Indian Journal of Agronomy **68** (3): 239–245 (September 2023)

Research Paper

Influence of organic amendments and different levels of nitrogen on production potential, economics and energetics of rice (*Oryza sativa*)–wheat (*Triticum aestivum*) cropping system

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Received: July 2021; Revised accepted: July 2023

ABSTRACT

A field experiment was conducted during 2018–19 and 2019–20 at the Punjab Agricultural University, Ludhiana and Research Station, Dyal Bharang, Amritsar, to study the influence of organic amendments and nitrogen levels on rice (*Oryza sativa* L.)-wheat (*Triticum aestivum* L.) cropping system. In rice, main plot treatments were green manuring (GM), farmyard manure (FYM), poultry manure (PM) and control (NA). Nitrogen levels in sub-plots comprised control (N_1), 50 kg N/ha (N_2),75 kg N/ha (N_3) and 100 kg N/ha (N_4). In wheat, residual effect of organic amendments and nitrogen levels applied to preceding rice was evaluated. The statistically highest grain yield of rice was obtained with PM (8.29 t/ha), followed by GM (8.02 t/ha) which was at par with FYM (7.90 t/ha). The lowest rice grain yield was obtained with NA (5.16 t/ha) and its subsequent wheat crop recorded significantly higher grain yield with PM (6.14 t/ha), followed by FYM (5.88 t/ha) and GM (5.72 t/ha). Treatment N_4 recorded significantly higher yield than N_2 and was at par with N_3. Maximum rice-equivalent yield (14.7 t/ha) was recorded with PM, while the highest energy-use efficiency of rice was recorded with green-manure (16.2) as compared to the other treatments. Treatment with the application of PM and N_4 recorded significantly the highest economic parameters and system productivity for both rice and wheat crops compared to rest of the treatments.

Key words: Economics, Nitrogen, Organic amendments, Residual effect, Rice, Wheat, Yield

Rice (*Oryza sativa* L.)–wheat (*Triticum aestivum* L.) cropping system (RWCS) is immensely dominant and profitable system for the food security and livelihoods in South Asia. It is the major cropping system of Punjab, occupying about 3.103 million ha, with total production of 19.136 million tonnes (PAU, 2021), whereas wheat was grown on 3.512 million ha with production of 17.830 million tonnes (PAU, 2020–21). However, recent years have witnessed a significant slowdown in the yield growth rate of RWCS, and the sustainability of this important cropping system is at risk due to second-generation technology problems and mounting pressure on natural resources.

Conjunctive use of organic material along with fertilizer has been proved as efficient source of nitrogen. Managing nitrogen fertilization in rice fields is a challenging task for farmers because of various kinds of losses due to de-nitrification, deep percolation and run-off in flooded soils resulting in low nitrogen-use efficiency. Use of appropriate nitrogen management practices for increasing rice yield per unit area has become an essential component of modern rice production technology (Rajesh *et al.,* 2015).

To make the production system more sustainable, application of ample amounts of organic manures through different sources is one of the best practices without adverse effects on the natural resources and the environment (Aulakh *et al.,* 2018). Green-manuring *in situ* by growing and adding biomass in soil, an important part of our cropping system, can increase the nitrogen supply by lowering the soil *p*H and enhances the micro-fauna with improvement in the soil health. Sunhemp (*Crotolaria juncea* L.), a tropical legume, has been achieved value as a cover crop owing to its quick and higher biomass production, nitrogen accumulation, reduced pests and pathogen infestation, and weed suppression when planted during the lean period before transplanting of rice. Owing to positive influence of organic components in rice-wheat cropping system, it is assumed that farmers who adopted organic management

Based on a part of Ph.D. Thesis of the first author submitted to the Punjab Agricultural University, Ludhiana, Punjab in 2021 (unpublished)

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practices found a way to improve the quality of their soil, or at least stemmed the deterioration. The system becomes long-term productive by protecting soils and enhancing their fertility ensuring productive capacity for future generations.

Due to intensive cultivation of crops with imbalanced dose of chemical fertilizers alone, the productivity of soil has gone down, and now, time has come to supplement these chemical fertilizers with organics to sustain the fertility and productivity of the soils. Supply of nutrients through bulky organics FYM, poultry manure and green-manuring along with chemical fertilizers can help to maintain the soil-nutrient reserves for attaining higher crop yields. Under these circumstances, integration of chemical and organic sources and their proper management have shown promising results not only in sustaining the productivity but also proved effective in maintaining soil health and enhancing nutrient-use efficiency (Thakur *et al.,* 2011). Hence, balanced nutrient application is must to harness the productivity of the crops and get maximum profit. As information on these aspects is lacking in rice–wheat cropping system, a field investigation was undertaken under the north-western India.

MATERIALS AND METHODS

The field experiment was conducted at Students' Research Farm, Department of Agronomy, Punjab Agricultural University, Ludhiana and at Research Station, Dyal Bharang, Amritsar, during the rainy (*kharif*) and winter (*rabi*) seasons of 2018–19 and 2019–20. The soil at Ludhiana was loamy sand (81.74% of sand, 11.44% of silt and 6.82% of clay) in texture, with average bulk density of 1.57 g/cm^3 and low in organic carbon (0.3%), low in available N (0.189 t/ha), medium in available P (0.0194 t/ha) and available K (0.184 t/ha) with normal range of *p*H (7.98) and electrical conductivity (0.21dS/m) of the soil, whereas at Dyal Bharang, Amritsar, soil was clayey loam, with average bulk density of 1.60 g/cm^3 and low in organic carbon (0.33%), low in available N (0.1856 t/ha), medium in available P (0.0188 t/ha) and available K (0.1838 t/ha). However, *p*H (8.1) and electrical conductivity (0.21dS/m) of the soil were found in the normal range. The experimental site is situated at 30° 54' N 75° 48' E and 247 m above mean sea-level. The site is categorized under Trans-Gangetic agro-climatic zone of India with even topography, uniform textural make-up and medium land, which some time to gets submerged in the rainy season and is suitable for rice in the rainy season and for other crops in winter and summer seasons. The climate of the experimental site is sub-tropical, semi-arid. The region exhibiting 4 distinct seasons distinguished as very hot and dry summer (April to June); hot and humid conditions (July to September); cold winters (November to January); mild climate (February, March and October). In summer season, maximum air temperature during May and June often exceeds 39^{o}C; in winter (December and January), minimum air temperature falls below 4^{o}C with frosty spells. Average annual rainfall is 650 mm; more than 75% of which is received during monsoon (July to September).

The experiment was conducted in split-plot design, replicated 4 times, comprising 4 main plot treatments in rice 'PR 126', i.e. A_1, green-manuring (GM-sunhemp); A_2, farmyard manure @ 15 t/ha (FYM); A_3, poultry manure @ 6.25 t/ha (PM) and A_4, control (NA). Four subplot treatments were different nitrogen levels, i.e. N_1, control; N_2, 50 kg N/ha; N_3, 75 kg N/ha and N_4, 100 kg N/ha. In succeeding wheat crop 'PBW 725', residual effect of green-manuring and other organic amendments applied to rice was evaluated with respect to soil health and quality of rice, and wheat for maintaining sustainability of agricultural soils. The plot size was 7 m × 3.30 m = 23.1 m^2. Individual plots were thoroughly prepared in each season to avoid the mixing of soil in different treatments. Different levels of nitrogen was applied to rice according to treatments such as control, 50 kg N/ha, 75 kg N/ha and 100 kg N/ha. The entire quantity of P_2O_5 and K_2O (30 kg P_2O_5 and 30 kg K_2/ha) was applied to rice before last puddling. Nitrogen was applied in 3 equal splits–one third was applied before last puddling and the remaining 3 weeks after transplanting. Well-decomposed FYM (N=0.75%, P=0.30% and K=0.70%), poultry manure (N=3.40%, P=2.73% and K=1.92%) available at agricultural research farm were used. The crops were irrigated optimally as and when required and need-based plant-protection measures were adopted. Similarly, all other recommended practices were followed.

The grain and straw yields of rice and wheat were recorded from net plot area and converted into t/ha under different treatments. The economics was calculated as per input cost and economic value of different crop produce in respective year of research as per the local market. The local market price was taken as 1,590 and 1,770 ₹/100 kg) for rice during 2018 and 2019 and 1,840 and 1,925 ₹/100 kg) for wheat during 2018–19 and 2019–20 in respect of economic produce. The cost of cultivation and gross returns (₹/ha) for all the treatments were worked out on the basis of the prevailing market price of input and the produce. The net returns (₹/ha) was calculated by substracting the cost of cultivation from the gross returns. The B:C ratio was calculated treatment-wise to assess the economic impact of the treatments by dividing the gross returns with the cost of cultivation. The yield obtained from rice and wheat crops were converted into rice-equivalent yield (REY).

Rice-equivalent yield of system was calculated by summation of REY of each crop grown in *rabi* and *kharif* seasons. The system productivity was calculated by converting the yield of all crops grown in system in terms of rice-equivalent yield in kg/ha and dividing it by the duration of system. It was expressed as kg/ha/day.

The energy output of different treatments was calculated on the basis of biological yield and expressed as total energy (MJ/ha) (Kaur *et al*., 2020). The energy efficiency and energy productivity (Deike *et al.,* 2008) were worked out as:

$$\text{EE (MJ/ha)} = \frac{\text{Energy output (MJ/ha)}}{\text{Energy input (MJ/ha)}}$$

where, EE= Energy efficiency and Energy output= Grain + straw

$$\text{EP (kg/MJ)} = \frac{\text{Grain yield (kg/ha)}}{\text{Energy input (MJ/ha)}}$$

where, EP= Energy productivity

The data were subjected to statistical analysis. To test the statistical significance of treatment effects, Analysis of Variance (ANOVA) was carried out. General Linear Model (GLM) procedure in SAS® 9.4 version 6.1.7061 for Windows (SAS Institute 2013) was used for statistical analysis of experimental data. Multiple comparisons were made using Tukey's multi comparison test at $P \leq 0.05$ to determine significant effects.

RESULTS AND DISCUSSION

Grain and straw yield

Grain and straw yield of rice varied significantly with the application of different amendments and nitrogen levels at both locations, i.e. Ludhiana and Dyal Bharang, Amritsar. Application of PM in rice increased the grain yield by 65.32 and 61.4% over NA, whereas the GM and FYM increase the yield 60.93, 56.1% and 55.3, 53.7% over NA during 2018 and 2019, respectively. Interaction effect of different amendments and nitrogen level on grain and straw yield of rice was significant in the both years (Tables 1 and 5). Integration of PM with 100 kg N/ha was recorded higher yield, which was at par with 75 kg N/ha and significantly better than 50 kg N/ha and the control at both the locations during both the years. At PAU, Ludhiana, combination of PM and N_4 gave the highest straw yield which was at par with combination of PM with N_3, GM with N_4 and GM with N_3 during 2018. Whereas during 2019, PM with N_4 recorded significantly higher straw yield which was at par with PM and N_3 followed by GM with N_4 and FYM with N_4. Similar trend was observed at Dyal Bharang, Amritsar. This may be ascribed to the fast decomposition of PM and GM than FYM, probably led to better availability of nutrients to the crop. Increase in straw yield with application of amendments could partly be attributed to its direct influence on dry-matter production of vegetative part and indirectly through increased morphological parameters of growth, i.e. plant height, dry-matter, leaf-area index and effective tillers/m^2.

Earlier findings reported that, organic sources (PM, GM and FYM) might have offered more balanced nutrition to the plants, especially supplement of major nutrients along with micronutrients which positively affected number of grains and subsequently the increased yield. The available nutrients might have helped in enhancing leaf area, which thereby resulted in higher photo-assimilates and more dry-matter accumulation. Incorporation of poultry manure resulted improvement in organic carbon and available nitrogen content of soil after crop harvesting. Application of manure plus chemical fertilizers are found to give significantly higher yield than that of sole application of chemical fertilizer. By adding nitrogen to the soil, manure can improve soil organic matter and minimized the fertilizer requirement. Gill and Aulakh (2018) reported that, the application of organic manures along with N fertilizers and combinations of different organic manures increased the N uptake in rice, which might attributed higher yield and increased N availability in the soil.

Data pertaining to grain yield of wheat showed that, grain yield was varied significantly with the application of different amendments and nitrogen levels at both locations, viz. Ludhiana and Amritsar (Table 1). Among different amendments, the treatment in which PM was applied to rice recorded significantly higher grain yield of wheat than treatment with FYM followed by GM-treated plots which were at par with each other during both years. However, N_4 recorded higher grain yield, being significantly superior to N_2 treatments and was at par with N_3. Addition of organic manures to soil not only supply the essential nutrients to crop plants but also improves the water-holding capacity of the soils and helps in maintaining better aeration for good seed germination and better root growth of the crops (Paul *et al.,* 2016). Bhukhari *et al.,* (2022) reported that, the combination of PM, FYM, green-manure and with inorganic sources resulted in the highest grain yield and straw yield of wheat.

Wheat straw yield was higher in 2019–20 than 2018–19. Of the different amendments, PM resulted in significantly higher straw yield than FYM, followed by GM-treated plots which were at par with each other during 2018–19 and 2019–20, respectively. When there was no application of amendment (NA), the straw yield of wheat was found significantly lower than treatments with the application of amendments. The effect of application of different nitrogen levels to rice was significant on straw

Table 1. Effect of different amendments and nitrogen levels on grain yield and straw yield of rice and succeeding wheat crop

Treatment	Rice								Wheat							
	PAU				Dyal Bharang				PAU				Dyal Bharang			
	Grain yield (t/ha)		Straw yield (t/ha)		Grain yield (t/ha)		Straw yield (t/ha)		Grain yield (t/ha)		Straw yield (t/ha)		Grain yield (t/ha)		Straw yield (t/ha)	
	2018	2019	2018	2019	2018	2019	2018	2019	2018–19	2019–20	2018–19	2019–20	2018–19	2019–20	2018–19	2019–20
Amendments																
A_1	8.0ba	8.02b	10.12ba	10.27b	7.92a	7.93a	9.94ba	10.09ba	5.69b	5.72b	8.63a	8.70a	5.54b	5.56b	8.41a	8.48a
A_2	7.88b	7.90b	9.74b	9.91b	7.79a	7.81a	9.56b	9.73b	5.86b	5.88b	8.72a	8.80a	5.71b	5.73b	8.50a	8.58a
A_3	8.22a	8.29a	10.51a	10.76a	8.13a	8.20a	10.33a	10.58a	6.10a	6.14a	8.90a	8.98a	5.95a	5.98a	8.67a	8.76a
A_4	4.93c	5.16c	6.82c	6.94c	4.84b	5.06b	6.68c	6.76c	4.90c	4.93c	7.31b	7.34b	4.79c	4.81c	7.09c	7.14c
Nitrogen																
N_1	4.90c	5.09c	6.22c	6.38c	4.92c	5.00c	6.04c	6.20c	4.74c	4.74c	7.16c	7.19c	4.60c	4.61c	6.94c	7.01c
N_2	7.41b	7.51b	9.52b	9.63b	7.36b	7.42b	9.39b	9.45b	5.52b	5.55b	8.26b	8.33b	5.38b	5.41b	8.04b	8.11b
N_3	8.29a	8.30a	10.61a	10.83a	8.16a	8.21a	10.44a	10.65a	6.11a	6.15a	8.98a	9.06a	5.95a	5.99a	8.76a	8.84a
N_4	8.43a	8.47a	10.83a	11.04a	8.35a	8.38a	10.65a	10.86a	6.19a	6.22a	9.15a	9.23a	6.03a	6.06a	8.92a	9.01a

The same alphabetical letters within a column denote no differences at the $P<0.05$ level based on Tukey's multi comparison test

A_1, Green-manure (GM); A_2, farmyard manure (FYM); A_3, poultry manure (PM); A_4, no application of amendment (NA); N_1, control; N_2, 50 kg N/ha; N_3, 75 kg N/ha; N_4, 100 kg N/ha.

yield of wheat during both the years at both the locations. Treatment N_4 recorded higher straw yield, being significantly superior to N_2 and was at par with N_3 treatment. Increase in straw yield with application of amendments could partly be attributed to its direct influence on dry-matter production of vegetative part and indirectly through increased morphological parameters of growth, i.e. plant height, dry matter, LAI and effective tillers/m^2. The combination of organic amendments and nitrogen had a significant effect on straw yield in both the years. An increasing trend of straw yield was observed with higher levels of N in combination with different manures in both years. Irin *et al.,* (2020) reported that, application of different amendments and higher rates of nitrogen were found to be effective in terms of nitrogen contribution and specially its incorporation into soil revealed the significant and positive effect of subsequent and succeeding crop yield.

Total system productivity

Higher system productivity was recorded with PM followed by FYM and GM as compared to NA in both the years (Table 2). Whereas, among the different nitrogen levels, N_4 recorded higher system productivity followed by N_3 as compared to N_2. The lowest system productivity was recorded with N_1. Among different amendments, system productivity was increased by 45.3 and 46.0% during the first year and 42.6 and 43.3% during the second year in PM, compared to NA. However, among different N levels, system productivity was increased by 50.9 and 52.3% during the first year and 48.6 and 49.8% during the second year in N_4, compared to N_1 at PAU, Ludhiana and Dyal Bharang, Amritsar respectively.

Rice-equivalent yield (REY)

The rice-equivalent yield (REY) was influenced by the application of different amendments and nitrogen levels (Table 2). The highest REY of 14.56 t/ha and 14.73 t/ha and 14.31 t/ha and 14.47 t/ha was recorded with the application of poultry manure (PM), being higher than those found in the other treatments during 2018–19 and 2019–20 at both the locations. The lowest REY was recorded in control (NA) treatment. Among the different nitrogen levels, N_4 treatment recorded higher REY followed by N_3 and N_2. The lowest REY were observed with N_0 at both the locations. It is clear from the data that sources of nutrients at different levels altered the REY significantly in both the years at both the locations. In rice–wheat cropping system, Banjara *et al.,* (2021) also recorded the highest equivalent yield under integrated nutrient management.

System economics

Application of different amendments and nitrogen

Table 2. Rice-equivalent yield and system productivity as influenced by different amendments and nitrogen levels in rice–wheat cropping system

Treatment	PAU, Ludhiana				Dyal Bharang, Amritsar			
	Rice equivalent yield (t/ha)		System productivity (kg/ha/day)		Rice-equivalent yield (t/ha)		System productivity (kg/ha/day)	
	2018–19	2019–20	2018–19	2019–20	2018–19	2019–20	2018–19	2019–20
Amendments								
A_1	13.92	14.03	50.2	50.6	13.68	13.76	49.4	49.7
A_2	13.97	14.07	50.4	50.8	13.73	13.82	49.6	49.9
A_3	14.56	14.73	52.6	53.2	14.31	14.47	51.7	52.3
A_4	10.03	10.32	36.2	37.3	9.82	10.11	35.4	36.5
Nitrogen								
N_1	9.82	10.07	35.5	36.4	9.59	9.84	34.6	35.5
N_2	13.15	13.32	47.5	48.1	12.92	13.08	46.6	47.2
N_3	14.65	14.75	52.9	53.3	14.39	14.49	52.0	52.3
N_4	14.86	14.99	53.6	54.1	14.60	14.73	52.7	53.2

A_1, Green-manure (GM); A_2, farmyard manure (FYM); A_3, poultry manure (PM); A_4, no application of amendment (NA); N_1, control; N_2, 50 kg N/ha; N_3, 75 kg N/ha; N_4, 100 kg N/ha.

levels influenced economics of rice–wheat system during both the years at both the locations (Table 3). The highest economics in terms of net returns (167.4 × 10^3 ₹/ha and 185.5 × 10^3 ₹/ha and 163.2 × 10^3 ₹/ha and 180.9 × 10^3 ₹/ha) and B:C ratio (2.22, 2.34 and 2.16, 2.28) among different organic amendments was observed with the treatment where PM was applied as compared to FYM and GM during 2018–19 and 2019–20 at PAU and Amritsar, respectively, and their residual effect in succeeding wheat crop indicated that it was much benefited by the residual effect. The lowest economic returns were obtained in the control plots, which might be due to the poor grain and straw yields (Table 1). Gross returns in PM were 44.1 and 43.0% higher in the first year and 42.2 and 42.8% in the second year as compared to NA, at PAU and Amritsar, respectively. Net returns were in order of PM > FYM > GM > NA. Among the N levels, treatment N_4 recorded higher net returns followed by N_3 and N_2. The lowest net returns were observed with N_0 at both the locations. Net returns were in order of $N_4 > N_3 > N_2 > N_1$ treatment on the basis of 2-year average.

Energetics

Among the organic amendments, the highest total energy output of rice and wheat was recorded with the application of PM to rice and their residual effect on succeeding wheat crop at both the locations, which may be owing to the highest grain and straw yields of both the crops. The lowest value of energy output was obtained in the control. With regard to different nitrogen levels, application of 100 kg N/ha, recorded the maximum value of total energy output of rice and wheat as compared to rest of other treatments at PAU and Dyal Bharang respectively. The lowest value of total energy output was under the control treatment (Table 4).

The highest energy-use efficiency of rice was recorded under incorporation of green-manure as compared to the other treatments. In wheat crop, residual effect of poultry manure recorded the highest energy-use efficiency, which may owing to the highest grain and straw yields as compared to rest of the treatments. On the other hand, the lowest energy efficiency was recorded with control treatment in both the crops. With regard to the nitrogen levels, application of 75 kg N/ha recorded the maximum value of energy-use efficiency of rice. Treatment N_4 recorded the maximum value of energy efficiency in succeeding wheat crop in comparison to remaining treatments at both the locations. The results are in accordance with the findings of Ransing and Tomar (2019). The highest energy productivity of rice was recorded under GM, while in succeeding wheat crop the highest energy productivity was recorded under the residual effect of poultry manure, which may be

Table 3. Effect of different amendments and nitrogen levels on economics of rice–wheat cropping system.

Treatment	PAU, Ludhiana								Dyal Bharang, Amritsar							
	Gross returns (× 10^3 ₹/ha)		Variable cost (× 10^3 ₹/ha)		Net returns (× 10^3 ₹/ha)		Benefit: cost ratio		Gross returns (× 10^3 ₹/ha)		Variable cost (× 10^3 ₹/ha)		Net returns (× 10^3 ₹/ha)		Benefit: cost ratio	
	2018–19	2019–20	2018–19	2019–20	2018–19	2019–20	2018–19	2019–20	2018–19	2019–20	2018–19	2019–20	2018–19	2019–20	2018–19	2019–20
Amendments																
A_1	231.9	252.1	75.6	79.5	156.3	172.6	2.07	2.17	227.8	247.4	75.6	79.5	152.2	167.9	2.01	2.11
A_2	233.0	253.0	75.8	79.7	157.1	173.2	2.07	2.18	228.9	248.5	75.8	79.7	153.0	168.8	2.02	2.12
A_3	242.8	264.8	75.4	79.3	167.4	185.5	2.22	2.34	238.7	260.2	75.4	79.3	163.2	180.9	2.16	2.28
A_4	168.5	186.2	75.0	78.8	93.5	107.3	1.25	1.36	166.9	182.2	75.0	78.8	91.9	103.3	1.23	1.31
Nitrogen																
N_1	165.0	181.4	75.4	79.2	89.6	102.1	1.19	1.29	162.9	177.2	75.4	79.2	87.5	98.0	1.16	1.24
N_2	219.4	239.7	75.4	79.3	143.9	160.3	1.91	2.02	216.0	235.3	75.4	79.3	140.5	156.0	1.86	1.97
N_3	244.2	265.3	75.5	79.3	168.7	185.9	2.23	2.34	239.2	260.6	75.5	79.3	163.6	181.2	2.17	2.28
N_4	247.8	269.6	75.5	79.4	172.3	190.2	2.28	2.39	243.7	265.0	75.5	79.4	168.1	185.5	2.23	2.34

A_1, Green-manure (GM); A_2, farmyard manure (FYM); A_3, poultry manure (PM); A_4, no application of amendment (NA); N_1, control; N_2, 50 kg N/ha; N_3, 75 kg N/ha; N_4, 100 kg N/ha

Table 4. Energy-use efficiency and productivity of rice and succeeding wheat crop as influenced by application of different amendments and nitrogen levels

Treatment	Rice								Wheat							
	PAU, Ludhiana				Dyal Bharang, Amritsar				PAU, Ludhiana				Dyal Bharang, Amritsar			
	Energy use efficiency		Energy productivity (kg/MJ)		Energy-use efficiency		Energy productivity (kg/MJ)		Energy use efficiency		Energy productivity (kg/MJ)		Energy-use efficiency		Energy productivity (kg/MJ)	
	2018	2019	2018	2019	2018	2019	2018	2019	2018–19	2019–20	2018–19	2019–20	2018–19	2019–20	2018–19	2019–20
Amendments																
A_1	16.1	16.2	0.524	0.525	15.8	16.0	0.518	0.519	8.08	8.13	0.240	0.241	7.87	7.92	0.234	0.235
A_2	15.2	15.4	0.502	0.504	15.0	15.2	0.497	0.498	8.23	8.28	0.247	0.248	8.02	8.08	0.241	0.242
A_3	15.6	15.9	0.505	0.510	15.4	15.6	0.500	0.504	8.47	8.54	0.257	0.259	8.26	8.33	0.251	0.252
A_4	10.4	10.7	0.324	0.340	10.3	10.5	0.326	0.334	6.89	6.93	0.207	0.208	6.71	6.75	0.202	0.203
Nitrogen																
N_1	10.2	10.5	0.334	0.347	10.1	10.3	0.335	0.341	6.71	6.73	0.200	0.200	6.51	6.55	0.194	0.194
N_2	14.8	15.0	0.479	0.485	14.6	14.7	0.476	0.480	7.78	7.83	0.233	0.234	7.57	7.63	0.227	0.228
N_3	16.1	16.3	0.523	0.524	15.8	16.1	0.515	0.518	8.52	8.59	0.258	0.259	8.31	8.37	0.251	0.253
N_4	16.0	16.2	0.519	0.522	15.8	16.0	0.515	0.516	8.66	8.72	0.261	0.262	8.44	8.51	0.254	0.256

A_1, Green-manure (GM); A_2, farmyard manure (FYM); A_3, poultry manure (PM); A_4, no application of amendment (NA); N_1, control; N_2, 50 kg N/ha; N_3, 75 kg N/ha; N_4, 100 kg N/ha

Table 5. Interaction effect of different amendments and nitrogen levels on grain yield of rice at PAU, Ludhiana and Dyal Bharang, Amritsar.

Treatments	Grain yield (t/ha)															
	PAU, Ludhiana Nitrogen (kg/ha)								Dyal Bharang, Amritsar Nitrogen (kg/ha)							
	2018				2019				2018				2019			
	N_1	N_2	N_3	N_4	N_1	N_2	N_3	N_4	N_1	N_2	N_3	N_4	N_1	N_2	N_3	N_4
A_1	5.10ed	8.16c	9.36a	9.40a	5.18e	8.16d	9.36bac	9.40ba	5.07d	8.05c	9.26ba	9.30ba	5.09d	8.06c	9.27ba	9.31ba
A_2	5.04ed	8.14c	9.12ba	9.21ba	5.14e	8.14d	9.12bc	9.21bac	5.03d	8.03c	9.01bac	9.10ba	5.05d	8.05c	9.03bac	9.12ba
A_3	5.12d	8.52bc	9.42a	9.81a	5.20e	8.70dc	9.45ba	9.84a	5.04d	8.54bc	9.25ba	9.68a	5.11d	8.61bc	9.32ba	9.75a
A_4	4.33e	4.85ed	5.28d	5.28d	4.85e	5.04e	5.32e	5.43e	4.56d	4.83d	5.12d	5.32d	4.76d	4.95d	5.22d	5.34d

A_1, Green-manure (GM); A_2, farmyard manure (FYM); A_3, poultry manure (PM); A_4, no application of amendment (NA); N_1, control; N_2, 50 kg N/ha; N_3, 75 kg N/ha; N_4, 100 kg N/ha

owing to the highest grain and straw yields (Walia *et al.,* 2014). As regard to the nitrogen levels, application of 75 kg N/ha recorded maximum value of energy productivity of rice. In succeeding wheat crop, N_4 recorded maximum energy productivity as compared to rest of the treatments.

Based on the study, it was concluded that highest total productivity, energetics, net returns and benefit: cost ratio were recorded in rice–wheat cropping system with the direct and residual effects of poultry manure and 100 kg N/ha (N_4) which was at par with 75 kg N/ha among all the levels of nitrogen. System productivity improved significantly owing the application of different amendments and nitrogen levels in rice–wheat cropping system.

REFERENCES

Aulakh, C. S., Singh, Hargopal, Walia, S.S., Phutela, R.P. and Singh, G. 2018. Evaluation of nutrient sources for organic production of rice (*Oryza sativa*)–wheat (*Triticum aestivum*) cropping system in north-west India. *Indian Journal of Agronomy* **63**(2): 137–144.

Banjara, T.R., Bohra, J.S., Kumar, S. and Prajapat, K. 2021. Sustainable alternative crop rotations to the irrigated rice–wheat cropping system of Indo-Gangetic plains of India. *Archives of Agronomy and Soil Science* **6**: 73–84.

Bukhari, B., Zakaria, S. and Syafruddin, S. 2022. Effect of organic amendments on the water stress resistance of corn varieties during vegetative stage in Ultisols. *Indian Journal of Agricultural Research* **56**(3): 276–282.

Deike, S., Pallutt, B. and Christen, O. 2008. Investigations on the energy efficiency of organic and integrated farming with specific emphasis on pesticide use intensity. *European Journal of Agronomy* **28**: 461–470.

Gill, P.K. and Aulakh, C.S. 2018. Effect of integrated nitrogen management on NPK uptake in rice (*Oryza sativa* L.). *Journal of Applied Natural Science* **10**(1): 258–261.

Irin, I.J., Biswas, P.K., Ullah, M.J., and Roy, T.S. 2020. Effect of in situ green manuring crops and chemical fertilizer on yield of T. Aman rice and mustard. *Asian Journal of Crop Soil Science and Plant Nutrition* **2**(2): 68–79.

Kaur, N., Vashist, K.K. and Brar, A.S. 2020. Energy and productivity analysis of maize-based crop sequences compared to rice–wheat system under different moisture regimes. *Energy* **216**: 119–286.

PAU. 2020–21. *Package and practices for crops of Punjab* (*Rabi*). Punjab Agricultural University, Ludhiana, India, p. 1.

PAU. 2021. *Package and practices for crops of Punjab* (*Kharif*). Punjab Agricultural University, Ludhiana, India, p. 1.

Paul, J., Choudhary, A.K., Sharma, S., Savita, B., Dixit, A.K. and Kumar, P. 2016. Potato production through bio-resources: Long-term effects on tuber productivity, quality, carbon sequestration and soil health in temperate Himalayas. *Journal of Horticultural Science* **213**: 152–163.

Rajesh, K., Padma, V., Voleti, S.R., Radhika, K. and Sankar, A.S. 2015. Response of rice (*Oryza sativa*) varieties on nitrogen use efficiency and yield under different nitrogen levels. *Annals of Plant and Soil Research* **17**: 161–163.

Ransing, D.M. and Tomar, G.S. 2019. Production potential, economics and energetic as influenced by integrated nutrient management in soybean–wheat cropping system. *Indian journal of Agronomy* **64**(3): 298–303.

Thakur, R., Sawarkar, S.D., Vaishya, U.K. and Singh, M. 2011. Impact of continuous use of inorganic fertilizers and organic manure on soil properties and productivity under soybean–wheat intensive cropping of a Vertisol. *Journal of the Indian Society of Soil Science* **59**(1): 74–81.

Walia, S.S., Gill, R.S., Aulakh, C.S. and Kaur, Mandeep. 2014. Energy-efficiency indices of alternative cropping systems of North-West India. *Indian Journal of Agronomy* **59**(3): 359–363.