J.K., Dawe D., Pathak H., Padre A.T., Yadav R.L., Singh B., Singh Y., Singh Y., Singh P., Kundu A.L., Sakal R., Ram N., Regmi A.P., Gami S.K., Bhandari A.L., Amin R., Yadav C.R., Bhattarai E.M., Das S., Aggarwal H.P., Gupta R.K., Hobbs P.R. (2003): How extensive are yield declines in long-term rice-wheat experiments in Asia? Field Crops Research, *81*: 159–180.

Li Z., Liu M., Wu X., Han F., Zhang T. (2010): Effects of long-term chemical fertilization and organic amendments on dynamics of soil organic C and total N in paddy soil derived from barren land in subtropical China. Soil and Tillage Research, *106*: 268–274.

Lin B., Xie J., Wu R., Xing G., Li Z. (2008): Integrated nutrient management: Experience from China. In: Aulakh M.S., Grant C.A. (eds.): Integrated Nutrient Management for Sustainable Crop Production. The Haworth Press, Taylor & Francis Group, Philadelphia, 327–368.

Mann R.A., Garrity D.P. (1994): Green manures in rice-wheat cropping systems in Asia. In: Ladha J.K., Garrity D.P. (eds.): Green Manure Production Systems for Asian Rice Lands. International Rice Research Institute, Los Banos, 27–42.

Miao Y., Stewart B.A., Zhang F. (2011): Long-term experiments for sustainable nutrient management in China. A review. Agronomy for Sustainable Development, *31*: 397–414.

Page A.L., Miller R.H., Keeney D.R. (1982): Methods of Soil Analysis, Part 2 – Chemical and Microbiological Properties.

Agronomy, No. 9. 2nd Edition. American Society of Agronomy, Soil Science Society of America Publishing, Madison.

Saleque M.A., Abedin M.J., Bhuiyan N.I., Zaman S.K., Panaullah G.M. (2004): Long-term effects of inorganic and organic fertilizer sources on yield and nutrient accumulation of lowland rice. Field Crops Research, *86*: 53–65.

Tang X., Li J., Ma Y., Hao X., Li X. (2008): Phosphorus efficiency in long-term (15 years) wheat-maize cropping systems with various soil and climate conditions. Field Crops Research, *108*: 231–237.

Timsina J., Connor D.J. (2001): Productivity and management of rice-wheat cropping systems: Issues and challenges. Field Crops Research, *69*: 93–132.

Yadav R.L., Dwivedi B.S., Prasad K., Tomar O.K., Shurpali N.J., Pandey P.S. (2000): Yield trends and changes in soil organic-C and available NPK in a long-term rice-wheat system under integrated use of manures and fertilisers. Field Crops Research, *68*: 219–246.

Yadav R.L. (1998): Factor productivity trends in a rice-wheat cropping system under long-term use of chemical fertilizers. Experimental Agriculture, *34*: 1–18.

Yang C., Yang L., Yang Y., Ouyang Z. (2004): Rice root growth and nutrient uptake as influenced by organic manure in continuously and alternately flooded paddy soils. Agricultural Water Management, *70*: 67–81.

Zhang F.S., Fan M.S., Zhao B.Q., Chen X.P., Li L., Shen J.B., Feng G., Chen Q., Jiang R.F., Ma W.Q., Zhang W.F., Cui Z.L., Fan X.L. (2006): Fertilizer use, soil fertility and integrated nutrient management in China. In: Fan M.S., Zhang F.S. (eds.): Improving Plant Nutrient Management for Better Farmer Livelihoods. Food Security and Environmental Sustainability, FAO, 188–211.

Received on January 15, 2014
Accepted on June 19, 2014

Corresponding author:

Rajiv Rakshit, Bihar Agricultural University, Department of Soil Science and Agricultural Chemistry, Sabour, Bhagalpur 813210, Bihar, India
e-mail: rajiv.ssaciari@gmail.com