

Impact of organic production practices on productivity, nutrient acquisition and microbial ecology in transplanted rice (*Oryza sativa* L.)

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Abstract

Field experiments were conducted during *Kharif* 2022 and 2023 at the Agriculture Research Station, Faculty of Agricultural Sciences, Siksha 'O' Anusandhan, Bhubaneswar, Odisha-751029, India, to assess the effects of various organic production practices on rice productivity. The experiment comprising nine organic production treatments was laid out in a randomized block design with three replications. The treatments were as follows: T₁: control; T₂: 100% RDN through the FYM; T₃: green manure (Dhaincha); T₄: green manure (Dhaincha) + 50% RDN through the FYM; T₅: T₄ + seedling root dip in Beejamrit @ 10%; T₆: T₄+ soil application of Jeevamrutha @ 10%; T₇: T₄+ soil application of the EM solution @10%; T₈: T₄+ foliar application of Panachagavya @ 3%; and T₉: T₄+ seedling root dip with Beejamrit + soil application of Jeevamrutha + soil application of the EM solution + foliar application of Panchagavya. The results revealed that among the organic production practices, the application of green manuring (*Dhaincha*) + 50% RDN through a FYM+ seedling root dip with Beejamrit + soil application of Jeevamrutha + soil application EM solution+ foliar application of Panchagavya resulted in the maximum yield, which was attributed to characteristics such as the number of panicles/m², filled grains/panicle, test weight, and panicle weight. The maximum values of grain yield and straw yield were also recorded in the green manuring (Dhaincha) + 50% RDN through a dip in the roots of the red red of the FYM+ Seedling with Beejamrit + soil application of the Jeevamrutha + soil application of the EM solution + the foliage application of Panchagavya, followed by the application of green Manuring (Dhaincha) + 50% RDN through the foliar application of 3% (T8) FYM+ Panchagavya. The maximum total N, P, and K uptake and the soil microbial population were recorded with T9 application, followed by T₈. The highest net return and return/rupee investment were obtained in the T8 treatment (T₄ + foliar application of Panchagavya), followed closely by those in the T₉ treatment. It can be concluded that the application of green manuring (Dhaincha) + 50% RDN through a FYM + seedling root dip with Beejamrit + soil application of Jeevamrutha + soil application of an EM solution + foliar application of Panchagavya performed better among the different organic practices for the organic production of transplanted rice.

Introduction

Traditionally, rice is grown with indigenous knowledge across different ecosystems, depending on land type and water availability. Afterward, it shifted toward chemical agriculture, which increased total food grain production and enabled bumper harvests from high-input, responsive varieties, thereby achieving self-sufficiency in the food sector. However, chemical agriculture increased food grain production but also led to the development of soil-related health hazards. The adverse effects on soil quality indices have raised questions about the sustainability of a healthy agricultural production environment, thereby unbalancing food security policy worldwide¹. Increased land use intensity, combined with insufficient and unbalanced chemical fertilizers and little to no organic manure, has resulted in a significant decline in fertility, slowing or even reducing agricultural output and quality as land area shrinks over time². Although the integrated nutrient management approach offered a viable solution that emphasized the combined use of inorganic and organic nutrients in different proportions, a U-turn is observed toward crop production packages.

Recently, organic farming has received increased attention, mainly because of consumer preference, and a boost is expected from the policy support recently announced by the central government, as evidenced. In the organic cultivation of a variety of crops, numerous organic liquid solutions are beneficial for foliar, soil, and seed/seedling treatments^{3,4}. Organic manure is a rich source of essential nutrients, providing a balanced and diverse array of nutrients necessary for the healthy growth of rice plants. Unlike synthetic fertilizers, which often supply a limited set of nutrients, organic manure contains macronutrients such as nitrogen, phosphorus, and potassium, as well as micronutrients such as zinc, copper, and manganese⁵. Crop nutrient needs can be met through various sources, such

as FYM, vermicompost, oilcake, green manure, biofertilizers, Jeevamrut, Beejamrut, and Amrutpani. Organic manure acts as a microbial stimulant, fostering the growth and activity of beneficial soil microorganisms⁶. In the international market, the importance of organic produce is increasing daily as consumers become more health conscious. In light of the above context, a field experiment was carried out to assess the effects of various organic production practices on on productivity, nutrient acquisition and microbial ecology in transplanted rice (*Oryza sativa* L.).

Materials and methods

2.1 Experimental plot site

A field experiment was carried out during 2023 and 2024 in *Kharif* at the Agriculture Research Station, Faculty of Agricultural Sciences, Siksha 'O' Anusandhan, Bhubaneswar, Odisha-751029, India. The research farm is located in the East and South-Eastern Coastal Plain agroclimatic zone of Odisha. It is situated between 20°26' N latitude and 85°67' E longitude at an altitude of 45 meters above mean sea level.

2.2 Season and climate

The experimental site is located in Odisha's East and South-Eastern Coastal Plain Agro Climatic Zone. The basic qualities of this location are warm and damp, with hot, humid summers and mild winters. The zone's primary rainfall season is the southwest monsoon. In Odisha, the monsoon typically begins in the second week of June and ends in October. The rainfall for this season was approximately 76%.

2.3 Weather during the 2023 crop growing season

During the crop season, the total rainfall was 285.7 mm, which was concentrated during the 9th meteorological standard week of 2023. The maximum temperature ranged from 27.20°C to 40.20°C during the meteorological standard week of the abovementioned years. The minimum temperature ranged from 15.00°C to 27.50°C and was observed during the 28th and 2nd meteorological standard weeks. A maximum relative humidity of 94% was observed during the 14th–15th meteorological week of 2023. The mean evapotranspiration gradually increased with increasing week. A maximum of 9.1 mm per day was observed during the 1st meteorological week. The duration of bright sunshine hours also varies. The maximum of 6.6 hr was recorded in the 23rd week, and the shortest 0.8 hr was recorded in the 4th and 10th weeks. During the 9th week, the maximum (5.3 km/hr) wind speed was recorded, whereas the lowest (0.6 km/hr) was recorded during the 7th week.

2.3.1 Weather during the 2024 crop growing season

During the crop season, the total rainfall was 310 mm, which was concentrated in August, the meteorological standard month, 2024. The maximum temperature ranged from 30.7°C to 35.5°C and was observed in September and July, the meteorological standard months of the aforementioned year. The maximum relative humidity of 80% was observed in September, the meteorological standard month of 2024.

2.4 Soil characteristics of the experimental site and cropping history

The textural class of the surface soil at the experimental site, which had received no chemical treatment for the preceding 6 years, was loamy sand (84.84% sand, 2% silt and 13.6% clay), with a bulk density of 1.45 g/cc, a total soil porosity of 43.6%, an available soil moisture of 1.9 cm/15 cm, a soil pH of 5.67 and an organic carbon content of

0.55%. The available nitrogen, phosphorus, and potash concentrations were 215, 22.8, and 165.47 kg/ha, respectively. The crops grown in the experimental field over the past 6 years are presented in Table 1.

Table 1
Cropping history of the experimental site

Year	<i>Kharif</i>	<i>Rabi</i>	Summer
2017	Rice (seed treatment with Bijamruta and applied with FYM @5t/ha + soil application of Jeevanmruta + foliar application of Panchagavya	Fallow	Green manuring with Sesbania
2018	Rice (seed treatment with Bijamruta and applied with FYM @5t/ha + soil application of Jeevanmruta +foliar application of Panchagavya	Fallow	Green manuring with Sesbania
2019	Rice (Bijamruta and applied with FYM @5t/ha + soil application of Jeevanmruta +foliar application of Panchagavya)	Fallow	Green manuring with Sesbania
2020	Rice (Bijamruta and applied with FYM @5t/ha + soil application of Jeevanmruta +foliar application of Panchagavya)	Moong	Green manuring with sunhemp
2021	Rice (Bijamruta and applied with FYM @5t/ha + soil application of Jeevanmruta +foliar application of Panchagavya)	Fallow	Moong and cowpea
2022	Organic rice varieties with different organic manures	Fallow	Moong and cowpea
2023 and 2024	The present study with a different formulation of the rice variety		

2.5 Treatment details and design

The field experiment was conducted at the Agriculture Research Station, Faculty of Agricultural Sciences, Siksha ‘O’ Anusandhan, Bhubaneswar, Odisha-751029, India, during the *kharif* seasons of 2023 and 2024 in a randomized blocked design with nine treatments, viz. T₁: Control, T₂: 100% of RDN through FYM, T₃: Green Manuring (Dhaincha), T₄: Green Manuring (Dhaincha) + 50% RDN through FYM, T₅: T₄ + Seedling root dip in Beejamrit @ 10%, T₆: T₄+ Soil application of Jeevamrutha @ 10%, T₇: T₄+ Soil application of EM Solution @10%, T₈: T₄+ foliar application of Panachagavya @ 3% and T₉: T₄+ Seedling root dip with Beejamrit + Soil application of Jeevamrutha + soil application EM solution + foliar application of Panchagavya. The preparation methods and application schedules are given in Table 2.

Table 2
Method of Preparation of Organic Formulations

Organic formulation	Preparation Process	Days required	Precautions taken	Application
Bijamrutha	1 litre water + 250 ml cow urine + 250 g cow dung + 2.5 g Lime.	2–3	Materials should be mixed and stirred properly	Seedling root dip for 2–3 hours before transplanting.
Jeevamrutha	200 litres water + 10 kg cow dung + 10 litre cow urine + 2 kg jaggery + 2 kg pulse flour + 50 g Virgin Soil.	7–10	Materials should be mixed properly and kept in the shade.	i) Basal apply at:7 DAT ii) Panicle Initiation iii) 50%flowering
Panchagavya	5 kg cow dung + 1 kg ghee. After 3 days, add 3 liters of cow urine. Then, after 15 days, add 2 liters of cow's milk and 2 kg of curd to the mixture.	25–30	Materials should be mixed properly at the proper interval and stirred daily. It should be kept in shade.	Foliar spray at: i) 21 DAT ii) Panicle Initiation iii) 50%flowering
EM solution	Add 1 kg of jaggery to 1 liter of stock EM solution and 1 liter of water.	1–2	Should be kept in a well container and mixed well.	i) Basal apply at 7 DAT ii) Panicle Initiation iii) 50%flowering

2.6 Crop management

The recommended package of practices was properly followed for the management of all experimental plots from seed sowing to harvest. The rice variety Nua Chinikamini was used in this experiment. A dry nursery of convenient length and 1.5 m width was prepared to raise the seedlings for use in the main experiment. The seedbed was well pulverized with a spade and thoroughly mixed with FYM @ 5.0 kg/10 m², and the seeds were sown in lines across the width. In the main experimental area, a puddle condition was created by operating the tractor twice, followed by levelling. The experimental site was divided into plots as needed using Pythagoras' theorem ($a^2 + b^2 = c^2$). Each plot was enclosed with 30 cm wide and 15 cm high bunds. Channels 30 cm wide were opened for irrigation-cum drainage purposes. Two 30-day-old seedlings were transplanted per hill, with a rectangular geometry of 20 cm row to row and 15 cm plant to plant, providing an effective area of 300 cm² per hill. The quantity of manure applied to the plot per treatment was based on the recommended nitrogen level (RDF: 60–30–30 kg/ha). A bioformulation using cow urine and *Ocimum tenuiflorum* leaf extract was applied to control bacterial leaf blight.

2.7 Measurements and analytical procedure

A random sampling technique was adopted to obtain the biometric observations. The plants in the outer two rows on both sides of the plot were considered border rows, and samples from the next-to-central rows were taken for observation. To harvest the crop at the maturity stage, an area of 4.0 m² was marked in each plot. These samples were used for yield estimation. After harvesting, small bundles were made and left in the field to dry in the sun for a few days. Threshing was performed after sun-drying with the help of a power-operated thresher, and the grains were kept separate for each plot. The dried grains were weighed plot-wise, and the data were used to calculate the yield at a 12% moisture content in kg/ha. Straw was also collected and sun-dried in the field to maintain a moisture level of approximately 12–14%. Afterward, the straw weight was also calculated for each plot, and the data were used to

estimate the straw yield in kg/ha. After crop harvesting, the uptake of different nutrients (N, P, and K) in the grain and straw was measured.

The samples were harvested at maturity and kept plot-wise. After the harvested samples were oven dried at $60 \pm 5^\circ\text{C}$ for 48 hours, they were ground in a Willey mill. Afterward, the ground plant material was passed through a 30-mesh sieve. Standard methods were followed to determine the N, P, and K contents. The uptake of N, P, and K in grain and straw was calculated separately by multiplying the respective yields by the corresponding nutrient contents. The data were recorded in kg/ha. Nutrient uptake was determined when the moisture content of the grain and straw was 12% each. For the analysis of the experimental data, Fisher's method of variance analysis was adopted, as outlined by Gomez and Gomez (1984)⁷, to draw a logical conclusion. The critical difference (CD) at the 5% significance level was used to test treatment variation.

2.8 Soil microbial studies (CFU)

Microbial analysis was conducted using the serial dilution method to evaluate population dynamics at various crop growth stages: before sowing, after treatment application, and at harvest. For the initial dilution (10^{-1}), 1 g of soil was added to a test tube containing 10 mL of sterile distilled water, and the mixture was thoroughly shaken. A 10^{-2} dilution was subsequently prepared by transferring 1 mL of the 10^{-1} suspension into 9 mL of sterile distilled water using a sterile pipette. Microbial population estimates were obtained at appropriate dilution levels: 10^6 for bacteria, 10^4 for fungi, and 10^5 for actinomycetes, depending on the specific microbial group.

Results and discussion

3.1 Effects of organic production practices on yield attributes of rice

Among the organic production practices, the maximum number of panicles/ m^2 , filled grains/panicle and panicle weight were recorded under treatment T_9 (green manuring (Dhaincha) + 50% RDN through a FYM+ seedling root dip with Beejamrit + soil application of Jeevamrutha + soil application of an EM solution+ foliar application of Panchagavya) at all the growth stages, followed by T_8 (green manuring (Dhaincha) + 50% RDN through a FYM+ foliar application of Panchagavya) over the other treatments in both 2022 and 2023 (Table 3).

Table 3
Effects of organic production practices on yield-attributing characteristics of rice

Treatment	Panicle length (cm)		Panicle/m ²		Filled grains/Panicle		Test weight (g)		Panicle Weight (g)	
	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023
T ₁	18.45	17.84	132.97 ^a	137.64 ^a	61.67 ^a	72.03 ^a	12.04	12.24	1.46 ^a	1.60 ^a
T ₂	19.19	20.47	158.07 ^c	166.74 ^c	79.33 ^{bc}	89.52 ^{bc}	12.13	13.24	1.62 ^{bc}	1.97 ^c
T ₃	18.53	18.56	138.02 ^{ab}	143.19 ^{ab}	70.67 ^b	79.89 ^b	12.08	12.54	1.49 ^{ab}	1.63 ^{ab}
T ₄	19.33	19.92	162.16 ^{cd}	169.58 ^{cd}	82.67 ^{cd}	90.31 ^{cd}	12.45	12.82	1.66 ^{cd}	2.03 ^{cd}
T ₅	19.66	20.59	167.06 ^{de}	181.94 ^{de}	86.67 ^e	94.57 ^e	12.77	12.88	1.70 ^e	2.07 ^e
T ₆	20.82	21.30	185.85 ^{ef}	207.01 ^{ef}	96.67 ^{ef}	106.17 ^{ef}	13.03	13.49	1.89 ^{ef}	2.43 ^{ef}
T ₇	21.30	21.63	200.79 ^{fg}	218.44 ^{fg}	101.24 ^{fg}	111.89 ^{fg}	13.25	13.54	2.02 ^{fg}	2.63 ^{fg}
T ₈	21.36	21.70	211.52 ^h	227.90 ^h	107.24 ^h	116.26 ^h	13.87	13.49	2.13 ^h	2.73 ^h
T ₉	22.09	22.14	230.27 ⁱ	246.58 ⁱ	116.24 ⁱ	126.07 ⁱ	14.04	13.96	2.30 ⁱ	3.00 ⁱ
S.Em (±)	0.83	1.10	6.14	5.78	2.64	2.90	0.63	0.53	0.05	0.07
CD (p ≤ 0.05)	NS	NS	17.81	16.77	7.64	8.42	NS	NS	0.15	0.22
T ₁ : Control, T ₂ : 100% of RDN through FYM, T ₃ : Green Manuring (Dhaincha), T ₄ : Green Manuring (Dhaincha) + 50% RDN through FYM, T ₅ : T ₄ + Seedling root dip in Beejamrit @ 10%, T ₆ : T ₄ + Soil application of Jeevamrutha @ 10%, T ₇ : T ₄ + Soil application of EM Solution @10%, T ₈ : T ₄ + foliar application of Panchagavya @ 3% and T ₉ : T ₄ + Seedling root dip with Beejamrit + Soil application of Jeevamrutha + soil application EM solution + foliar application of Panchagavya										

The lowest yield attributes were recorded in the control plot, followed closely by treatment T₃ (green manuring with Dhaincha) in both years. Treatment T₇ (green manuring (Dhaincha) + 50% RDN through FYM + soil application of EM solution @10%) recorded a par value of the number of panicles/m², no. of filled grains per panicle, and panicle weight with treatment T₈ (green manuring (Dhaincha) + 50% RDN through FYM + foliar application of Panchagavya) and T₆ (green manuring (Dhaincha) + 50% RDN through FYM + soil application of Jeevamrutha @ 10%) in both years. In 2022 and 2023, the number of panicles/m² was 73.17% and 79.14% greater, respectively, in the T₉ treatment than in the control plot. However, compared with that in the control plot, panicles/m² increased by 59.07% in 2022 and 65.57% in 2023 with the application of treatment T₈ (green manuring (Dhaincha) + 50% RDN through FYM + foliar application of Panchagavya). The number of panicles/m² was 17.49% and 18.43% greater in treatment T₄ (green manuring with Dhaincha + 50% RDN through FYM) than in treatment T₃ (green manuring with Dhaincha) at harvest in 2022 and 2023, respectively. Treatments T₂ (100% of RDN through the FYM), T₄ (green manuring with Dhaincha + 50% RDN through the FYM), and T₅ (green manuring (Dhaincha) + 50% RDN through the FYM + seedling root dip in Beejamrit @ 10%) were recorded at a par value of panicle/m², number of filled grains per panicle, and panicle weight. Compared with the control plot, the T₉ treatment resulted in 87.09% growth in 2022 and 75.02% growth in 2023, with more filled grains per panicle. However, the filled grains/panicle increased by 73.89% and 61.40% with the application of treatment T₈

(green manuring (Dhaincha) + 50% RDN through FYM + foliar application of Panchagavya) compared with the control plot in 2022 and 2023, respectively (Table 3). The test weight and panicle length did not differ significantly across the different organic production practices.

3.2 Effects of organic production practices on the yield of rice

Among the organic production practices, the maximum grain and straw yields were recorded in treatment T₉, followed by T₈, in both years (Table 4). The lowest grain and straw yields were recorded in the control plot. In the T₉ treatment, the grain yields were 73.04% and 76.44% greater than those in the control plots in 2022 and 2023, respectively. However, the yield increased by 58.89% and 61.08% with T₈ application compared with that in the control plot in 2022 and 2023, respectively. In treatment T₇, the values of grain and straw yield were similar to those in treatments T₈ and T₆ during both years. The yields of treatment T₄ were 20.47% and 17.45% greater than those of treatment T₃ during 2022 and 2023, respectively (Table 4). No significant differences in the harvest index values were observed among the organic production practices.

Table 4
Effects of organic production practices on the yield, harvest index and economics of rice

Treatment	Grain yield (kg/ha)		Straw yield (kg/ha)		Harvest index (%)		Net return (Rs/ha)	Return/rupees invested
	2022	2023	2022	2023	2022	2023	Pooled data	
T ₁	1506 ^a	1647 ^a	2476 ^a	2593 ^a	37.77	38.80	-9874	0.84
T ₂	1945 ^c	2103 ^c	2912 ^c	2935 ^c	40.12	41.80	17870	1.25
T ₃	1626 ^{ab}	1839 ^{ab}	2539 ^{ab}	2608 ^{ab}	39.01	41.37	9546	1.15
T ₄	1959 ^{cd}	2160 ^{cd}	2923 ^{cd}	2951 ^{cd}	40.08	42.23	19264	1.27
T ₅	1973 ^{de}	2169 ^{de}	2939 ^{de}	2966 ^{de}	40.16	42.27	19808	1.28
T ₆	2185 ^f	2404 ^f	3212 ^f	3305 ^f	40.46	42.13	30710	1.39
T ₇	2278 ^{fg}	2604 ^{fg}	3360 ^{fg}	3563 ^{fg}	40.41	42.31	28488	1.35
T ₈	2393 ^{gh}	2653 ^{gh}	3491 ^{gh}	3689 ^{gh}	40.71	41.86	39378	1.52
T ₉	2606 ⁱ	2906 ⁱ	3709 ^{hi}	4055 ⁱ	41.26	41.74	37096	1.48
S.Em (±)	70.08	78.93	91.10	109.61	1.07	1.06	-	-
CD (p ≤ 0.05)	203.16	228.84	264.13	317.79	NS	NS	-	-
T ₁ : Control, T ₂ : 100% of RDN through FYM, T ₃ : Green Manuring (Dhaincha), T ₄ : Green Manuring (Dhaincha) + 50% RDN through FYM, T ₅ : T ₄ + Seedling root dip in Beejamrit @ 10%, T ₆ : T ₄ + Soil application of Jeevamrutha @ 10%, T ₇ : T ₄ + Soil application of EM Solution @10%, T ₈ : T ₄ + foliar application of Panachagavya @ 3% and T ₉ : T ₄ + Seedling root dip with Beejamrit + Soil application of Jeevamrutha + soil application EM solution + foliar application of Panchagavya								

3.6 Effects of organic production practices on the economics of rice

Among the different organic production practices, the highest net return (Rs. 39378/ha) and return/Rs. Invested (1.52) samples were obtained with the application of Green Manuring (*Dhaincha*) + 50% RDN through FYM +foliar application of Panchagavya (T_8). This treatment was closely followed by T_9 Green Manuring (*Dhaincha*) + 50% RDN through a dip of the roots of the foliage through the fungus and Seedling with Beejamrit + soil application of Jeevamrutha + soil application of the EM solution + foliar application of Panchagavya (Table 4).

3.3 Correlation analysis

Correlation analysis was performed using pooled data from 2022–2023 to assess the relationships among yield and yield-attributing traits (Fig. 1). Panicle length was positively correlated with filled grains per panicle ($r = 0.99$), grain yield ($r = 0.99$), and straw yield ($r = 0.98$), contributing to overall productivity. Similar results were reported by Russinga et al. (2020)⁸, and Biswas et al. (2011)⁹ reported positive correlations between panicle length and grain-related traits, including plant height and grain parameters.

The panicles/m² was positively correlated with filled grains/panicle ($r = 1.00$), test weight ($r = 1.00$), panicle weight ($r = 1.00$), and straw yield ($r = 1.00$), suggesting that higher panicle density enhances yield components (Fig. 1). Filled grains/panicles and test weight were positively correlated with grain yield ($r = 1.00$), indicating a direct role in determining grain yield (Fig. 1). Similarly, panicle weight is positively correlated with grain yield ($r = 0.99$).

The harvest index was strongly positively correlated with panicle length ($r = 0.80$), filled grains/panicle ($r = 0.78$), and grain yield ($r = 0.80$) but was relatively weakly correlated with panicle weight ($r = 0.70$) and test weight ($r = 0.72$). A greater number of filled grains ensures a better sink capacity, whereas increased test weight reflects improved grain filling and assimilate partitioning (Fig. 1). These components directly contribute to increased grain yield, as confirmed by similar findings from Khan et al. (2009)¹⁰ and Bhadru et al. (2011)¹¹. The harvest index showed moderate to high positive correlations with grain yield and other traits, indicating efficient partitioning of assimilates towards economic yield. However, its relatively weak association with some traits suggests that its contribution is indirect compared with that of primary yield components.

The grain yield was positively correlated with all the major traits, including the panicle length ($r = 0.99$), panicle number ($r = 0.99$), number of filled grains per panicle ($r = 1.00$), test weight ($r = 0.99$), and panicle weight ($r = 0.99$), indicating that these parameters directly impact grain yield (Fig. 1). Straw yield also followed a similar trend, showing positive correlations with all the traits. This indicates increased biomass production, which is associated with economic yield.

3.4 Effects of six-year organic production practices on N, P, and K uptake

The maximum nitrogen uptake in the grain and straw was 33.15 kg/ha and 27.01 kg/ha, respectively, in T_9 , followed by T_8 (26.91 kg/ha and 24.93 kg/ha) and T_7 (34.86 kg/ha and 24.53 kg/ha). The minimum nitrogen content in the grain and straw (6.6 kg/ha and 10.94 kg/ha, respectively) occurred in treatment T_1 (Fig. 2).

The higher nitrogen uptake under the T_9 treatment may be attributed to the synergistic effects of green manuring, FYM, and liquid organic formulations such as Beejamrit, Jeevamrutha, the EM solution, and Panchagavya, which enhanced microbial activity and nutrient mineralization, thereby increasing nitrogen availability and uptake. The uptake of P and K by grain and straw followed a similar pattern, with the maximum values observed in treatment T_9 ,

followed by T₈. The maximum phosphorus (P) uptake in the grain and straw was 17.42 kg/ha and 12.93 kg/ha, respectively, in the T₉ treatment, followed by that in the T₈, T₇, and T₆ treatments. The increased phosphorus uptake under the integrated treatments may have been due to enhanced solubilization of native soil phosphorus through organic acid production and increased microbial activity induced by organic amendments (Fig. 2). The lowest phosphorus uptake in the grain and straw (5.221 kg/ha and 4.44 kg/ha, respectively) occurred in treatment T₁. The maximum potassium (K) uptake in grain and straw (14.58 kg/ha and 52.32 kg/ha, respectively) occurred in T₉, followed by T₈, T₇, and T₆ (Fig. 3).

The increased potassium uptake may be attributed to improved soil physical properties and high cation exchange capacity resulting from organic matter addition, which enhanced potassium uptake. The lowest potassium uptake in the grain and straw occurred in the T₁ treatment. A similar trend followed for total nutrient uptake (Fig. 2). The maximum nutrient uptake was recorded in the T₉ treatment, followed by the T₈ (26.91 kg/ha and 24.93 kg/ha) and T₇ treatments.

3.5 Effects of organic production practices on the soil microbial population

The results revealed that compared with the control treatment (T₁), all integrated organic treatments significantly increased the microbial population. Compared with individual applications, the combined application of green manuring (Dhaincha) with 50% RDN through FYM (T₄) markedly improved the microbial population (Table 5). This indicated that the synergistic effect of organic amendments improved soil biological activity. Further enhancement was observed with the addition of bioenhancers. T₆ (T₄ + jeevamrutha) and T₇ (T₄ + EM solution) significantly increased the microbial counts, indicating that microbial inoculants play a crucial role in stimulating soil microflora (Table 5).

Table 5

Effects of different organic production practices on bacterial (10^6), fungal (10^4) and actinomycete (10^5) populations (CFU g^{-1} of soil) at harvest in transplanted rice

Treatments	Bacteria		Fungi		Actinomycetes	
	2023	2024	2023	2024	2023	2024
T ₁	11.47 ^a	11.67 ^a	14.63 ^a	15.80 ^a	14.13 ^a	14.47 ^a
T ₂	24.27 ^c	25.00 ^c	24.60 ^c	27.27 ^c	25.93 ^c	28.63 ^c
T ₃	17.90 ^b	20.77 ^b	19.57 ^b	22.40 ^b	20.23 ^b	23.23 ^b
T ₄	24.87 ^{cd}	26.53 ^{cd}	25.87 ^{cd}	28.47 ^{cd}	27.87 ^{cd}	30.63 ^{cd}
T ₅	25.93 ^{de}	27.60	26.23 ^{de}	29.23 ^{de}	29.93 ^{de}	31.77 ^{de}
T ₆	30.93 ^g	32.13 ^{fg}	29.27 ^{fg}	31.10 ^{fg}	32.77 ^g	34.77 ^g
T ₇	31.87 ^{gh}	33.70 ^{gh}	30.93 ^{gh}	32.73 ^{gh}	33.23 ^{gh}	35.70 ^{hi}
T ₈	27.27 ^f	28.93 ^{ef}	27.60 ^{ef}	29.77 ^{ef}	30.27 ^{ef}	32.03 ^{ef}
T ₉	33.23 ^{hi}	35.10 ^{hi}	32.90 ^{hi}	34.23 ^{hi}	35.77 ⁱ	37.27 ^{ij}
S.Em ($\pm$)	1.16	1.37	0.86	0.90	0.85	0.90
CD ($p \leq 0.05$)	3.37	3.97	2.50	2.61	2.47	2.63
T ₁ : Control, T ₂ : 100% of RDN through FYM, T ₃ : Green Manuring (Dhaincha), T ₄ : Green Manuring (Dhaincha) + 50% RDN through FYM, T ₅ : T ₄ + Seedling root dip in Beejamrit @ 10%, T ₆ : T ₄ + Soil application of Jeevamrutha @ 10%, T ₇ : T ₄ + Soil application of EM Solution @10%, T ₈ : T ₄ + foliar application of Panachagavya @ 3% and T ₉ : T ₄ + Seedling root dip with Beejamrit + Soil application of Jeevamrutha + soil application EM solution + foliar application of Panchagavya						

The highest microbial populations were recorded under treatment T₉, which included the integrated application of Beejamrit, Jeevamrutha, the EM solution, and Panchagavya, along with T₄. This treatment (T₉) resulted in bacterial populations of 33.23 and 35.10, fungal populations of 32.90 and 34.23, and actinomycete populations of 35.77 and 37.27 during 2023 and 2024, respectively. These values were significantly greater than those of all the other treatments. The increase in the microbial population under the T₉ treatment may be attributed to the combined effects of organic inputs and microbial inoculants, which provide a favourable environment, nutrient supply, and growth-promoting substances for soil microorganisms (Table 5).

Discussion

The incorporation of organic amendments, such as FYM, facilitates better root establishment and nutrient uptake, which are essential for increasing yield attributes^{12–14}. Most of these yield attributes were significantly positively correlated with the grain yield of rice in treatment T₉ (T₄+ Seedling root dip with Beejamrit + Soil Application of Jeevamrutha + soil application EM solution+ foliar application of Panchagavya), which appeared to affect dry matter production and indirectly via an increase in panicle length, number of panicles/m², and number of filled grains per panicle, possibly as a result of increased nutrient uptake^{15–17}.

The highest grain yield, uptake of different nutrient by grain and straw was found maximum when the crop receives green manuring, soil application of jeevamurth along with foliar application of either panchgavya or sea weed sap. The combined use of nutrients from different manifested excellent results throughout the entire period of surveillance¹⁶. They opined that the integration of different sources of plant nutrients (e.g. FYM, greenmanure, liquid jeevamurth. Panchagavya etc) has a favorable role on all the yield attributes vis-à-vis yield of rice grown either as a single sole crop or as a component crops. This may be due to the fact that organic manures like FYM, maintain the physical condition of soil besides supplying plant nutrients slowly but steadily. Moreover, the pre incorporation of dhanicha, in presence of organic manures applied to the soil, may produce growth regulating substances, fix atmospheric nitrogen, improve root development and thus result in increased mineral and water uptake vis-à-vis vegetative growth and ultimately the superior crop yield. The combined use of such things improves the soil nutrient status even after harvest of rice crop. This may be due to the use bulky organic manures and other organic substances like FYM, jeevamurth, panchagavya, sea weed sap etc results in the improvement in soil physical, chemical and biological properties leading to better root proliferation, improved nutrient uptake and better accumulation of photosynthates. They provide nutrients to rice bit by bit but in a steady manner along with the added advantage of rapid, bounty and easy nutrient supplying capacity. Again, jeevamurtha and panchagavya performs the dual function of both fertilizer and pesticide, acts as soil enricher, reduces the growth of soil pest and bacteria, provides macro and micro nutrients essential for overall plant growth and helps to increase the yield of plants in the long run; it is biodegradable vis-à-vis eco-friendly and excellent soil conditioner.

Ghosh et al. (2012)¹⁸ reported that FYM application increased microbial biomass C and mineralizable C, thereby improving growth characteristics. The superiority of green manure over FYM in increasing rice productivity was also reported by Ram et al. (2019)³ and Li et al.(2019)¹⁹. Instances of higher, more sustainable yields of rice among farmers who adopted organic farming than among those who adopted conventional farming were reported by Oebjani et al. (2012)²⁰ and Eyhorn et al.(2018)²¹. Panchagavya increased the synthesis of growth-promoting substances, which, in turn, increased growth and yield attributes and, ultimately, grain yield. Similarly, Nayak et al. (2022)²² and Choudhary et al. (2014)²³ and Panchal et al. (2017)²⁴ reported the same findings. By increasing the availability of plant nutrients, long-term organic matter application may increase soil physicochemical characteristics, leading to increased productivity²⁵. Additionally, organic matter maintained consistent macro- and micronutrient supplies in the soil, thereby increasing yields ²⁶ According to Bera et al. (2024)²⁷, better nutrient absorption, steady breakdown of the FYM, and nutrient release throughout a crop's growth stage contribute to increased yield.

The quality parameters of rice viz. anthocyanin content, protein content also improves with the combined use of different organic manures, green manures and sea weed sap. Organics through panchagavya improved the quality and other physico-chemical properties which helped plant take up more nutrients from soil and transform it into useful sink. Panchagavya - known to extend stimulatory effect to plant through phytohormones like IAA, GA3, cytokinin could successfully influence the plant to perform better which finally increased the yield by 33.40% over control where no panchagavya was applied.

Conclusion

The findings of the study concluded that the application of green manuring (Dhaincha) + 50% RDN through a FYM + seedling root dip with Beejamrit + soil application of Jeevamrutha + soil application of an EM solution + foliar application of Panchagavya performed better among the different organic practices for the organic production of transplanted rice.

Declarations

Declaration of Competing Interest

The authors declare that they have no competing interests.

Author Contribution

GKB, KS : conceptualization and methodology; GKB, KS, : data collection and analysis; GKB, SRM AND KS : writing the manuscript; SRM , KS, : reviewing and final editing; GKB AND KS : supervision; All the authors reviewed the findings and accepted the final version of the manuscript.

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Data Availability

The datasets generated during and/or analysed during the current study will be available from the corresponding author upon request.

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Figures

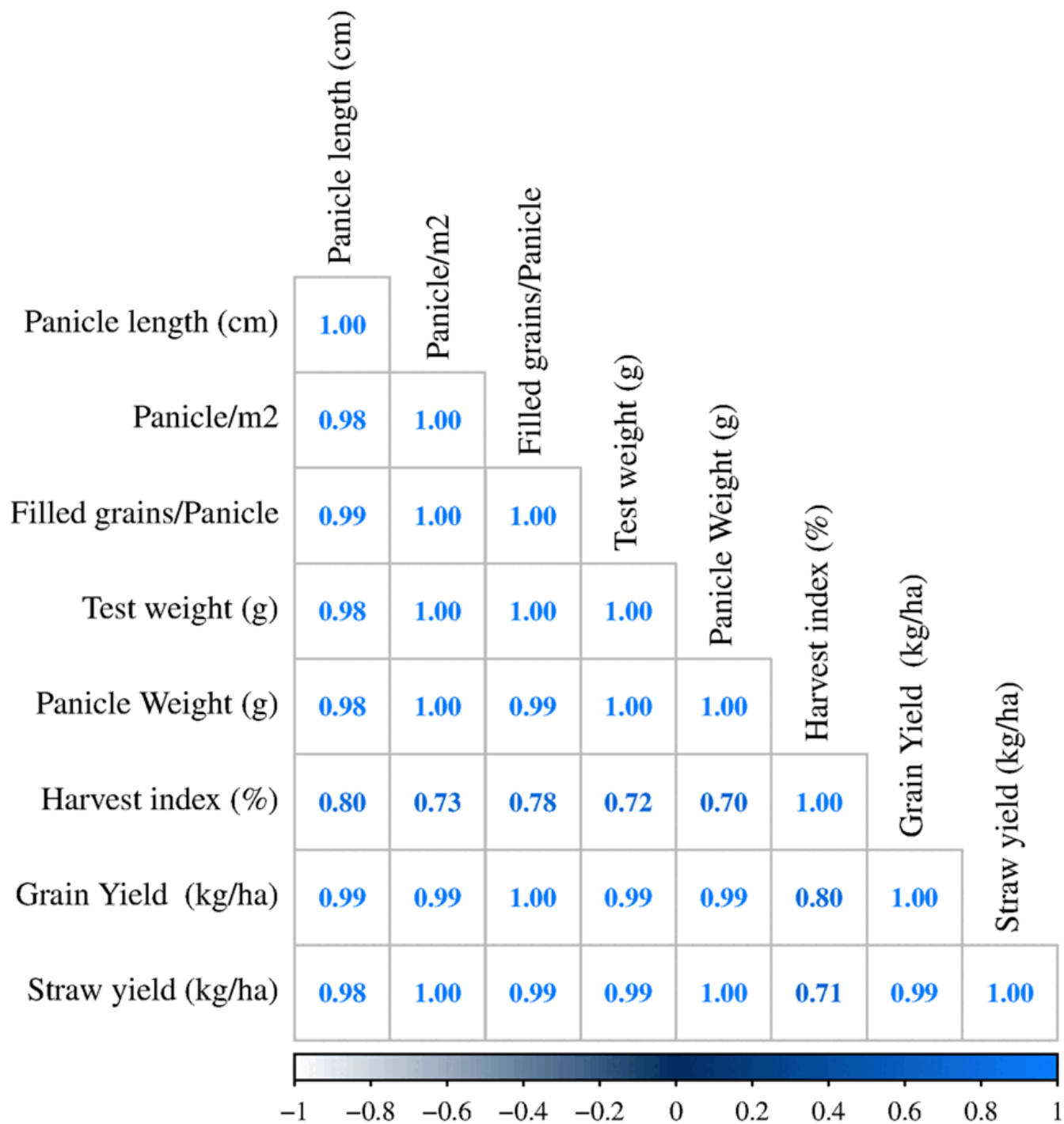


Figure 1

Pearson’s correlation matrix among the traits contributing to grain yield and yield (pooled: 2022–2023) at $p \leq 0.05$

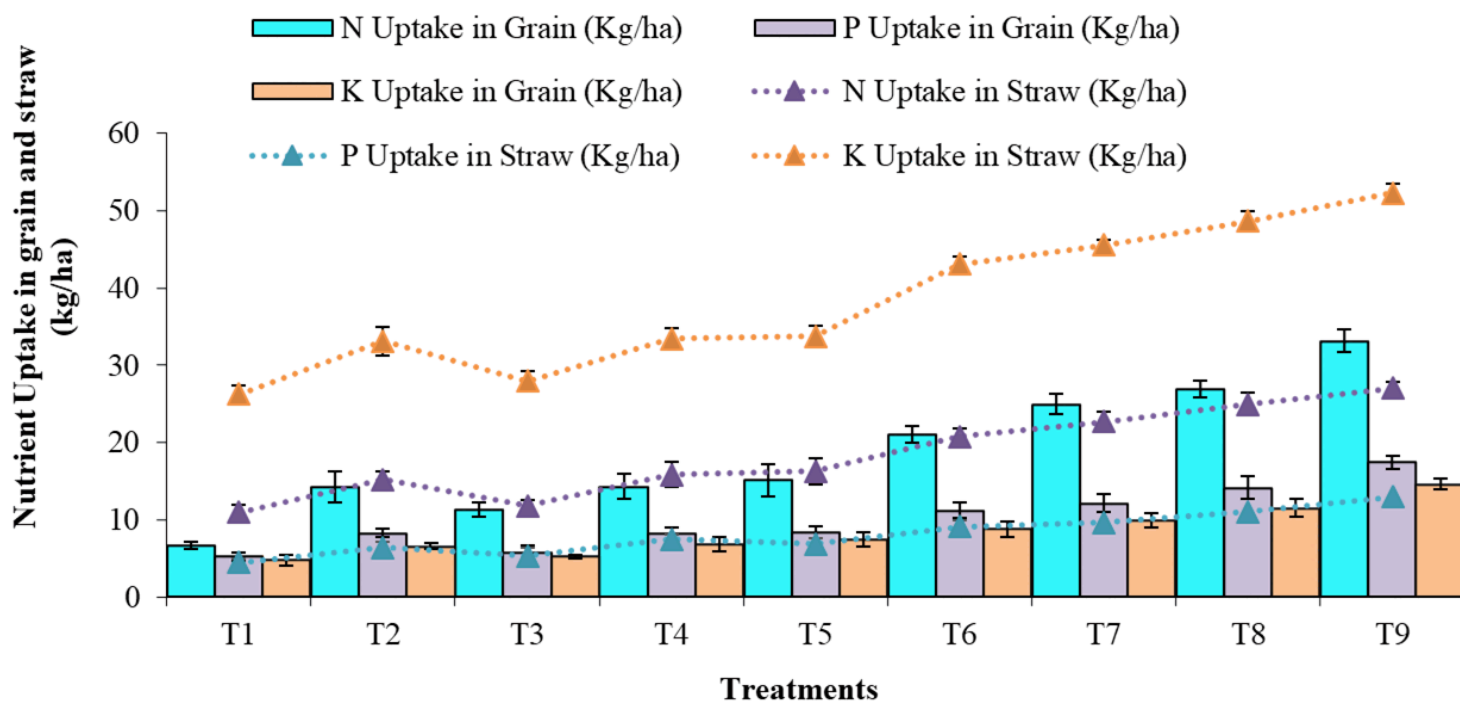


Figure 2

Effects of different organic production practices on N, P, and K uptake by grain and straw. T₁: Control, T₂: 100% of RDN through FYM, T₃: Green Manuring (Dhaincha), T₄: Green Manuring (Dhaincha) + 50% RDN through FYM, T₅: T₄ + Seedling root dip in Beejamrit @ 10%, T₆: T₄+ Soil application of Jeevamrutha @ 10%, T₇: T₄+ Soil application of EM Solution @10%, T₈: T₄+ foliar application of Panachagavya @ 3% and T₉: T₄+ Seedling root dip with Beejamrit + Soil application of Jeevamrutha + soil application EM solution + foliar application of Panchagavya

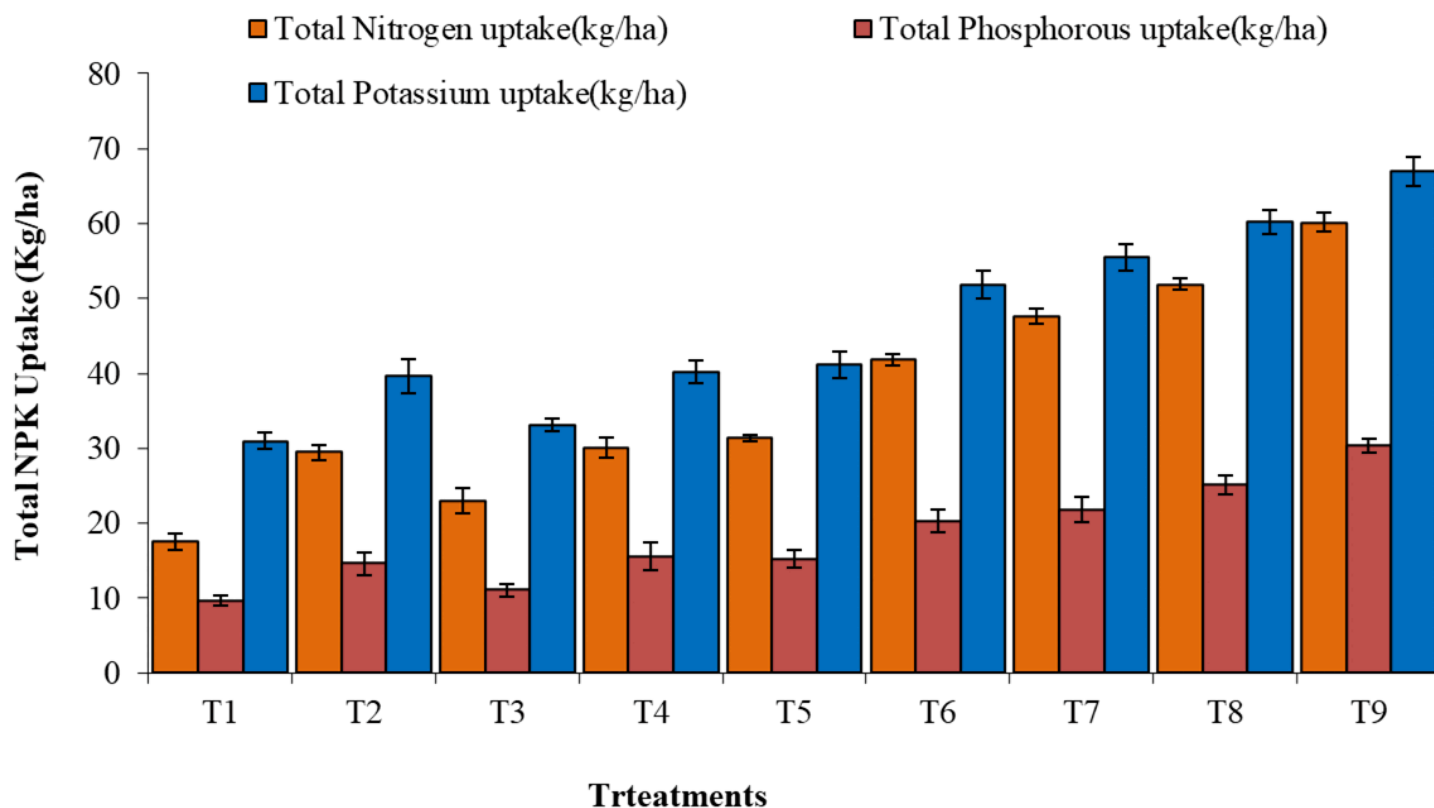


Figure 3

Effects of different organic production practices on total N, P, and K uptake (kg/ha). T₁: Control, T₂: 100% of RDN through FYM, T₃: Green Manuring (Dhaincha), T₄: Green Manuring (Dhaincha) + 50% RDN through FYM, T₅: T₄ + Seedling root dip in Beejamrit @ 10%, T₆: T₄+ Soil application of Jeevamrutha @ 10%, T₇: T₄+ Soil application of EM Solution @10%, T₈: T₄+ foliar application of Panachagavya @ 3% and T₉: T₄+ Seedling root dip with Beejamrit + Soil application of Jeevamrutha + soil application EM solution + foliar application of Panchagavya