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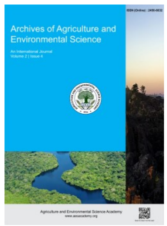

ORIGINAL RESEARCH ARTICLE

CrossMark

Long-term fertilization effect on yield and land productivity of rice-wheat cropping system of Bangladesh

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ABSTRACT

A factorial study was carried out at Bangabandhu Sheikh Mujibur Rahman Agricultural University to determine the effect of long term fertilization on yield performance of *T. aman* rice and wheat. The experimental plot received different organic manures for the last 26 years (1988-2014). The organic manure cowdung, compost, green manure and rice straw were applied at the rate of 25, 25, 7.5 and 1.5 t ha^{-1}, respectively in a yearly sequence. Three levels of nitrogen *viz.*, 0, 75 and 100 kg ha^{-1}for rice and 0, 80 and 120 kg ha^{-1} for wheat were applied. Application of nitrogen fertilizer along with organic manure significantly increased yield of rice and wheat .The highest rice grain yield was found in 2014 under the N_{75} and no manure treatment, which was 6.48 t ha^{-1} whereas grain yield of wheat was found maximum in 2008 from the interaction of N_{120} and rice straw application where yield was recorded 5.25 t ha^{-1}. In rice-wheat cropping sequence, the plots that received no nitrogen, LPI value was less than 2 (0.80) in the observed years. When the plots were treated with nitrogen fertilizer showed LPI values > 2 in 2008, 2009, 2012 and 2013, which indicates the trend of higher productivity of land due to long term fertilization. The maximum sustainable yield index was found in rice (0.69)> wheat (0.40) with 100 kg ha^{-1} and 120 kg ha^{-1} N treatment respectively. So, Long term fertilization strategy can be effective way to improve the yield, land productivity and sustainable yield index of rice and wheat through rescheduling the rates of organic and inorganic fertilizers that ensure balanced supply of plant nutrients.

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INTRODUCTION

Rice is the staple food grain in Bangladesh and covers about 80% of the total cropped area accounting for over 90% of total grain production of Bangladesh. Wheat is the second most important food grain and is commonly grown after rice. Over 85% of the total wheat area of the country is preceded by transplanted monsoon rice grown from July to December (Saunders, 1991). It is the most important predominant cropping system in Bangladesh which played a significant role in the sustainable food security. But, in recent findings, there has been clear evidence of declining trends of rice and wheat yield (Chauhan *et al.*, 2012). The demand for production of rice will endure rising in the near future due to shrinkage of cultivable land and over population growth (Alam *et al.*, 2019b). The productivity of rice-wheat system in Bangladesh is declining year after year. One of the main constraints to rice and wheat production is low organic matter content and low indigenous nutrient supply (Biswas and Sharma, 2008). Modern varieties give higher crop yields but respond to more nutrients than local varieties because of higher amount of potential biomass production. On an average, the farmers of Bangladesh use 190 kg nutrients (149 kg N, 16 kg P, 18 kg K and others 7 kg) ha^{-1} yr^{-1}, while the estimated removal is around 280-350 kg/ha/yr. (Islam, 2008). The cumulative negative nutrient balance over the years resulted in the fertility degradation of land. Consequently, soils are degrading day by day, losing their health and potentiality for crop production (Khan *et al*., 2008).

Soil is an essential non-renewable resource with potentially rapid degradation rates and extremely slow formation and regeneration processes (Van-Camp *et al*., 2004). Most of the cultivable lands are degraded day by day due to indiscriminate use of agro-chemicals, excessive and deep tillage, luxury irrigation, intensive cropping with high yielding varieties, little or no use of organic materials and improper soil management practices (Lal, 2008). Soil organic matter (SOM) content in Bangladesh is not only poor but it is declining gradually which is the number one key to soil fertility and productivity.

Rice-wheat cropping system is the most adopted and vital cropping system for achieving food security of Asia (Ray and Gupta, 2001; Singh *et al*., 2007) and sustainability of this system is very important. Intensive cropping of rice-wheat system with no return of crop residues and other organic materials results in loss of soil organic matter and may have some adverse deleterious effect on soil fertility as well as production provided utmost care is not taken and thus the system is not sustainable (Samui *et al*., 1998; Singh *et al*., 2007). As the optimum soil physical environment for the puddled rice and upland wheat differs substantially, cropping sequence that includes both the crops requires special management practices like manuring to become sustainable (Islam, 1994; Singh *et al*., 2007). The necessary removal of organic material in the form of harvested crop is compensated for by growing green manure crops or by amending with compost. Long-term experiments play an important role in understanding the complex interaction involving plants, soils, climate and management practices and their effects on crop productivity. In fact, agricultural scientists have recognized the long-term sites as invaluable tools in the study of agro-ecosystem dynamics. To improve or to sustain the productivity of rice-wheat system in Bangladesh, Bhuiyan *et al.* (1993) recommended the long-term evaluation of the use of organic manure or green manure for maintaining soil fertility. It is now essential to increase organic matter content through periodic addition of organic matter along with the application of inorganic fertilizer for maintaining productivity to achieve maximum and stabilized crop yield in the country. A comprehensive breakthrough and capturing knowledge on the transformation of soil organic matter and N in soils is necessary to escalate soil fertility management practices and increase crop productivity, which may ensure food security and play a vital role in climate change mitigation (Alam *et al*., 2019a).

Studies by Bhandari *et al.* (2002) attributed the productivity of the rice-wheat system is reduced due to declining SOM, decreased soil fertility, occurrence of nutrient imbalances, and inappropriate fertilizer practices. Previous research considered that the continued use of mineral fertilizers may result in decline of soil productivity. In most long-term experiments, a combination of mineral fertilizers and organic manure has generally given the best crop yield and soil quality (Wang *et al*., 2004; Chalk *et al*., 2003). Therefore, present investigation was undertaken to observe the performance of the integrated use of organic manure and chemical fertilizer to assess the yield and land productivity in a rice-wheat cropping system. To achieve this goal an experiment was initiated in 1988 to study the effect of long term manuring along with three doses of nitrogen on soil properties and yield of *T. aman* rice and wheat. The present study utilized the yield data generated during 2007 to 2014 from the Long-Term Experiment (LTE).

MATERIALS AND METHODS

Description of study site

The current study is a part of long-term manuring experiment that started in July, 1988 with T. aman rice-wheat cropping sequence at Bangabandhu Sheikh Mujibur Rahman Agricultural University. Data used in the study for the period of 2007-2014, while as per design and treatments, the experiment was conducted for one year only (2013-2014). The experimental farm is located in the center of the Agro-ecological Zone (AEZ) of Madhupur Tract (AEZ-28) at about 24.23° North Latitude and 90.08° East Longitude having a mean elevation of 8.4m above mean sea level and about 40 km north of Dhaka. The climate of the location is tropical monsoon. The land selected for the long-term experiment had been a virgin land where no crop was grown before. The soil belongs to Salna series representing the Shallow Red Brown Terrace and is classifed as Inceptisols according to USDA Taxonomy (Brammer, 1978). The soil is characterized by heavy clays within 50 cm from the surface and is acidic in nature. Some basic chemical properties of the soil, prior to setting the Long term experiment, are presented in the Table 1.

Table 1. Chemical properties of initial soil (0-15 cm) of the long-term experimental plot (Islam, 2003).

Parameters	1988	2003
pH	5.60	5.88
Organic carbon (%)	0.42	0.30
Total nitrogen (%)	0.03	0.05

Experimental design

The experimental design of the study was in a factorial randomized complete block design with two replications and plot size was 12m × 7m. The factorial experiment included five different organic materials treatments (application of cow-dung (CD) @ 25 t/ha, compost @ 25 t/ha, green ipil-ipil leaves @ 7.5 t/ha, rice straw (RS) @ 1.5 t/ha, no manure application) and three nitrogen treatments (For rice 0, 75 and 100 kg N/ha and for wheat 0, 80 and 120 kg N/ha). The high yielding rice variety BRRI dhan39 and wheat variety BARI Gom 24 (prodip) were used as the test crops. Seeds were collected from Bangladesh Agricultural Development Corporation (BADC). One week after proper paddling the field, twenty-five-days old seedlings of BRRI dhan39 were transplanted maintaining a spacing of 25 cm × 20 cm and wheat seeds were directly sown in 18th November 2013 in continuous lines having the line to line distance of 20 cm. Fertilizer doses of P and K were applied as triple super phosphate (TSP)and muriate of potash (MoP) at the rate of 44.05 and 66.67 kg ha-1) The whole amount of TSP, MoP and gypsum was applied during final land preparation. Urea was applied in three equal splits at final land preparation, 15 days after transplanting (DAT) and 5-7 days before panicle initiation stage. During *T. Aman* 2013, irrigations were given to the rice plots to maintain standing water for almost all the time except maturity. Six irrigations were given on 5 Days after sowing (DAS), 11DAS, 21DAS, 29DAS, 40DAS and 50DAS during wheat season (Rabi 2014). After irrigation the soil was made loosen. Weeding and thinning were also done simultaneously at that time. At maturity BRRI dhan39 was harvested in 28th September 2013 and BARI Gom 24 was harvested in 20th March 2014.

Land Productivity Index (LPI)

The yield data of rice and wheat for the year of 2007 to 2013 were collected from the records of previous study.

Land productivity index of rice and wheat were determined which were calculated using the following equation (Ranamukhaarachchi *et al.*, 2005).

$$\mathbf{LPI} = \sum_{i=1}^{n} \left(\frac{Yob}{Yavg}\right)\mathbf{i}$$

Where, Yob = observed/actual yield of the ith crop (rice and wheat); Yavg = average yield of the ith crop (rice and wheat); i = the component crop grown in the cropping systems in a year; n = number of crops grown in the cropping systems in a year

Although, the LPI offers the opportunity to use the potential crop yield to examine the contribution of cropping systems effect on yield gaps, as they reflect with the average productivity in the farming area. The LPI value of 2 was used as the standard value for determining the productivity of cropping systems containing two crops grown per year in sequence.

Sustainable Yield Index (SYI)

Sustainable yield index of rice and wheat were analyzed to determine the yield sustainability of rice and wheat. SYI of rice and wheat were calculated using the equation provided by Singh *et al.* (1990).

$$SYI = (y-s)/Y_{max}$$

Where, y = estimated average yield; s = standard deviation of yield across years; Y_{max} = maximum observed yield

SYI nearness to 1 implies the closeness to an ideal condition that can sustain maximum crop yields over year.

Statistical analysis

Data were statistically analyzed using STATISTICS-10.0 software. ANOVA and univariate analyses were performed to test all parameters. Treatment means were separated by least significant difference (LSD). Different graphs were prepared using Microsoft Excel (Office 2007).

RESULTS AND DISCUSSION

Yield of rice as influenced by long-term manuring and nitrogen fertilization in different years

The effect of manure and N fertilizer application on rice yield is presented in (Table 2). Manure and crop residues application did not show significant effect on rice yield except in 2012. Yields under different manure and residues treated plot ranged from 3.2 to 4.88 t ha^{-1}. In 2007, the plots that received no nitrogen fertilizer yielded 2.10 t ha^{-1}, which was increased to 4.82 and 4.87 t ha^{-1} grain in N_{75} and N_{100} treatments, respectively. It was found that rice yield significantly increased under N_{75} and N_{100} treatments over the control in all years since 2007 to 2014. However, there were insignificant differences found in rice yields between N_{75} and N_{100} treatments. Except the year 2007 and 2011, the yield of rice progressively increased from 2008 and onwards (Table 2). The highest grain yield (6.23 t ha^{-1}) was found in 2014 under the N_{75} treatment, which was insignificantly higher over the yield found in N_{100} treatment.

The interaction of nitrogen fertilizer and manure application was found significant (Table 2). The treatment that received no nitrogen and no manure or crop residues provided the lower yield of rice. The highest rice grain yield was found in 2014 under the N_{75} and no manure treatment, which was 6.48 t ha^{-1}. However, this yield was insignificantly varied with the yields found under the interaction of N_{75} with different manures and N_{100} with different manure and residues. In IPNS, the integrated use of chemical fertilizer and organic manure enhanced growth and yield contributing characters of wheat and *T. Aman* rice in the wheat–rice cropping systems reported by Haque *et al.* (2018).

Yield of wheat as influenced by long-term manuring and nitrogen fertilization in different years

Long-term application of nitrogen fertilizer and manures exerted significant role on grain yield of wheat (Table 3). Nitrogen application provided significantly higher yields over the control treatment where no nitrogen was applied. Grain yield of wheat

Table 2. Yield of rice as influenced by long-term manuring and nitrogen fertilization in different years.

Treatments		Rice yield t ha^{-1}) in different years							
Nitrogen (kg ha^{-1})		2007	2008	2009	2010	2011	2012	2013	2014
0		2.10b	2.11b	2.13b	2.23b	2.17b	2.23b	2.17b	2.24b
75		4.82a	4.51a	4.53a	4.95a	3.77a	4.89a	4.46a	6.23a
100		4.87a	4.76a	4.59a	4.85a	3.87a	4.86a	4.55a	5.97a
SE(±)		0.12	0.15	0.21	0.19	0.09	0.09	0.26	0.20
Manure (t ha^{-1})									
0		3.85	3.73	3.78	4.05	3.18	3.81b	3.63	4.87
CD (25)		4.05	3.88	3.80	3.93	3.29	4.08a	3.67	4.75
CP (25)		3.94	3.88	3.71	3.91	3.40	3.94ab	4.00	4.84
GM (7.5)		3.91	3.86	3.64	4.13	3.20	4.02ab	3.57	4.80
RS (1.5)		3.90	3.63	3.81	4.02	3.28	4.11a	3.77	4.80
SE(±)		0.15	0.19	0.27	0.25	0.12	0.11	0.34	0.25
Nitrogen × Manure									
Nitrogen (kg ha^{-1})	Manure (t ha^{-1})								
0	0	2.01b	2.03d	2.08b	2.03b	2.04c	2.04d	2.03b	2.01b
0	CD (25)	2.23b	2.13d	2.18b	2.18b	2.09c	2.13d	2.13b	2.18b
0	CP (25)	2.10b	2.20d	2.13b	2.23b	2.16c	2.23d	2.23b	2.25b
0	GM (7.5)	2.04b	2.08d	2.15b	2.28b	2.23c	2.43d	2.33b	2.48b
0	RS (1.5)	2.13b	2.13d	2.13b	2.43b	2.33c	2.43d	2.33b	2.48b
75	0	4.53a	4.17bc	4.19a	5.13a	3.69ab	4.78bc	4.65a	6.48a
75	CD (25)	5.03a	4.75abc	4.97a	4.75a	3.81ab	5.23a	4.42a	6.30a
75	CP (25)	4.78a	4.63abc	4.75a	4.63a	4.03a	4.73bc	4.71a	5.98a
75	GM (7.5)	5.00a	4.94a	4.09a	5.13a	3.56b	4.90abc	4.09a	6.03a
75	RS (1.5)	4.75a	4.06c	4.63a	5.13a	3.75ab	4.80bc	4.43a	6.38a
100	0	5.00a	5.00a	5.06a	5.00a	3.82ab	4.60c	4.21a	6.13a
100	CD (25)	4.90a	4.75abc	4.25a	4.88a	3.97ab	4.90abc	4.46a	5.78a
100	CP (25)	4.94a	4.81ab	4.25a	4.88a	4.00a	4.88abc	5.06a	6.30a
100	GM (7.5)	4.69a	4.56abc	4.69a	5.00a	3.81ab	4.83abc	4.48a	6.08a
100	RS (1.5)	4.81a	4.69abc	4.69a	4.50a	3.75ab	5.10ab	4.56a	5.55a
SE(±)		0.26	0.33	0.47	0.43	0.20	0.19	0.58	0.44
CV (%)		6.71	8.81	12.55	10.68	6.13	4.76	15.65	9.17

M_0 = No manure, CD = cowdung @ 25 t ha^{-1}, CP = Compost @ 25 t ha^{-1}, GM = Green manure @ 7.5 t ha^{-1}, RS = Rice straw @ 1.5 t ha^{-1}, N_0 = No nitrogen, N_{75} = 75 kg N ha^{-1}, N_{100} = 100 kg N ha^{-1}. Means followed by same letter (s) in a column do not differ significantly at 5% by LSD.

Table 3. Yield of wheat as influenced by long-term manuring and nitrogen fertilization in different years.

Treatments		Wheat yield (t ha^{-1}) in different years					
Nitrogen (kg ha^{-1})		2008	2009	2010	2011	2012	2013
0		1.24c	1.29b	0.59c	0.83b	1.00b	1.38c
80		4.33b	3.94a	2.49b	2.73a	2.88a	3.15b
120		4.99a	4.30a	3.20a	2.75a	3.13a	3.89a
SE(±)		0.22	0.30	0.12	0.18	0.27	0.06
Manure (t ha^{-1})							
0		3.43	2.90	2.14	1.92	2.35	2.31d
CD (25)		3.28	3.31	2.02	2.03	2.24	2.52c
CP (25)		3.52	3.49	2.24	2.14	2.68	2.67c
GM (7.5)		3.73	2.88	2.12	2.24	2.11	3.04b
RS (1.5)		3.63	3.30	1.94	2.19	2.31	3.50a
SE(±)		0.28	0.39	0.15	0.23	0.35	0.07
Nitrogen × Manure							
Nitrogen (kg ha^{-1})	Manure (t ha^{-1})						
0	0	1.30c	1.25d	0.78d	0.88b	0.88cd	0.90i
0	CD (25)	1.50c	1.19d	0.63d	0.94b	0.81cd	1.03hi
0	CP (25)	1.05c	2.19cd	0.59d	0.72b	1.94bc	1.18h
0	GM (7.5)	1.58c	0.90d	0.53d	0.94b	0.63d	1.58g
0	RS (1.5)	0.75c	0.94d	0.41d	0.67b	0.75cd	2.20f
80	0	4.25ab	3.81ab	2.44c	2.50a	3.00ab	2.75e
80	CD (25)	3.50b	4.50ab	2.38c	2.53a	2.89ab	3.16d
80	CP (25)	4.38ab	4.03ab	3.06ab	2.97a	2.91ab	3.23d
80	GM (7.5)	4.63a	3.06bc	2.50bc	2.91a	2.88ab	3.29d
80	RS (1.5)	4.88a	4.28ab	2.06c	2.75a	2.75ab	3.34cd
120	0	4.75a	3.63abc	3.19a	2.38a	3.19ab	3.28d
120	CD (25)	4.85a	4.25ab	3.06ab	2.63a	3.03ab	3.36cd
120	CP (25)	5.13a	4.25ab	3.06ab	2.72a	3.19ab	3.60c
120	GM (7.5)	4.98a	4.69a	3.33a	2.88a	2.83ab	4.25b
120	RS (1.5)	5.25a	4.69a	3.35a	3.13a	3.43a	4.95a
SE(±)		0.49	0.68	0.27	0.39	0.60	0.13
CV (%)		13.87	21.31	12.75	18.77	25.70	4.48

M_0 = No manure, CD = cowdung @ 25 t ha^{-1}, CP = Compost @ 25 t ha^{-1}, GM = Green manure @ 7.5 t ha^{-1}, RS = Rice straw @ 1.5 t ha^{-1}, N_0 = No nitrogen, N_{80} = 80 kg N ha^{-1}, N_{120} = 120 kg N ha^{-1}. Means followed by same letter (s) in a column do not differ significantly at 5% by LSD.

was found significantly different between the N_{80} and N_{120} treatments in 2008, 2010 and 2013, while statistically similar yield was observed in 2009, 2011 and 2012. Manure application showed significant effect on wheat yield only in 2013 where rice straw application provided the highest yield which was 3.5 t ha^{-1} (Table 3). The interaction effect of nitrogen fertilizer and manure application was found significant in producing grain yield of wheat, where no nitrogen and no manure gave the lowest yield. In most of the cases nitrogen application at the rate of 80 and 120 kg ha^{-1} with or without different manures did not show significant differences in wheat yield except in the year 2013. The highest grain yield of wheat was found in 2008 from the interaction of N_{120} and rice straw application where yield was recorded 5.25 t ha^{-1}. Combined applications of organic and chemical fertilizers are more effective than sole application of organic or chemical fertilizers for sustainable Wheat and soil productivity enhancement (Chekolle, 2017).

Land productivity index (LPI) of rice and wheat

Since the types of crop yields were different, land productivity index (LPI) was developed to use a common basis for comparing cropping systems having different crops. When assuming the LPI of a single crop is one, two-crop cropping sequence will have theoretically a LPI of two. If the calculated LPI exceeds the theoretical LPI, the cropping system is considered to be biologically productive.

Effect of long-term application of nitrogen and manure on land Productivity index (LPI) of rice and wheat

Long-term application of nitrogen produced greater significant role on the productivity of rice and wheat (Figure 1). In rice-wheat cropping sequence, the plots that received no nitrogen, LPI value was less than 2 (0.80) in the observed years. When the plots were treated with nitrogen fertilizer showed LPI values > 2 in 2008, 2009, 2012 and 2013, which indicated the higher productivity when compared to long-term mean productivity. Although LPI values were slightly low in 2010 and 2011, they were also very close to two and would be economically sound.

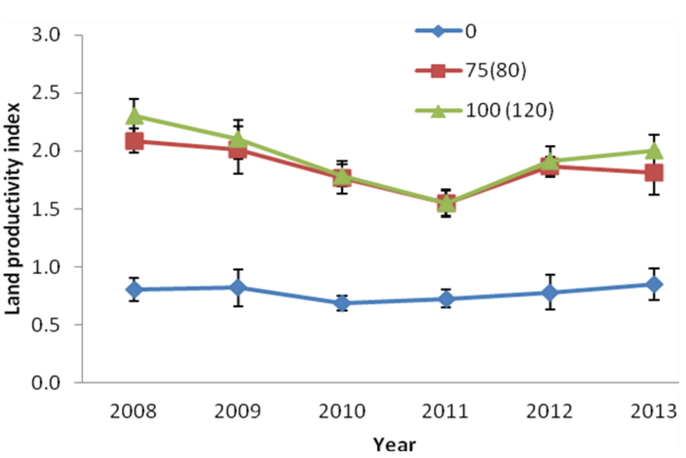

Figure 1. *Effect of long-term application of different manure on LPI of rice and wheat (Vertical bars indicates standard errors).*

The LPI value < 2 revealed that there is scope to increase yield of both rice and wheat through adoption of different modern soil and crop management practices.

Similar trend of results were observed in case of manure application (Figure 2). However in all cases of manure application the observed LPI values were much lower than theoritical LPI values of double crops cropping pattern. Therefore, there is also ample scope to increase the productivity of rice and wheat following different soil and crop management options. Rates of manure and residue application may need to refix to supply required amount of essential nutrients to crop plants. It also need to be confirmed that manures and residues are well composted before application to plots.

Sustainable Yield Index (SYI) of rice and wheat

Effect of long-term application of nitrogen and manure on sustainable yield Index (SYI) of rice and wheat

In case of rice, without application of nitrogen (N_0), the SYI of rice was 0.42, which increased to 0.63 with N_{75} and 0.69 with N_{100} treatments, respectively (Figure 3). The maximum sustainable yield index (0.69) was found when 100 kg ha^{-1} nitrogen was applied. SYI near to one implies that the closeness to an ideal condition that can sustain maximum crop yields over years, while deviation from one indicates the losses of sustainability (Singh *et al*., 1990). In case of wheat similar trend of result was observed (Figure 3). At zero nitrogen application SYI value for wheat was found 0.18, while at 80 and 120 kg N/ha SYI values were 0.38 and 0.39, respectively. It can be observed that SYI of rice was much higher than that of wheat. Nayak *et al.* (2012) also found that rice showed higher SYI value than wheat by conducting experiment in indo Gangetic plains of India.

Long-term application of manure has positive effects on the sustainability of rice and wheat (Figure 4). In case of rice, cow dung amended plots gave the maximum sustainable yield index (0.60) followed by RS and CP treated plots and the lowest SYI was found in the control treatment. In case of wheat, the highest SYI value (0.33) was obtained in the plots that received cow dung. Compost, green manure and rice straw applied plots showed slightly lower SYI value than that of cow dung applied plot. But all the SYI value of wheat was very low compared to standard SYI value. Effect of manure application on the yield of wheat was found unsustainable. Sustainability of grain yield of wheat must be achieved following improved management activities. SYI for wheat in both nitrogen and manure treatments were found very low compared to the standard SYI 1.0, and therefore there is ample scope to increase wheat yield. The rates of nitrogen fertilizer along with other micro and macro nutrients need to compute based on soil test nutrient values. Balanced fertilization should be ensured supplying either inorganic fertilizer or in combination of inorganic and organic fertilizers to get higher grain yield of wheat. Application of organic manures can be helpful in obtaining the sustainability of crop production was noted by Muhmood *et al.* (2015).

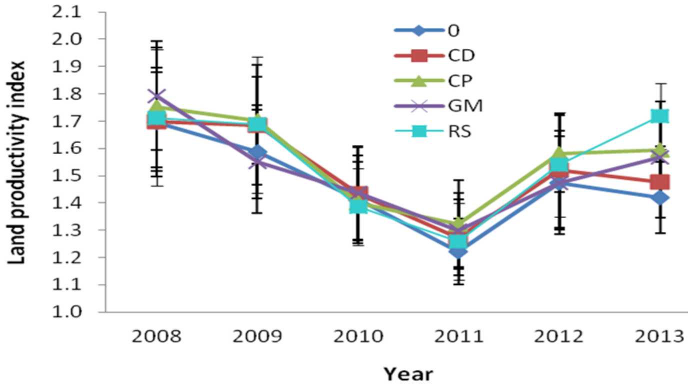

Figure 2. *Effect of long-term application of nitrogen fertilizer on LPI of rice and wheat (Vertical bars indicates standard errors).*

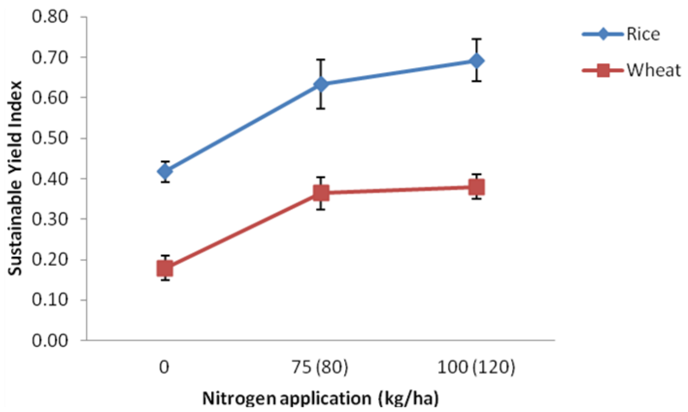

Figure 3. *Effect of long-term application of different nitrogen on SYI of rice and wheat (Vertical bars indicates standard errors).*

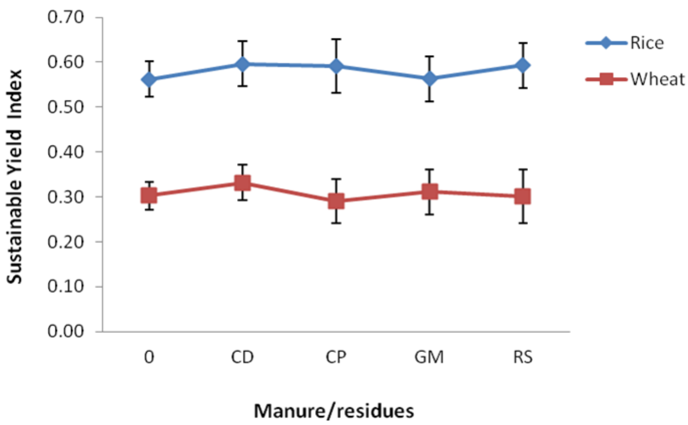

Figure 4. *Effect of long-term application of different manure on SYI of rice and wheat (Vertical bars indicates standard errors).*

Conclusion

From the experimental results it can be concluded that the combined use of organic manure with inorganic fertilizers performed better than inorganic fertilizers alone to sustain soil fertility and system productivity. Long-term addition of manures increased rice and wheat yield positively. In case of rice, the cow dung and rice straw performed better as compared to compost and green manure. In case of wheat, green manure and rice straw performed better. However, the yield increase due to organic amendment was not as much as obtained with N fertilizer application. Both LPI and SYI for rice and wheat were found low compared to the standard values which indicated that there are ample scopes to increase rice and wheat yields following better soil and crop management practices.

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Conflict of interest

The authors declare there are no conflicts of interest.

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