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Effect of inorganic and organic nitrogenous sources on soil fertility, nutrient uptake and economics of paddy (*Oryza sativa*) crop in Indo-Gangetic plains

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ABSTRACT

Present study was carried out during rainy (*kharif*) seasons of 2021 and 2022 at Rice Research Station, Chaudhary Charan Singh Haryana Agricultural University, Kaul, Haryana to explore the merits of organic farming compared to inorganic farming for sustainable agriculture. The experiment consisting of 7 treatments in paddy (*Oryza sativa* L.) crop conducted in randomized block design (RBD) with 5 replications. Organic treatments include application of different nitrogenous sources, viz. farmyard manure; green manure (*Sesbania*); vermicompost and mustard cake on equivalent nitrogen basis and inorganic sources include urea fertilizer. The results revealed that the application of urea as an inorganic nitrogen source resulted in higher status of available nitrogen (171.4 kg/ha), phosphorus (25.56 kg/ha), and potassium (319.2 kg/ha) in soil as compared to other treatments. Similarly, the uptake of NPK by paddy grains was highest in the treatment with 100% nitrogen through urea (43.77 kg/ha, 16.33 kg/ha, and 17.69 kg/ha, NPK, respectively), being at par with other organic treatments during both the seasons. While higher uptake of NPK (42.5 kg/ha, 19.78 kg/ha, 100.31 kg/ha, respectively) by paddy straw was recorded in treatment where 100% N through inorganic urea was applied. Organic farming system (increase ranged from 22.5 to 29.9%) performed similar to conventional farming (31.2% increased) in terms of yield over absolute control plot. Notably, treatments receiving 150% nitrogen through farmyard manure and 100% nitrogen through urea exhibited higher benefit-to-cost (B:C) ratios of 2.78 and 2.73, respectively. Therefore, organic farming emerges as an environmentally sustainable alternative to conventional practices, contributing to soil health and ensuring a consistent paddy crop yield.

Keywords: Farmyard manure, Mustard cake, *Sesbania*, Soil fertility, Vermicompost, Yield

In ancient India, the farmers get adhered to the natural law which helps to maintain soil fertility over the period (Chandra and Chauhan 2004). As per the statistics of financial year 2022, the net area under organic farming has been increased upto 2.45% over than the last year (Keelery 2023). For sustainable crop production, good soil fertility system is must which required the continuous usage of organic nutrient sources. Organic fertilizers as a source of nutrients include farm yard manure, green manuring using *Sesbania*, mustard cake, vermicomposting using earthworms, press-mud, bagasse, sheep manure, poultry litter, sewage sludge, bio-fertilizers etc (Iqbal *et al.* 2019). These organic sources not only supplement N, P and K nutrients to plant but also make unavailable form of major nutrients, micro-nutrients and decomposed plant residues into form which is easily available to plant (Yadav *et al.* 2013). Therefore, organic agriculture is considered as a holistic approach for agriculture which not only assure sustainable crop production but also helps to enhance agro ecosystem and the resulting crops are more nutritious (Yadav *et al.* 2016).

However, yields in organic farming systems are lower and less reliable than in conventional agricultural systems and thus, need to be modified to ensure high yields and quality of agricultural products.

In India, rice stands as a pivotal staple, catering to over 60% of the population. By 2021–22, its area had expanded to 46.38 million hectares, marking a remarkable 50.53% surge. Concurrently, production levels have witnessed a significant upswing, escalating from 20.58 million tonnes in 1950–51 to 130.29 million tonnes in 2021–22, as reported by the Directorate of Economics and Statistics (DES 2022). However, the present scenario reveals a plateau in the average yield of rice, persistently behind its production potential. This stagnation could be attributed to the imbalanced utilization of inorganic fertilizers in the

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agricultural domain. Consequently, this study was carried out to compare the various organic inputs and their potential to release necessary nutrients into soil while mitigating the burden on farmers' cultivation costs. The objectives of the study were: to assess the effect of organic and inorganic management on nutrient soil chemical properties, nutrient uptake and yield under the organic or inorganic cultivation of rice; and to study the economic feasibility of organic over inorganic nutrient sources.

MATERIALS AND METHODS

The experiment was conducted during rainy (*kharif*) seasons of 2021 and 2022 at Rice Research Station, Chaudhary Charan Singh Haryana Agricultural University, Kaul (29.51°N and 76.39°E, at an altitude of 230.7 m), Haryana. The majority of the rainfall occured during the south-west monsoon from May to October and ranged from 236.7 mm in 2021 to 79.5 mm in 2022. During the season, maximum temperature ranged from 29.2–39.3°C during 2021 and 29–44°C in 2022 while minimum temperature ranged from 13.7–26.9°C in 2021 and 13.9–26.3°C in 2022. The experimental soil is classified as clay loam, featuring a *p*H of 8.2. Initially, the soil showed low to medium organic carbon content (0.5%), low availability of nitrogen (151.5 kg N/ha), low to medium availability of phosphorus (17.2 kg P/ha), and high potassium (280.5 kg K/ha).

Field preparation and transplanting: The paddy nursey was raised in June as recommended by package of practices of CCS Haryana Agricultural University, Kaul, Haryana. From the field, the representative soil samples were taken and air dried for nutrient analysis. One-month old nursery was transplanted in the main field. Field was prepared for transplanting using rotavator for puddling and followed by planking. Plots of 7.0 m × 11.0 m were prepared and all the organic inputs were added and mixed into the field by puddling before one month of transplanting throughly. Crop was transplanted on 25 July 2021 and 24 July 2022 with spacing 20 cm × 15 cm.

Experimental treatments: The experiment was conducted in a randomized block design (RBD) comprised of 7 treatments, viz. T_1, Absolute control; T_2, 100% RDN; T_3, 100% N (farmyard manure); T_4, 150% N (farmyard manure); T_5, 50% N (farmyard manure) + 50% N (green manure); T_6, 50% N (farmyard manure) + 50% N (vermicompost; T_7, 50% N (farmyard manure) + 50% N (mustard cake), replicated five times. The variety Basmati CSR 30 was used during the study. The inorganic sources of N, P and zinc used were urea, di-ammonia phosphate (DAP) and zinc sulphate monohydrate, respectively. The organic source of N used were farmyard manure, green manure (*Sesbania*), vermicompost and mustard cake. The recommended dose of N for Basmati CSR 30 as per CCS Haryana Agricultural University package of practice is 60 kg/ha. A common recommended dose of 30 kg/ha P_2O_5 and 25 kg/ha $ZnSO_4$ was applied in all the plots except in control plot. The urea was applied in two equal splits i.e. first split after 3 week of transplanting and second split after 6 weeks of transplanting. Full dose of DAP and zinc sulphate monohydrate was applied at the time of puddling. Nutrient content (%) of farmyard manure, vermicompost, mustard cake and *sesbania* are shown on dry weight basis (Supplementary Table 1).

Soil sampling and analysis: Soil samples were collected from root zone of each plot just after harvesting of the paddy crop. Subsequently, the collected samples were dried in the shade, ground, and sieved through a 2 mm mesh before being stored in polythene bags for soil chemical analysis. The processed soil samples underwent comprehensive analysis, including determination of soil *p*H, electrical conductivity (EC), organic carbon (OC) content, available nitrogen (N), phosphorus (P) and potassium (K). The determination of soil *p*H and EC followed the method outlined by Jackson (1967). Organic carbon content was assessed using the wet digestion method introduced by Walkley and Black (1934). The available nitrogen content was determined based on the method defined by Subbiah and Asija (1956). Extraction of available phosphorus from the soil was conducted using a sodium bicarbonate extractant, and the concentration of phosphorus in the extract was resolved using Olsen's method (Olsen 1954). Lastly, the available potassium content was determined through the method outlined by Merwin and Peech (1951).

Plant sampling and calculations: Upon completion of the paddy harvest, both grain and straw samples were collected and placed into paper bags for drying within a forced air oven set at a temperature of 65° ± 2°C for a duration of 48 h. Afterwards, the dried samples underwent a meticulous grinding process within a stainless-steel jar using a mixer grinder. The resulting particles were separated through a 0.5 mm sieve and then preserved in moisture-resistant plastic bags within a desiccated environment. To ensure uniformity in weight, each sample was subjected to additional time in the oven. For the quantification of nitrogen content in plant samples, the Modified Kjeldahl method (Bremner and Mulvaney 1982) was done, while phosphorus was assessed using the Vanado molybdophosphoric acid method (Koenig and Johnson 1942), and potassium via the flame photometer technique (Black 1965). Nutrient absorption calculations were determined by multiplying the percentage absorption of a specific nutrient by the yields of both grain and straw.

Economic analysis: The cultivation cost, gross return, and net return under varied treatments were calculated using the present market cost of various inputs. Other input costs were calculated using market prices. The gross return was calculated as the total income generated from the economics of grain and straw yield produced. The net return was determined as:

$$\text{Net return} = \text{Gross return} - \text{Cost of cultivation}$$

Statistical analysis: The recorded data was analyzed by using OPSTAT software package (Sheoran 1998) for randomized block design (RBD) for analysis of variance (ANOVA).

RESULTS AND DISCUSSION

Inorganic versus organic amendments on soil fertility: Results showed that use of recommended dose of N (RDN) through urea or vermicompost or green manuring using *Sesbania* or mustard cake or farmyard manure improved the soil fertility over unfertilized control treatment in both the seasons (Table 1). However no significant difference was noticed on soil *p*H, EC and soil organic carbon (SOC) after addition of organic inputs for continuous two years. But numerically, there was increase in SOC content in all organic treatments over control. The SOC status was higher in the year 2022 compared to 2021 and this increase was higher in the treatment receiving organics compared to inorganic inputs. Singh *et al.* (2015) also indicated that after nine years of crop rotation and application of farmyard manure or vermicompost either alone or in combination with crop residue increased the soil organic carbon (0.56–0.68%) compared to the control plot. During first season, the highest available nitrogen (171.4 kg/ha), phosphorus (25.56 kg/ha) and potassium (319.2 kg/ha) were recorded in treatment T_2 i.e. 100% RDN which was found significantly superior over absolute control (T_1) (124.5 kg/ha, 15.9 kg/ha and 258.6 kg/ha NPK, respectively) but at par with other treatments. While in second season, the highest available NPK (178.2 kg/ha, 31.4 kg/ha and 338.1 kg/ha, respectively) was recorded in treatment receiving 100% RDN through urea, which was found significantly superior to other treatments except T_3 (100% equivalent N through farmyard manure) and T_4 (150% equivalent N through farmyard manure). The lowest available NPK status was recorded in unfertilized plot (T_1) (128.6 kg/ha, 19.9 kg/ha and 272.1 kg/ha NPK, respectively) which was remarkably lesser as compared to other treatments. This could be attributed to an increase in microbial activity, which assured the increased availability of all essential nutrients through the ongoing mineralization of organic manures and the soil's nutrient-supplying capability. This might be due to increase in microbial activity which ensures the supply of essential nutrients by the continuous mineralization of organic manures and nutrient supplying capacity of the soil. These results are in accordance with the findings of Moe *et al.* (2019).

Nutrient uptake by grain and straw: Nutrient uptake by paddy is the NPK absorbed by the grain and straw under different organic and inorganic treatments. The compiled data on NPK uptake of two seasons (Table 2), unveils the significant effect of various nitrogen sources- specifically urea, farmyard manure, vermicompost, mustard cake, and *Sesbania* on the nutrient absorption by rice grain and straw. In the first season, a significant increase in the uptake of NPK by both grain and straw was observed with the introduction of nitrogenous inorganic and organic fertilizers. However, during the subsequent season, the application of 100% recommended nitrogen dose through urea and farmyard manure amplified the NPK absorption by rice grain compared to treatments involving a combination of 50% nitrogen through organic sources like vermicompost, green manuring using *Sesbania* or mustard cake. Higher uptake of NPK in grain was recorded in the treatment where 100% Nitrogen through urea was applied (43.77 kg/ha, 16.33 kg/ha and 17.69 kg/ha NPK, respectively but non-significant with the other organic treatments. Conversely, the treatment with no fertilizer application, i.e. the absolute control, recorded significantly lower uptake of nitrogen, phosphorus and potassium (30.14 kg/ha, 10.14 kg/ha, and 11.59 kg/ha NPK, respectively) in grain. Likewise, in paddy straw, the treatment employing 100% recommended nitrogen dose through urea exhibited the highest uptake of 39.33 kg/ha, 17.83 kg/ha, 92.58 kg/ha NPK in 2021 and 45.67 kg/ha, 21.72 kg/ha, 108.04 kg/ha NPK in 2022. Conversely, the lowest NPK uptake by paddy straw was recorded in the complete control treatment (33.36 kg/ha, 14.98 kg/ha, 82.68 kg/ha NPK, respectively) throughout both seasons.

This might be due to continuous and gradual supply of NPK nutrients from nitrogenous inorganic and organic fertilizers to the plant to maintain chlorophyll content of plant and thereby increased the photosynthetic rate which

Table 1 Effect of organic paddy cultivation on soil chemical properties in paddy crop

Treatment	2021						2022					
	Soil *p*H	EC (dS/m)	OC (%)	Available N (kg/ha)	Available P_2O_5 (kg/ha)	Available K_2O (kg/ha)	Soil *p*H	EC (dS/m)	OC (%)	Available N (kg/ha)	Available P_2O_5 (kg/ha)	Available K_2O (kg/ha)
T_1	8.4	0.13	0.48	124.5	15.9	258.6	8.40	0.14	0.51	128.6	19.9	272.1
T_2	8.2	0.13	0.50	171.4	25.56	319.2	8.21	0.15	0.50	178.2	31.4	338.1
T_3	8.3	0.12	0.49	166.8	22.14	312.9	8.30	0.14	0.52	168.7	29.7	331.4
T_4	8.3	0.14	0.49	170.7	25.02	316.1	8.44	0.15	0.54	171.9	28.9	334.3
T_5	8.6	0.15	0.50	163.9	24.02	318.2	8.47	0.15	0.55	165.6	25.5	326.4
T_6	8.4	0.12	0.49	164.0	22.64	314.2	8.18	0.13	0.52	167.3	26.8	329.9
T_7	8.4	0.13	0.49	166.1	23.26	316.1	8.26	0.14	0.53	166.1	26.2	327.8
CD (P=0.05)	NS	NS	NS	10.8	4.1	18.91	NS	NS	NS	8.0	6.9	17.8

Treatment details are given under Materials and Methods. NS, Non-significant; EC, Electrical conductivity; OC, Organic carbon.

increased the dry matter accumulation and translocation of photosynthates to the sink (Nagabovanalli *et al.* 2021). The crop yield increased with application of organics because grain and straw yield, which is the final product of crop depends upon the development of yield attributes i.e. effective tillers, panicles/m^2, grains/panicle, panicle length and test weight (Kamaleshwaran and Elayaraja 2021). Over the control, all yield attributes and yield were higher with the substitution of nitrogen supply either with FYM, vermi-compost or green manuring or mustard cake. These might have provided essential minerals and acted as a catalyst for the efficient utilization of applied nutrients to increase yield attributes. Veerendra *et al.* (2012) and Sepehya *et al.* (2012), also reported that the application of organics increased yield and yield attributes in paddy through several microbial activities. The treatment with no fertilizer, i.e., absolute control, produced the lowest grain and straw yield. Straw yield showed greater variability, and it was highest in 2022 rather than 2021. The lower paddy yield in 2021 was most likely due to increased rainfall and its unequal distribution during the growing season of year 2021, which reduced the production of paddy crop. Furthermore, the high mean temperature of 2022 boosted photosynthetic rate, dry matter buildup, and photosynthate translocation from source to sink. N'Ganzoua *et al.* (2016) confirmed the similar findings.

Inorganic versus organic amendments on yield: Different organic and inorganic treatments of nitrogen sources had a significant effect on paddy yield (grain + straw) during both seasons (Table 3). The paddy grain yield showed an upward trend with the introduction of nitrogenous sources compared to the control treatment, which did not involve any fertilizer application. The treatment employing 100% nitrogen (urea) at recommended dosage (RDN) resulted in the highest grain yield recorded at 3244 kg/ha. Across both inorganic and organic treatments, there was a noteworthy boost in grain yield ranging from 22.5–31.2% in comparison to the control treatment. The observed increase in grain and straw yield due to nutrient addition can be attributed to the efficient absorption of essential nutrients, subsequently enhancing the production of dry matter, as elucidated by Siavoshi *et al.* (2011). Crop yield experienced a marked rise with the application of organic treatment due to the influential development of yield attributes, such as effective tillers, panicles/m^2, grains/panicle, panicle length, and test weight, as expounded by Kamaleshwaran and Elayaraj (2021). Moreover, Kai *et al.* (2020) demonstrated that adopting organic fertilizer and reducing pesticide usage enhanced soil bacterial biomass and activated the nitrogen cycle through microbial activity. Supporting these findings, N'Ganzoua *et al.* (2016) also affirmed similar outcomes in their research.

Economics: Higher B:C ratio of 2.78 was obtained in treatment which received 150% N through farmyard manure followed by 2.73 in T_2 (100% RDN through urea) (Table 3). The lower B:C ratio of 1.91 was recorded where treatment 50% N (farmyard manure) + 50% N (mustard cake) was applied, as the cost of mustard cake decreases the net

Table 2 Effect of organic paddy cultivation on nutrient uptake by paddy grain and straw (kg/ha)

Treatment	Grain uptake (kg/ha)									Straw uptake (kg/ha)								
	Nitrogen			Phosphorus			Potassium			Nitrogen			Phosphorus			Potassium		
	2021	2022	Mean	2021	2022	Mean	2021	2022	Mean	2021	2022	Mean	2021	2022	Mean	2021	2022	Mean
T_1	29.78	30.5	30.14	10.32	9.97	10.14	11.84	11.34	11.59	31.19	35.53	33.36	13.31	16.65	14.98	77.59	87.78	82.68
T_2	40.79	46.76	43.77	15.66	17.01	16.33	16.46	18.91	17.69	39.33	45.67	42.5	17.83	21.72	19.78	92.58	108.04	100.31
T_3	38.08	43.28	40.68	14.42	17.16	15.79	14.95	17.71	16.33	37.36	42.19	39.78	16.73	19.94	18.34	88.12	101.99	95.06
T_4	39.77	45.42	42.59	15.18	18.26	16.72	14.83	18.78	16.81	38.27	43.38	40.83	17.21	20.78	18.99	91.82	106	98.91
T_5	38.87	40.03	39.45	14.29	14.59	14.44	13.67	15.14	14.41	38.71	40.42	39.56	16.81	17.75	17.28	92.12	94.46	93.29
T_6	38.59	40.32	39.45	15.22	17.33	16.27	15.66	16.44	16.05	37.21	40.26	38.73	17.44	19.63	18.54	90.99	98.97	94.98
T_7	39.38	40.43	39.9	13.9	15.42	14.66	14.4	15.94	15.17	38.8	41.76	40.28	16.34	18.61	17.47	92.66	99.49	96.07
CD (P=0.05)	4.25	4.73		2.05	2.43		2.18	2.49		3.95	3.59		2.38	NS		6.6	10.74	

Treatment details are given under Materials and Methods.

Table 3 Effect of organic paddy cultivation on grain and straw yield and economic cost of paddy crop production (average of year 2021 and 2022)

Treatment	Grain yield (kg/ha)			Per cent increase in grain yield over control	Straw yield (kg/ha)			Biological yield (kg/ha)	Cost of cultivation (₹/ha)	Gross returns (₹/ha)	Net returns (₹/ha)	B:C ratio
	2021	2022	Mean		2021	2022	Mean					
T_1	2485	2460	2473	0	6210	6943	6577	9049	18880	40429	21549	2.14
T_2	3083	3405	3244	31.2	7013	8019	7516	10760	18190	49638	31448	2.73
T_3	2931	3238	3085	24.7	6800	7682	7241	10326	17527	47297	29771	2.70
T_4	3043	3381	3212	29.9	6909	7781	7345	10557	17604	49022	31419	2.78
T_5	3013	3048	3031	22.5	7099	7257	7178	10209	17960	48560	30600	2.70
T_6	3039	3167	3103	25.5	6957	7495	7226	10329	22250	48961	26711	2.20
T_7	3021	3150	3086	24.8	7099	7400	7250	10335	25450	48683	23233	1.91
CD (P=0.05)	252	239			565	633						

Treatment details are given under Materials and Methods.

return and B:C ratio. As the maximum cost of cultivation (₹25450/ha) was recorded under treatment where 50% N (farmyard manure) + 50% N (mustard cake) was applied. This was primarily due to higher expenses of mustard cake as compared to other organic sources, viz., farmyard manure, green manure and vermicompost. While higher gross return (₹49638/ha) and net return (₹1448/ha) was recorded where 100% RDN through urea was applied. This might be due to lesser cost of cultivation in inorganic practice and higher grain yield obtained. Among organics, lowest B:C was obtained in treatment 50% N (farmyard manure) + 50% N (mustard cake) because of higher cost of cultivation and lower yield, which decreases the benefit cost ratio.

It is evident from the study that application of N through inorganic urea significantly improved nutrient content and its uptake by rice grain and straw, with increase in paddy yield in first year. But in second year of study, there was improvement in soil fertility and crop productivity with the addition of 100% recommended dose of N through organic sources i.e. farmyard manure, vermicompost, mustard cake and green manuring through *Sesbania* for continuous season. The application of 100% recommended dose of N through farmyard manure or 50% recommended dose of N through farmyard manure + remaining 50% N through green manure/vermicompost/mustard cake gave yield similar to that obtained with the application of 100% application of N through urea in basmati crop. Therefore, there is a need to switch from inorganic N source (urea) to organic N, viz. farmyard manure, vermicompost, green manuring through *Sesbania* either alone or in combination for sustainable productivity and to maintain soil health for future generation.

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