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Innovative organic nutrient management and land arrangements improve soil health and productivity of wheat (*Triticum aestivum* L.) in an organic farming system

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Introduction: Soil health is vital for ecosystems, but excessive use of fertilizers, chemicals, and irrigation harms soil fertility, leading to reduced yields and degradation. Thus, exploring innovative land arrangements and nutrient management for staple crops such as wheat is essential. Organic farming offers a promising solution. This study hypothesized that an appropriate land arrangement, combined with split applications of farmyard manure (FYM) and liquid organic fertilizer, can enhance wheat productivity while also improving soil health. The objective of this study was to investigate the effects of different sowing methods and organic nutrient management practices on the productivity of wheat and soil health.

Methods: This study aimed to examine the impact of sowing methods and nutrient management practices on soil health and organic wheat productivity during the winter seasons of 2021–22 and 2022–23 at the Organic Farming Unit (Agronomy), Rajasthan College of Agriculture, MPUAT, Udaipur. The experiment was arranged in a split-plot design, with three land arrangements/sowing methods in the main plot and eight nutrient management approaches in the subplots.

Results: Concerning different land arrangements, the furrow irrigated raised bed sowing (FIRB) method resulted in the maximum wheat yield (4.34 t ha^{-1}) compared with flat row sowing and zero tillage sowing. With respect to nutrient management practices, 75% of the recommended dose of N (RDN) through the FYM was basal + 25% RDN with the 1st irrigation + *Jeevamrut* application at 500 L ha^{-1} during sowing, and the 1st irrigation + *Panchagavya* spraying at 5% during the booting stage resulted in the highest grain yield (4.47 t ha^{-1}). Both the zero tillage and FIRB land arrangements resulted in better soil biological activities and microbial counts than did flat sowing. The results indicate that sowing wheat via the FIRB method, with the recommended nitrogen dose applied through split applications of FYM along with liquid organic manures such as *Jeevamrut* and *Panchagavya*, can be an excellent option for organic wheat cultivation. This approach can enhance both yield and soil health.

Conclusion: Seventy-five percent RDN through FYM as a basal + 25% RDN during the 1st irrigation + *Jeevamrut* at 500 L ha^{-1} during sowing and the 1st irrigation + spraying of *Panchagavya* at 5% during the booting stage effectively increased the growth and yield of organic wheat. With respect to land arrangements, both FIRB and zero tillage resulted in better growth, yield, and soil biological properties. The practical utility of this study is the optimization of split applications of FYM and land arrangements for organic wheat cultivation.

KEYWORDS

wheat yield, organic manures, nutrients, soil health, sowing methods

1 Introduction

With the increasing demand for organic produce due to concerns about environmental sustainability and human health, the cultivation of organic wheat has garnered substantial attention in recent years (Naik et al., 2024). Wheat (*Triticum aestivum* L.) is a crucial cereal crop worldwide that serves as a staple food for a large part of the global population. India ranks second in terms of wheat production, contributing 109.52 million tons or 13% of the global production (Singh et al., 2023). The notion of organic farming is gaining traction, and the demand for organic food is expanding swiftly in several countries, including India (Sharma et al., 2021; Naik et al., 2022). Organic farming has several challenges since it takes time for changes in the chemical, physical, and biological properties of the soil to reach ecological equilibrium (Barnwal et al., 2021). The soil quality has deteriorated due to monocropping. If this trend continues, the nation will face significant challenges in managing its limited natural resources (Bhattacharyya et al., 2015). Initially, the grain yield under organic management is generally lower than that under conventional production systems because of the 3-year conversion period. However, once the inherent health of the soil is restored, yields become comparable to those of conventional farms (Sharma et al., 2018). Soil plays a crucial ecological role in sustaining and supporting life by serving as a foundation for plant growth, regulating water supply and filtration, cycling essential nutrients, and providing a habitat for a vast array of microorganisms and other living organisms. Managing soil health is vital for maintaining biodiversity and ensuring sustainable agricultural productivity (Pramanick et al., 2024). Therefore, maintaining and protecting soil health is crucial for the survival of ecosystems. The physical, chemical, and biological characteristics of soil control its overall health. Excessive use of fertilizers, chemicals, and irrigation has reduced soil fertility, impacting soil carbon levels, microorganism populations, and the physical properties of soil (Pahalvi et al., 2021).

Numerous studies have shown that excessive tillage in cereal-intensive cropping systems negatively impacts soil health by depleting the soil carbon stock, degrading soil physical properties, and reducing biodiversity (Lal, 1999, 2004; Mathew et al., 2012; Pramanick et al., 2024). Sowing methods influence the physical environment of the soil, affecting plant rooting, soil nutrient availability, and moisture extraction patterns. These factors, in turn, impact crop establishment, growth, and yield (Mollah et al., 2009).

Optimizing the utilization of farm resources and minimizing losses are the goals of nutrient management in organic systems (Kopke, 1995). An appropriate amount of nitrogen is provided to organic wheat via FYM, compost, or other organic sources (Sharma et al., 2018). However, the amount of manure applied needs to be reduced by complementing other nutrient sources; otherwise, farmers will not have access to large quantities of organic manures equivalent to the recommended dose of nitrogen in wheat, which will result in low wheat yields under organic farming. Therefore, enhancing the efficiency of organic manures involves splitting their application multiple times and supplementing organic liquid manures at varying doses to provide nutrients and growth-regulating elements at specific growth stages. Organic wheat cultivation can increase farmers' economic prospects by allowing them to obtain premium prices, as the quality of organically grown wheat is superior to that of conventionally grown wheat (Krejčířová et al., 2007). However, several challenges exist in the development of successful organic wheat cultivation practices. Proper nutrient management and land arrangement are crucial for the success of organic wheat cultivation.

There is a significant gap in current knowledge regarding the development of innovative protocols for the split application of farmyard manure (FYM) or other organic manures. Furthermore, the application protocols for liquid organic manures, such as *Jeevamrut* and *Panchagavya*, in conjunction with FYM, have yet to be explored within organic farming practices. The benefits of such innovative applications of organic sources of nutrients to crops remain unclear. Additionally, the impact of these organic farming systems on soil health is not yet well-understood. This study hypothesized that split applications of organic manure, combined with organic liquid manure and appropriate land management practices, could increase wheat productivity while preserving soil health. This study aimed to investigate the effects of different sowing methods and nutrient management practices on soil physical, chemical, and biological properties. Furthermore, this research explored the influence of these soil properties on the growth and development of wheat grown in an organic farming system.

2 Materials and methods

2.1 Experimental location

The experiment was conducted during the winter seasons of 2021–22 and 2022–23 at the Organic Farming Unit (Agronomy), Rajasthan College of Agriculture, MPUAT, Udaipur, India, to examine the performance of organic wheat under various sowing methods and nutrient management practices. The experimental site is situated at 24°35′ N latitude, 72°42′ E longitude, and at an altitude of 581.13 m above the mean sea level (MSL) in the Subhumid Southern Plain and Aravali Hills of Rajasthan. According to Thornthwaite's classification, the experimental site is classified as CA'w Climatic, which denotes a humid subtropical climate with warm, rainy summers and dry winters with little precipitation. The experimental site normally receives an average of 637 mm of rainfall, with the southwest monsoon season (July–September) accounting for more than 70% of the total precipitation. The experimental soil was clay loam falling under the Vertisol category with a slightly alkaline reaction (pH 8.0 and 7.9), medium in terms of soil organic carbon (0.66–0.68%), available nitrogen (256.1–257.2 kg ha^{-1}) and phosphorus (25.51–25.88 kg ha^{-1}), and high in available potassium (304.90–305.11 kg ha^{-1}).

2.2 Treatment details

The experiment was conducted in a split-plot design that included three land arrangements/sowing methods as the main factor and eight nutrient management approaches as subfactors with four replications. The detailed treatment combinations are shown in Table 1.

TABLE 1 Treatment details.

Treatments	Treatments details
Sowing methods	
S_1	Flat row sowing
S_2	Furrow irrigated raised bed (FIRB) method
S_3	Zero tillage sowing
Nutrient management practices	
M_1	100% RDN through FYM as basal
M_2	50% RDN through FYM as basal + 50% RDN with 1st irrigation
M_3	75% RDN through FYM as basal + 25% RDN with 1st irrigation
M_4	50% RDN through FYM as basal + 25% RDN with 1st irrigation + 2% RDN with 2nd irrigation
M_5	M_1 + *Jeevamrut* at 500 L ha^{-1} during sowing and 1st irrigation + spraying of *Panchagavya* at 5% at booting stage
M_6	M_2 + *Jeevamrut* at 500 L ha^{-1} during sowing and 1st irrigation + spraying of *Panchagavya* at 5% at booting stage
M_7	M_3 + *Jeevamrut* at 500 L ha^{-1} during sowing and 1st irrigation + spraying of *Panchagavya* at 5% at booting stage
M_8	M_4 + *Jeevamrut* at 500 L ha^{-1} during sowing and 1st irrigation + spraying of *Panchagavya* at 5% at booting stage

FYM and RDN denote farmyard manure and the recommended dose of nitrogen, respectively.

2.3 Experimental details

2.3.1 Land arrangements/sowing methods

In the case of the flat row sowing method, the seeds were sown in opened furrows manually at a depth of 5 cm in rows spaced 22.5 cm apart. In the furrow irrigated raised bed (FIRB) system, the beds were designed with dimensions of 90 cm wide at the top, 15 cm in height, and a furrow width of 30 cm at the top. The spacing between the centers of adjacent furrows was maintained at 120 cm. Seeding was conducted with five rows spaced 18 cm apart on these raised beds. In the zero-tillage sowing method, seeds are sown directly without any land preparation with the help of a tractor-drawn zero-till-ferti-seed drill.

2.3.2 Organic nutrient management

For the organic production of wheat, farmyard manure (FYM) was used to supply the recommended dose of nitrogen. It was procured from the Livestock Unit, RCA, Udaipur, and a split application of FYM was applied according to the treatments. The recommended dose of nitrogen (120 kg ha^{-1}) was applied in three splits, *viz.* as basal, at first irrigation, and at second irrigation through the FYM (Table 1). The fully decomposed FYM contained 0.5% N, 0.25% P, and 0.5% K on a dry weight basis (Table 2).

To prepare Jeevamrut, a barrel was filled with 200 liters of water, to which 10 kg of fresh desi cow dung and 10 liters of aged cow urine were added. Then, 2 kg of jaggery flour and 2 kg of pulse flour were mixed, which served as nutrients to stimulate microbial growth. Additionally, ~100 grams of living soil collected from under the canopy of a banyan tree was added to introduce beneficial microorganisms. The entire mixture was stirred thoroughly to ensure the even distribution of all the components and then allowed to ferment in a shaded area for 48 h. This fermentation process allows beneficial microbes to multiply, creating nutrient-rich biofertilizer that enhances soil health and promotes plant growth (Table 1). The prepared *Jeevamrut* contained 1.84–1.97% N, 0.19–0.20% P, and 0.20–0.29% K (Table 2).

To prepare *Panchagavya*, an earthen container was used to mix 5 kg of fresh cow dung with 1 kg of cow ghee. This mixture was allowed to ferment for 3 days, with thorough stirring each morning and evening for at least 15 min to ensure proper aeration

TABLE 2 The average compositions of *Jeevamrut*, *Panchagavya*, and FYM.

Parameters	*Jeevamrut*	*Panchagavya*	FYM
Total nitrogen (%)	1.84–1.97	0.44	0.50
Total phosphorus (%)	0.190–0.201	0.41	0.25
Total potassium (%)	0.200–0.291	0.99	0.50
Total zinc (ppm)	4.20–4.32	70–74	1.13
Total iron (ppm)	280–287	112–116	1.20
Bacterial count (cfu ml^{-1})	$5.30*10^8$-$7.25*10^8$	$38.15*10^8$-$43.75*10^8$	–
Fungal count (cfu ml^{-1})	$4.15*10^4$-$5.85*10^4$	$34.75*10^5$-$36.65*10^5$	–
Actinomycetes (cfu ml^{-1})	$2.35*10^4$-$3.70*10^4$	$34.75*10^5$-$36.65*10^5$	–
Acid phosphatase (μg ml^{-1})	0.74–1.25	114.46–133.20	–
Alkaline phosphatase (μg ml^{-1})	0.87–3.79	136.42–147.89	–
Dehydrogenase (μg TPF ml^{-1} hr^{-1})	0.94–4.47	416.30–445.76	–

and uniformity. After the initial 3-day fermentation, 3 liters each of cow urine and cow milk, along with 2 kg of cow curd and 500 grams of jaggery, were added to the container. These ingredients provide nutrients to promote the growth of beneficial microorganisms. The mixture was then fermented for an additional 15 days, with regular stirring twice daily, morning and evening, to facilitate fermentation. Once fermentation was complete, the mixture was sieved through a fine cloth to remove any solid particles, resulting in the *Panchagavya* stock solution. This solution can be used as an effective organic growth promoter for crops, enhancing soil fertility and plant health. This *Panchagavya* solution, containing 0.44% N, 0.41% P, and 0.99% K, was applied as a spray at a 5% concentration during the booting stage (Table 1). Total nitrogen (N) was determined by digesting the FYM samples via the semi-Kjeldahl method (Jackson, 1973). For the determination of phosphorus (P) and potassium (K), the FYM samples were digested in a mixture of HNO3, HClO4, and H_2SO4 at a 3:1:1 ratio, with P analyzed via the vanadomolybdate yellow color method and K via a flame photometer. The Zn and Fe contents were analyzed via an atomic absorption spectrophotometer (Jackson, 1973). The total carbon (C) and nitrogen (N) contents in *Panchagavya* and *Jeevamrut* were determined via a CHNS Analyser (Elementar Vario ELIII). Total phosphorus was determined via the vanadomolybdo-phosphoric yellow color method after the sample was digested with a diacid, and potassium was measured via a flame photometer (Jackson, 1973). The bacterial and fungal populations were estimated via serial dilution and pour plate techniques with soil extract agar and Rose Bengal agar media, respectively (Lochhead and Chase, 1993; Martin, 1950). *Panchagavya* was prepared according to Natarajan (2007), whereas *Jeevamrut* was prepared following the method provided by Palekar (2005).

2.4 Growth and yield characteristics

During the 2-year experiment, biometric observations of wheat growth and yield parameters, including plant height, plant dry matter, total chlorophyll content (SPAD Meter, SPAD-502Plus, Konica Minolta Inc., Osaka, Japan), number of tillers, number of grains per ear, and grain yield, were recorded. The heights of five randomly tagged plants from each plot were measured from the ground to the tip of the upper spikelet of the main ear (excluding the awns). The five plants from the respective net plots were uprooted. The root portion was removed, and the plants were chopped into small pieces, placed in a perforated labeled brown paper bag and dried first in sunlight and then in a thermostatically controlled oven at $60 \pm 2°C$. Drying was performed until a constant weight was reached, and the mean dry matter accumulation per plant was determined.

At harvest, yield-contributing characteristics and yield characteristics were observed. The number of effective tillers was counted from five randomly selected plants taken from each plot. The average of the values is expressed as the number of tillers per plant. Five randomly selected spikes were taken from each plot and threshed manually. The number of grains was counted, and the number of grains per ear was averaged. The net plot crop was harvested, threshed, and winnowed. The grains harvested from each net plot were sun-dried for 2–3 days to reach 10% moisture, after which the weight of the grains in the net $plot^{-1}$ area was recorded and expressed in t ha^{-1}. Pictures of the organic wheat crops under study are included in Supplementary Figure S1.

2.5 Soil analysis

The Walkley and Black (1934) method was used to determine soil organic carbon (SOC) through a rapid titration method involving potassium dichromate, orthophosphoric acid, sodium fluoride, and sulfuric acid. For this procedure, 0.5 g of processed soil was mixed with 10 mL of potassium dichromate and 20 mL of concentrated sulfuric acid in a conical flask and allowed to react for 30 min. Then, 250 mL of distilled water, 10 mL of orthophosphoric acid, and a small amount of sodium fluoride were added, and the mixture was allowed to cool. Subsequently, 1 mL of diphenylamine indicator was added, and the solution was titrated with ferrous ammonium sulfate to determine the SOC content. The soil available nitrogen was determined via the modified Kjeldahl method as described by Jackson (1973). Available phosphorus was estimated via Olsen's method (Jackson, 1973) with a UV–VIS double-beam spectrophotometer (Systronics India Pvt. Ltd., Ahmedabad, India). The soil available potassium was determined with a flame photometer (Systronics India Pvt. Ltd., Ahmedabad, India) after extraction with 1 N ammonium acetate (Jackson, 1973). An atomic absorption spectrophotometer (Perkin Elmer, Waltham, MA, USA) was used to determine the Zn and Fe contents in the soil, following the methods described by Tandon (2005). The detailed procedure can be found in our previously published paper (Lakshmi et al., 2021). The soil microbial counts, *viz.*, bacteria, fungi, and actinomycetes, were quantified via standard serial dilution and plate count methods as described by Scmidt and Colwell (1967). Thornton's (1992) agar medium, Jensen's (1930) agar medium, and Martin's (1950) Rose Bengal streptomycin agar medium were used to count the total number of viable bacteria, actinomycetes and fungi, respectively.

The dehydrogenase activity (DHA) in the soil was measured according to the method of Klein et al. (1971), which involves the reduction of 2,3,5-triphenyltetrazolium chloride (TTC) to triphenyl formazan (TPF), followed by spectrophotometric analysis at a wavelength of 485 nm. Urease activity (UA) was determined by quantifying the NH4+ released during a 2-h soil incubation at 37°C, followed by distillation with magnesium oxide (MgO) and back titration with 0.005 N sulfuric acid (Kapoor and Paroda, 2007). Acid phosphatase (ACP) and alkaline phosphatase (ALP) activities were estimated by detecting p-nitrophenol (PNP) released after a 1-h incubation at 37°C at pH 6.5 via the use of p-nitrophenyl phosphate disodium (Tabatabai and Bremner, 1969).

2.6 Statistical analysis

The data were recorded for evaluation of treatment and subjected to statistical analysis of variance as described by Cochran and Cox (1967). Analysis of the pooled data was also performed to test the homogeneity of variance through Bartlett's test (Snedecor and Cochran, 1989). The critical difference was calculated to estimate the significance of the treatment means wherever the "F" values were significant at the 5% level of significance. Using the least significant difference (LSD) approach, differences between treatment means were assessed (Gomez and Gomez, 1984). All the data recorded in this study were statistically analyzed via the software package R (Agricole version). All the graphs were drawn via MS Excel v21.0 software.

3 Results

3.1 Growth parameters

Table 3 presents the growth attribute data. When considering pooled data, the FIRB sowing method resulted in significantly greater plant height and dry matter accumulation at 45 DAS than the flat row sowing and zero tillage methods did. Specifically, FIRB resulted in 3.74 and 7.22% greater plant height and dry matter accumulation than did flat row sowing and 4.09 and 11.72% greater values than did the zero-tillage method, respectively. With respect to nutrient management practices, the split application of RDN through FYM (treatment M_3) resulted in significant increases of 5.80 and 3.47% in plant height and dry matter accumulation, respectively, at 45 DAS in wheat compared with those in treatments M_1 and M_4. The split application of RDN through FYM combined with *Jeevamrut* and *Panchagavya* (treatment M_7) significantly increased plant height and dry matter accumulation in wheat at 45 DAS. Compared with those in the M5 and M8 treatments, plant height in the M5 and M8 treatments increased by 6.82 and 4.66%, respectively, while dry matter accumulation increased by 6.48 and 4.00%, respectively.

3.2 Yield attributes and yield

In terms of different land arrangements, the FIRB method resulted in a notable increase in the number of effective tillers per wheat plant at harvest, as well as in the number of grains per ear and in the grain yield, with improvements of 5.88 and 9.36%, 1.92 and 4.69%, and 5.75 and 11.68%, respectively, compared with those of the S_1 (flat row sowing) and S_3 (zero tillage) treatments (Table 4). Among the nutrient management practices, treatment M_3, involving the split application of RDN through FYM alone, notably increased the number of effective tillers, grains per ear, and wheat grain yield by 10.97 and 5.20%, 5.22 and 2.83%, and 6.36 and 4.92%, respectively, compared with those of treatments M_1 and M_4. Split application of RDN through FYM with *Jeevamrut* and *Panchagavya* (M_7) significantly increased the number of effective tillers, number of grains per ear, and grain yield of wheat by 6.63, 6.37, 5.03, 3.99, 8.81, and 6.12%, respectively, compared with those under M_5 and M_8.

3.3 Soil properties

3.3.1 Soil chemical status

The best attainments of soil chemical status in terms of SOC, soil available N, P, and K were found under the zero-tillage system, and this land management was closely followed by the FIRB system (Figure 1). Compared with the flat-sowing system, the zero-tillage system presented ~8–9% greater SOC content and soil NPK status.

With respect to the different nutrient management practices, split application of RDN through FYM with *Jeevamrut* and *Panchagavya* (treatment M_7) resulted in the maximum values of SOC, soil available N, P, and K, and this treatment was found on par with M_6. M_7 presented ~8–12% higher values of soil organic carbon and NPK than those under the commonly practiced 100% RDN with FYM as the base. In terms of the soil micronutrient status, a trend similar to that recorded in the case of macronutrients was also observed. The zero-tillage system resulted in the highest value of soil available Zn, and its performance was comparable to that of the FIRB system (Figure 2). The split application of RDN through FYM combined with *Jeevamrut* and *Panchagavya* (treatment M_7) also led to the maximum soil available Zn, which was on par with that in treatment M_6. Compared with the full application of FYM, which applied as a basal dose rather than split applications, treatment M7 resulted in ~9% greater soil available Zn.

3.3.2 Microbial count in the soil

The microbial count data are depicted in Figure 3. Figure 3 shows that treatment S_3 (zero tillage) resulted in the maximum values of the soil microbial count, *viz.* bacteria (74.69 × 10^6 cfu g^{-1} of soil), fungi (30.94 × 10^6 cfu g^{-1} of soil) and actinomycetes (39.24 × 10^6 cfu g^{-1} of soil).

S_3 presented increases in the bacterial, fungal, and actinomycete populations of 7.40, 9.98 and 11.60%, respectively, compared with those of the flat row sowing treatment (S_1). With respect to the bacterial and actinomycete counts, treatment S_3 (zero tillage) was similar to treatment S_2 (FIRB). With respect to the different nutrient management methods, the microbial count increased

TABLE 3 Effects of land arrangements and nutrient management practices on the growth of organic wheat.

Treatments	Plant height at 45 DAS (cm)			Plant dry matter at 45 DAS (g plant^{-1})		
	2021–22	2022–23	Pooled	2021–22	2022–23	Pooled
Land arrangements/sowing methods						
S_1	40.51	41.52	41.02	2.89	2.96	2.93
S_2	42.56	42.66	42.61	3.02	3.07	3.05
S_3	39.12	40.37	39.74	2.72	2.73	2.73
LSD ($P \leq 0.05$)	1.76	1.33	0.98	0.15	0.16	0.10
Nutrient management practices						
M_1	38.08	39.06	38.57	2.58	2.68	2.63
M_2	39.35	40.38	39.87	2.80	2.88	2.84
M_3	40.29	41.32	40.81	2.90	2.90	2.90
M_4	38.87	39.91	39.39	2.74	2.80	2.77
M_5	41.01	41.31	41.16	2.92	2.93	2.93
M_6	43.11	43.31	43.21	3.00	3.04	3.02
M_7	43.43	44.51	43.97	3.11	3.13	3.12
M_8	41.71	42.32	42.01	2.98	3.03	3.00
LSD ($P \leq 0.05$)	1.81	1.70	1.23	0.16	0.13	0.10

The treatment details are given in Table 1.

TABLE 4 Effects of land arrangements and nutrient management practices on the characteristics and yield of organic wheat.

Treatments	Effective tillers at harvest			Grains ear^{-1}			Grain yield (t ha^{-1})		
	2021-22	2022-23	Pooled	2021-22	2022-23	Pooled	2021-22	2022-23	Pooled
Land arrangements/sowing methods									
S_1	8.02	8.29	8.16	38.83	39.11	38.97	4.05	4.16	4.10
S_2	8.51	8.78	8.64	39.24	40.20	39.72	4.29	4.39	4.34
S_3	7.83	7.98	7.90	37.73	38.16	37.94	3.83	3.94	3.88
LSD ($P \leq 0.05$)	0.51	0.42	0.30	0.99	1.26	0.71	0.21	0.21	0.13
Nutrient management practices									
M_1	7.27	7.67	7.47	36.30	37.54	36.92	3.75	3.86	3.81
M_2	8.04	8.37	8.21	37.97	38.34	38.16	3.92	4.10	4.01
M_3	8.25	8.33	8.29	38.82	38.89	38.85	3.97	4.12	4.05
M_4	7.78	7.98	7.88	37.67	37.89	37.78	3.77	3.94	3.86
M_5	8.18	8.39	8.29	38.68	39.17	38.93	4.06	4.16	4.11
M_6	8.49	8.69	8.59	39.83	40.52	40.18	4.33	4.38	4.36
M_7	8.74	8.95	8.84	40.69	41.08	40.89	4.45	4.48	4.47
M_8	8.21	8.42	8.31	38.81	39.82	39.32	4.17	4.25	4.21
LSD ($P \leq 0.05$)	0.53	0.50	0.36	1.13	1.11	0.78	0.20	0.21	0.14

The treatment details are given in Table 1.

through the split application of FYM as per the RDN. In the case of the split application of RDN through the FYM with *Jeevamrut* and *Panchagavya* (treatment M_7), a significantly greater population of bacteria, fungi, and actinomycetes in the soil was recorded after the wheat harvest than in treatment M_6 (Figure 3).

3.3.3 Enzymatic activity of the soil

The pooled data given in Table 5 indicate that among the different land arrangements/sowing methods, treatment S_3 (zero tillage) resulted in significantly greater values of soil enzymatic activity, *viz.*, urease, alkaline, and acid phosphatase, than

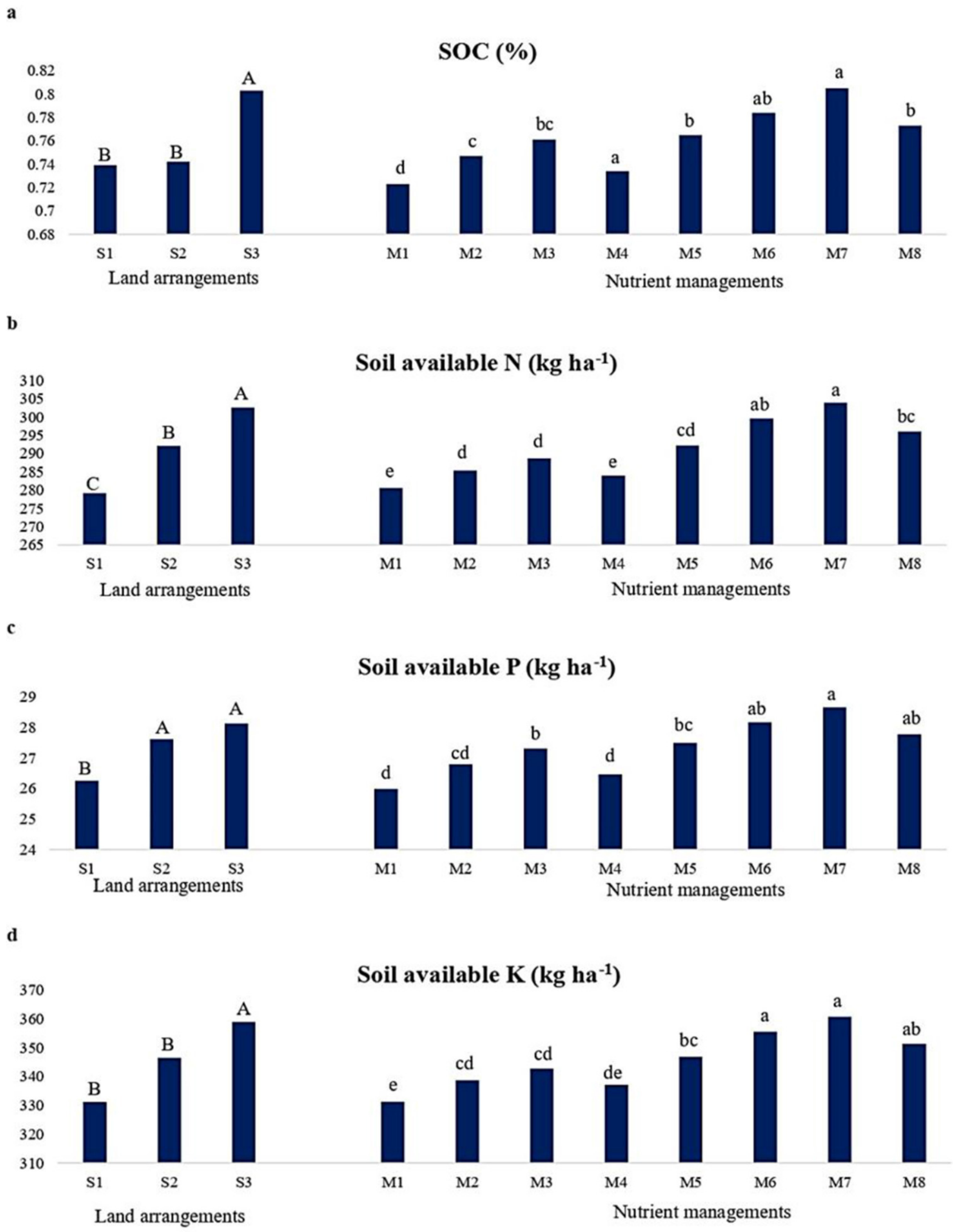

FIGURE 1
Effects of different land arrangements and nutrient management practices on soil nutrient status after the study: **(a)** SOC, **(b)** soil available N, **(c)** soil available P, and **(d)** soil available K. Treatment details are listed in Table 1; the same letters (capital or small) above the bars are statistically significant; otherwise, they are significant ($p \leq 0.05$).

treatments S_1 (flat row sowing) and S_2 (FIRB). In the case of dehydrogenase activity, S_3 and S_2 were at par.

With respect to the different nutrient management practices, the split application of only RDN through FYM (treatment M_3) resulted in significantly greater values of urease, dehydrogenase, alkaline, and acid phosphatase enzymes in the soil than those in treatments M_1 and M_4. Moreover, the split application of RDN through FYM with *Jeevamrut* and *Panchagavya*, i.e., treatment M_7, resulted in the highest activity of urease, dehydrogenase, alkaline, and acid phosphatase enzymes in the soil (Table 5).

5 Discussion

5.1 Growth parameters

The experimental findings prove that the FIRB sowing method results in greater growth attributes, which can be attributed to the suitable environment for vegetative growth of the crop. The FIRB sowing method provides a better environment for wheat growth and development, where water is used more efficiently, and increases the photosynthetic potential (Wang et al., 2004;

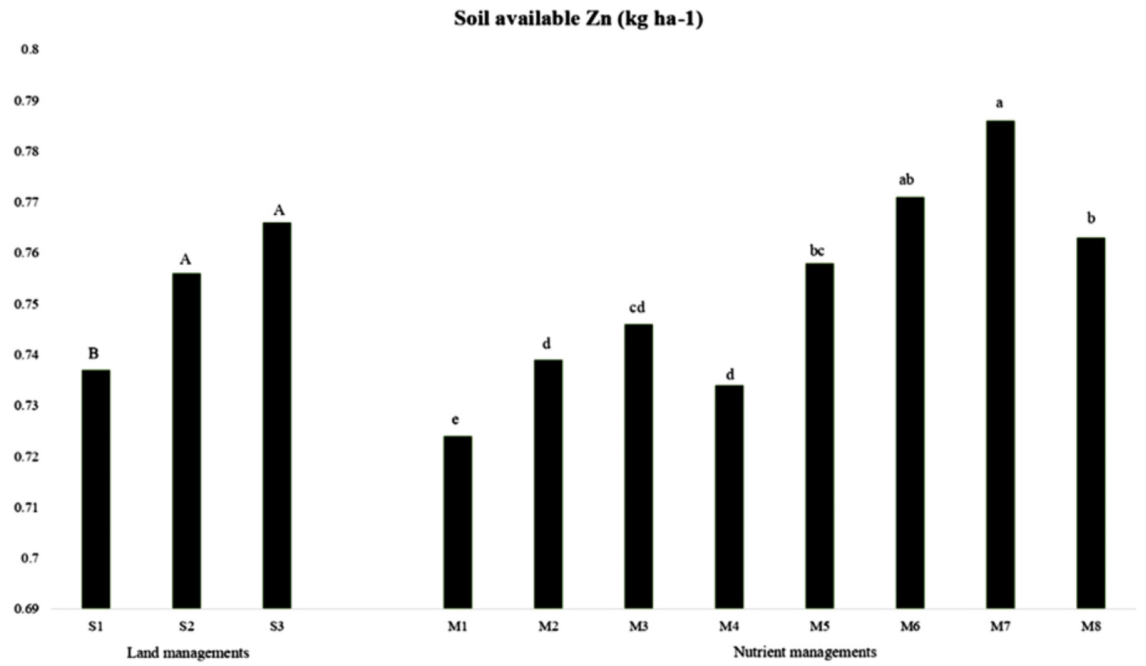

FIGURE 2
Effects of different land arrangements and nutrient management practices on the soil available Zn status. The treatment details are listed in Table 1; the same letters (capital or small) above the bars are statistically significant; otherwise, they are significant ($p \leq 0.05$).

Das et al., 2021). This can be attributed to the fact that FIRB-based management practices create a favorable microenvironment and enhance soil health, thereby improving crop stand early in the growth stages and promoting the development of vigorous plants. These findings are in accordance with the observations of Mollah et al. (2015), Kumar et al. (2019), and Jat et al. (2011). The impact of split application of RDN, with and without *Panchgavya* and *Jeevamrut*, significantly enhances crop growth by supplying essential plant nutrients, including micronutrients, and through synergistic interactions with other nutrients. Meena et al. (2017) reported similar results to those of their study on a maize–wheat cropping system.

5.2 Yield attributes and yield

The FIRB system resulted in greater growth of the crop; hence, the yield attributed to these characteristics increased, and the yield of the crop increased. The FIRB system ensures better water availability and reduces salinity or alkalinity problems in the soil, as reported by Das et al. (2021). This situation is ultimately beneficial for crop growth and development. The FIRB method can reduce lodging and improved soil quality, as well as improve input availability and utilization (Suthar, 2006). Therefore, a greater yield was recorded under this land arrangement system. Sepat et al. (2010), Kaur and Dhaliwal (2015), and Tanwar et al. (2014) reported improved yields of wheat when it was seeded via the FIRB sowing method. Organic manures had a positive effect on vegetative and reproductive growth, which ultimately led to higher values for yield attributes, leading to higher yields of crops (Singh et al., 2017). The split application of FYM with liquid manure such as *Jeevamrut* or *Panchagavya* ensured better availability of nutrients to the crop during the entire growth period, which ultimately resulted in a higher yield of the crop. Sharma et al. (2020) reported a greater yield with the application of *Jeevamrut* and *Panchagavya* in the case of corn.

5.3 Soil health

The zero-tillage system improved the soil chemical status, as reduced soil oxidation and enhanced soil microbial activity were observed under zero tillage practices. Consequently, compared with that under other arrangements, the soil organic carbon (SOC) content under this land management approach increased. The improvement in SOC also contributed to higher soil NPK and Zn levels. Similar results were reported by Pramanick et al. (2024) and Kumar et al. (2021). Zero tillage and FIRB land arrangements resulted in a greater microbial count than flat sowing did because improved soil biophysical conditions were more conducive to microbial proliferation (Mangalassery et al., 2015). Zero-tillage systems result in increased soil organic carbon, which is ultimately beneficial for soil microbes (Pramanick et al., 2024). The application of FYM, combined with liquid manures such as *Jeevamrut* and *Panchagavya*, also increased soil organic carbon, which in turn led to a greater count of soil microbes (Kumbar et al., 2015). Both *Jeevamrut* and *Panchagavya* enhanced the soil microbial activity and population, leading to increased mineralization of soil nutrients. As a result, the availability of soil NPK and Zn significantly improved in plots where these two liquid

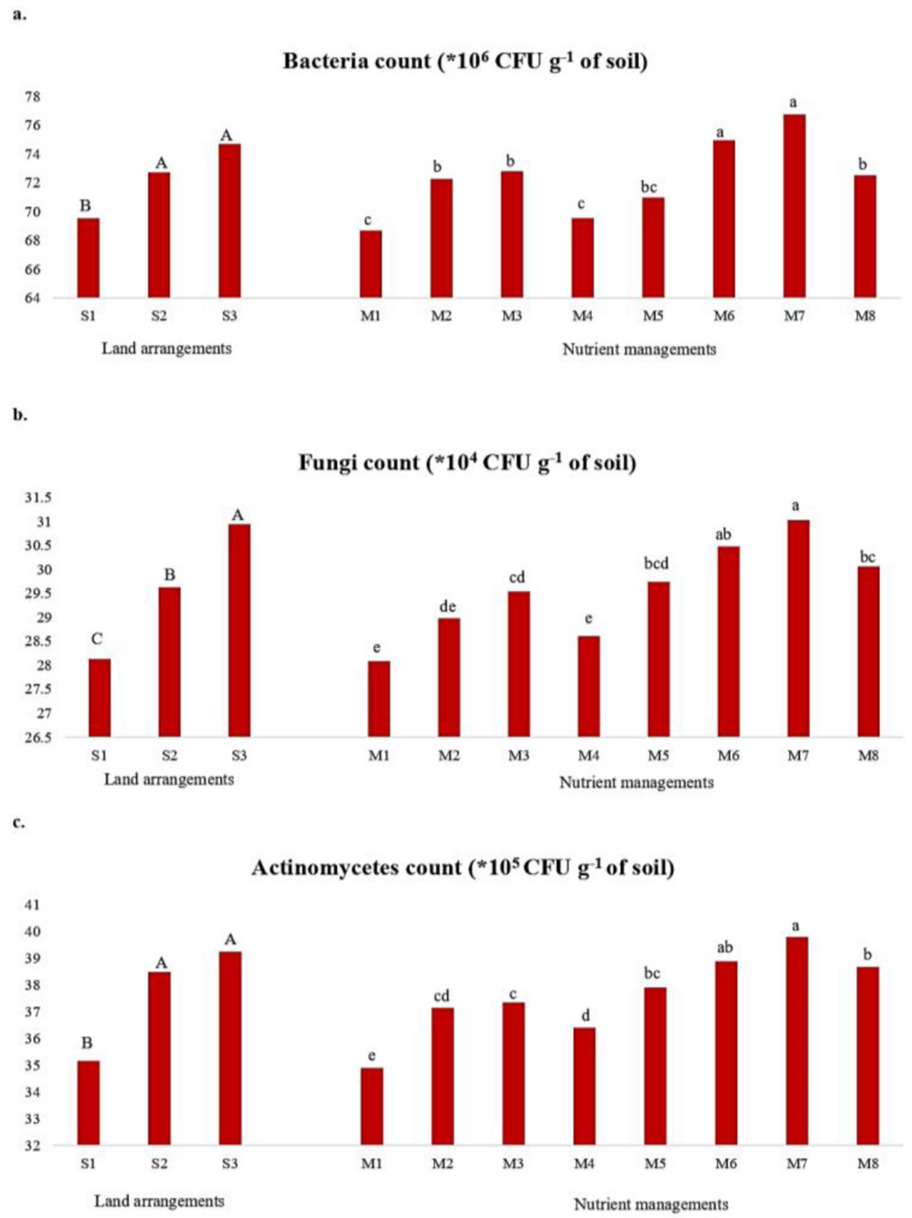

FIGURE 3
Effects of different land arrangements and nutrient management practices on the soil microbial count: **(a)** bacteria, **(b)** fungi, and **(c)** actinomycetes. The treatment details are listed in Table 1; the same letters (capital or small) above the bars are statistically significant; otherwise, they are significant ($p \leq 0.05$).

organic manures were applied, along with the split application of FYM. Majumdar et al. (2024) reported similar results to those of their previous studies.

Dick et al. (2019) reported that urease activity was greater in zero-tillage-practiced soils. Nannipieri (1994) also concluded that more enzymatic activities in zero-till soil were due to larger proportions of microbial biomass and carbohydrate-C per unit of organic C. The increased microbial biomass and enzymatic activities observed in zero-till soil may be due to a more continuous supply of organic materials to soil microorganisms in the absence of tillage (Balota et al., 2003). In the case of FIRB, soil biological activities were also found to be greater than those associated with flat sowing. The improved soil biophysical properties under this land arrangement contributed to this outcome. Organic manure applications are beneficial in terms of enhancing soil microbe function, which is directly linked to nutrient cycling and transformation (Kakraliya et al., 2017). Srivastava et al. (2020) reported that the application of 100% RDN through organic manures resulted in a significant increase in soil biomass over initial values in soil after crop harvest. Increased enzymatic activities are linked to improved soil health, as there is a strong correlation between available nitrogen in the soil and both dehydrogenase activity (DHA) and urease activity (UA) (Pramanick et al., 2024). Elevated DHA levels are also associated with increased soil organic

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TABLE 5 Effects of land arrangements and nutrient management practices on the activities of urease, dehydrogenase, alkaline phosphatase, and acid phosphatase in the soil after the harvest of organic wheat.

Treatments	Urease (μg of TPF g^{-1} of soil h^{-1})			Dehydrogenase (μg of TPF g^{-1} of soil h^{-1})			Alkaline phosphatase (μg of TPF g^{-1} of soil h^{-1})			Acid phosphatase (μg of TPF g^{-1} of soil h^{-1})		
	2021–22	2022–23	Pooled	2021–22	2022–23	Pooled	2021–22	2022–23	Pooled	2021–22	2022–23	Pooled
Land arrangements/sowing methods												
S_1	87.91	88.52	88.21	64.44	64.83	64.64	52.03	53.56	52.80	28.55	28.68	28.61
S_2	90.27	90.85	90.56	68.35	68.60	68.48	55.95	56.48	56.21	29.60	29.85	29.73
S_3	92.60	93.53	93.07	70.65	71.26	70.96	58.74	59.42	59.08	31.06	31.32	31.19
LSD ($P \leq 0.05$)	2.93	2.65	1.76	3.26	3.44	2.11	2.20	2.91	1.62	1.50	1.63	0.99
Nutrient management practices												
M_1	87.07	87.26	87.17	64.38	64.71	64.55	50.92	52.45	51.69	28.73	28.93	28.83
M_2	88.77	89.30	89.03	67.38	68.57	67.97	54.37	55.77	55.07	29.47	30.04	29.75
M_3	89.16	90.54	89.85	68.22	68.96	68.59	55.35	56.07	55.71	29.84	30.11	29.97
M_4	87.47	88.50	87.99	65.00	65.78	65.39	53.94	54.71	54.32	28.42	28.81	28.62
M_5	91.06	91.57	91.32	66.67	66.80	66.74	56.18	56.86	56.52	29.16	29.26	29.21
M_6	92.47	93.33	92.90	70.53	70.52	70.53	57.63	58.31	57.97	30.86	30.90	30.88
M_7	94.18	95.20	94.69	72.27	72.17	72.22	58.83	59.78	59.30	31.62	31.62	31.62
M_8	91.88	92.03	91.95	68.08	68.32	68.20	57.36	57.97	57.66	29.78	29.93	29.85
LSD ($P \leq 0.05$)	2.56	2.63	1.82	3.18	3.34	2.28	2.63	2.18	1.69	1.54	1.59	1.09

The treatment details are given in Table 1.

carbon (SOC), which is essential for maintaining overall soil health. Greater activities of alkaline and acid phosphatase enzymes indicate greater availability of soil P to the crop (Kumar et al., 2021).

4 Conclusion

In conclusion, this study highlighted the substantial effects of land arrangements and nutrient management practices on the soil properties and productivity of organic wheat. Through meticulous experimentation and analysis, it has been demonstrated that the choice of land arrangements and nutrient management strategy plays a pivotal role in shaping the soil health parameters and yield of organic wheat. Compared with the flat sowing and zero-tillage methods, the FIRB land arrangement resulted in ∼7 and 11% greater dry matter production in wheat, respectively. Additionally, this method resulted in ∼6 and 12% greater grain yields than flat sowing and zero-tillage, respectively. With respect to nutrient management, 75% RDN through the FYM as the base + 25% RDN during the 1st irrigation + *Jeevamrut* at 500 L ha^{-1} during sowing and the 1st irrigation + *Panchagavya* at 5% during the booting stage presented ∼19% and 17% greater dry matter production and yield, respectively, of wheat than did the commonly practiced 100% RDN through the FYM as the base. This innovative nutrient management method also resulted in 9–15% greater soil microbial activity than did 100% RDN through FYM as a base. The FIRB sowing method with 75% RDN through the FYM as the base + 25% RDN during the 1st irrigation + *Jeevamrut* at 500 L ha^{-1} during sowing and the 1st irrigation + *Panchagavya* at 5% during the booting stage was found to enhance both yield and soil biological properties. The practical utility of this study is the optimization of split applications of FYM and land arrangements for organic wheat cultivation. The limitations of this study include the absence of multilocational studies of organic wheat cultivation. Future research should focus on exploring the quality aspects of organic wheat cultivation and conducting a comprehensive study on soil health.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding authors.

Author contributions

AS: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Validation, Visualization, Writing – original draft. SS: Conceptualization, Investigation, Methodology, Resources, Supervision, Validation, Visualization, Writing – original draft. LV: Conceptualization, Investigation, Methodology, Resources, Validation, Visualization, Writing – original draft. SY: Conceptualization, Investigation, Methodology, Resources, Supervision, Validation, Visualization, Writing – original draft. BP: Data curation, Formal analysis, Resources, Software, Writing – review & editing. BS: Data curation, Formal analysis, Funding acquisition, Project administration, Software, Writing – review & editing. OO: Data curation, Formal analysis, Funding acquisition, Project administration, Software, Writing – review & editing. VB: Data curation, Formal analysis, Funding acquisition, Project administration, Software, Writing – review & editing. MB: Data curation, Formal analysis, Software, Writing – review & editing. AG: Data curation, Formal analysis, Funding acquisition, Project administration, Software, Writing – review & editing. MA: Software, Writing – review & editing, Resources, Formal analysis, Data curation. AH: Writing – review & editing, Funding acquisition, Supervision, Software, Data curation, Formal analysis.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2024.1455433/full#supplementary-material

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