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Innovative crop management strategies for sustainable nutrient use and higher yield of rice in an Alfisol

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ABSTRACT

Growing awareness of soil health and environmental quality has increased the emphasis on sustainable agricultural practices that reduce ecological harm. Consequently, the farm resources based natural and organic farming inputs have emerged as popular eco-friendly options for crop production and nutrient management. This trend may be broader movement toward harmonizing agricultural productivity with environmental stewardship. However, the sustainability of nutrients supplying potential of acidic soil under these condition is critical issue. A field experiment was conducted to evaluate the impact of these inputs, including natural farming components, on nutrient availability and rice yield in an Alfisol under a rice-maize cropping system. The study assessed five different treatments: T1 (control), T2 (complete natural farming), T3 (AI-NPOF- all India network programme on the organic farming package), T4 (integrated crop management-1), and T5 (integrated crop management-2). The results revealed that organic farming inputs significantly (p≤0.05) increased nutrient availability, with available nitrogen (N) and potassium (K) levels rising by 27.8% and 33.7%, respectively, compared to the control. Natural farming did not lead to any significant (p≤0.05) increase in nutrient availability (N and P) compared to the other treatments, aside from the control plots. However, available potassium in natural farming plots was 1.81% and 5.15% higher compared to ICM-2 and ICM-1, respectively. Organic farming exhibited the highest DTPA-extractable zinc, while natural farming had the highest copper content. In terms of yield, grain and straw yields, as well as harvest index, were significantly (p≤0.05) higher under ICM-1, which recorded the highest grain yield (3.12 Mg ha^{-1}) and straw yield (4.50 Mg ha^{-1}). Although natural farming improved grain yield over the control, it was outperformed by both ICM-1 and ICM-2 treatments. Overall, ICM-1 showed the most favorable results in terms of both yield and harvest index, while organic farming contributed to higher soil organic carbon and micronutrient content. These findings underscore the importance of crop management practices in enhancing soil health and improving rice productivity, offering valuable insights into sustainable agricultural practices. In nutshell, intregrated crop management with biopesticide based insect pest mangment may be most suitable in acidic soil of humid subtropical climate for enhancing cabon content of soil, yield of rice crop with proper soil helath status of the area.

Keywords: *Natural farming, organic farming, sustainable agriculture, smart farming, soil organic carbon.*

Introduction

Modern agriculture has transformed food production, enabling the global food system to meet the demands of a growing population through higher yields. However, this progress has come at a significant environmental cost, including soil degradation, biodiversity loss, and an increasing dependence on chemical inputs. The widespread use of chemical fertilizers and pesticides has compromised soil health [1], contributed to water pollution, and led to the depletion of essential nutrients [2]. Furthermore, these practices exacerbate climate change, with agriculture being a major contributor to greenhouse gas emissions, thereby worsening environmental conditions [3]. As global warming intensifies, its adverse effects on agricultural productivity are becoming increasingly evident. Erratic weather patterns, prolonged droughts, and rising temperatures are heightening challenges to food security, with an estimated 840 million people likely to be hungry by 2030, up from 690 million today [4]. This underscores the urgent need for sustainable farming practices.

Natural farming has emerged as a promising alternative to conventional agricultural methods. Emphasizing minimal intervention and a deep understanding of ecological principles, natural farming prioritizes soil health, biodiversity, and the intricate relationships between crops and their environment [5]. This holistic approach aims to restore and enhance the natural processes that sustain agricultural productivity. Key practices within natural farming include the use of *beejamrit*, a microbial seed coating; *jeevamrit*, a fermented microbial culture that enhances soil fertility by boosting earthworm activity and nutrient availability; *acchadana*, or mulching, which conserves moisture and promotes soil humus formation; and *whapasa*, which ensures proper moisture and air balance in the soil [6]. Organic farming similarly prioritizes the use of organic inputs, such as compost and green manure, to improve soil structure and fertility, while avoiding synthetic chemicals. Integrated crop management, on the other hand, takes a holistic approach by integrating biological, cultural, and mechanical methods to

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manage soil fertility, pest control, and overall crop production in a balanced and sustainable way. As concerns about soil health, chemical pollution, and food security continue to grow, the need for sustainable agricultural practices has never been more pressing. Natural farming is recognized for its ability to improve soil structure, enhance nutrient availability, and foster microbial diversity [7]. Unlike organic farming, which often requires substantial quantities of farmyard manure (FYM), natural farming offers a more efficient alternative by boosting soil organic carbon levels without relying heavily on external inputs [8]. These alternative farming systems have the potential to improve nutrient availability in soils by enhancing soil organic matter content, stimulating microbial activity, and promoting better nutrient cycling.

This study aims to assess the comparative effects of natural farming, organic farming, and integrated crop management (ICM) practices on nutrient availability and crop yields in acidic Alfisol under rice-maize cropping systems. The research seeks to evaluate and identify the potential method for improving nutrient availability, and crop productivity and contributing to the long-term sustainability of agricultural production.

Materials and Method

Experimental site description

A long-term field experiment was initiated in the cropping season of 2010-11 with nine different combinations of organic and inorganic treatments at Birsa Agricultural University, Ranchi, Jharkhand, India. The experimental site was located at 23°17' N latitude and 85°19' E longitude. The area has a dry, humid tropical climate and is situated at an elevation of 629 meters above sea level. The region received 1128 mm of rainfall during the 2022-2023 year. The climate is classified as sub-humid with hot, moist conditions. The soil at the experimental site is sandy clay loam, categorized as hyperthermic, mixed Typic Paleustalf according to USDA soil taxonomy. In the year of 2020-21, the number of treatments in the experimental was reduced to five based on their significant effects on crop yield and soil properties.

Treatment details and management

The experiment followed a rice-maize cropping system, where rice was grown as the *Kharif* crop (July to December) and maize as the *Rabi* crop (January to April). The treatments were laid out in a randomized block design (RBD), with each plot measuring 14 m × 3.6 m. The treatments include, T1 (Control)- no additional inputs except basic intercultural operations, serving as the baseline. T2 (Complete Natural Farming)- emphasizes a holistic, organic approach, utilizing *beejamrit, jeevamrit, ghanjeevamrit*, crop residue mulching, and *whapasa* to enhance soil health and crop growth without synthetic chemicals. T3 (AI-NPOF- All India Network Programme on Organic Farming package) - focused on intercropping with seed treatments of *Trichoderma* and *Azotobacter*, and incorporates organic inputs like FYM, vermicompost, rice straw, and neem cake, along with pest management through cow urine fortified with neem leaves. T4 (Integrated Crop Management-1) - blends of 50% organic inputs (FYM, vermicompost, rice straw, neem cake) with 50% inorganic fertilizers (NPK), using bio-pesticides like *neemaster* and *agniaster* for pest control. T5 (Integrated Crop Management-2) follows a similar nutrient strategy as treatment T4, but uses chemical pesticides for pest management. In the ICM treatments, urea, di-ammonium phosphate (DAP), and muriate of potash (MOP) were used as sources of nitrogen, phosphorus, and potassium.

In all treatments, *Sesbania aculeata* (Dhaincha) was intercropped in a 3:1 replacement series as a green manure crop. At 35 days after sowing (DAS), the standing Dhaincha was incorporated into the soil using a cono weeder. Direct seeding of rice was performed on flatbeds using the variety Karjat-8. Prior to rice sowing, various pre-sowing crops were grown in rotation. These included sunhemp (20 kg ha^{-1}) in control, AI-NPOF, and ICM-2 plots, and a combination of maize, green gram, cowpea, sesame, sunhemp, and rice bean (alternatively) in the natural farming and ICM-1 plots. This rotation practice was carried out from the last week of April until rice sowing.

Soil sampling and processing

Soil samples were collected in December 2023 at the harvesting stage of the rice crop. A zig-zag pattern was followed to collect samples from 6-7 random spots in each plot at 0-15 cm soil depth. The samples were mixed, labelled, and transported to ICAR-Indian Agricultural Research Institute, New Delhi, for further analysis. The collected samples were sieved through 2 mm sieve and kept in air-tight bags.

Analysis of soil

Soil pH was measured in a soil-water suspension (1:2.5) using a digital pH meter, while electrical conductivity (EC) was determined by measuring the conductivity of the supernatant at 25°C [9]. The soil organic carbon (SOC) was determined using the [10], with 1N $K_2Cr_2O_7$ as the oxidizing agent. Available nitrogen was measured by oxidizing 5g soil sample with alkaline potassium permanganate ($KMnO_4$) and NaOH, as per [11] method. Available phosphorus was extracted using 0.03 N NH_4F + 0.1 N HCl (1:20 ratio) and quantified by the ascorbic acid method at 660 nm [12]. Available potassium was determined by shaking the soil with 1N ammonium acetate and measuring potassium concentration with a flame photometer [13]. DTPA-extractable micronutrients (Zn, Cu, Fe, and Mn) were analyzed using atomic absorption spectrophotometry [14].

Computation of indices

Harvest index (HI) was determined by using the following formula as suggested by [15].

$$Harvest\ index\ (\%) = \frac{Grain\ yield}{Biological\ yield} * 100$$

Statistical analysis

The results for the various soil properties were analyzed statistically according to the methodology described by [16]. To assess the effects of crop management practices on different parameters, the data was subjected to one-way analysis of variance (ANOVA), performed with R software (Version 4.2.2), utilizing the *Agricolae*package. The Fisher least significant difference (LSD) method was used to compare treatment means at the significance level of p<0.05.

Results

Effect of crop management practices on soil reaction and organic carbon (SOC)

The pH values across the different treatments are presented in figure 1. No significant (p≤0.05) changes in soil pH were observed between treatments, with the highest pH recorded in organic farming plots (5.31) and the lowest in integrated crop management-2(ICM-2) plots (5.14). Similarly, electrical conductivity (EC) was highest in organic farming plots (0.30 dS m^{-1}) and lowest in ICM-2 plots (0.23 dS m^{-1}), but no significant (p≤0.05) differences were noticed across different treatments (figure 2).

Soil organic carbon (SOC) in soil was significantly (p≤0.05) affected by crop and nutrient management practices in acidic Alfisol. Organic farming plots exhibited the highest soil SOC (6.07 g kg^{-1}), followed by ICM-2 (5.86 g kg^{-1}) plots, with both treatments statistically similar (p≤0.05) (figure 3). The soil organic carbon in organic farming (OF) plots was 23.4% higher than in the control and 13.6% higher than in natural farming plots.

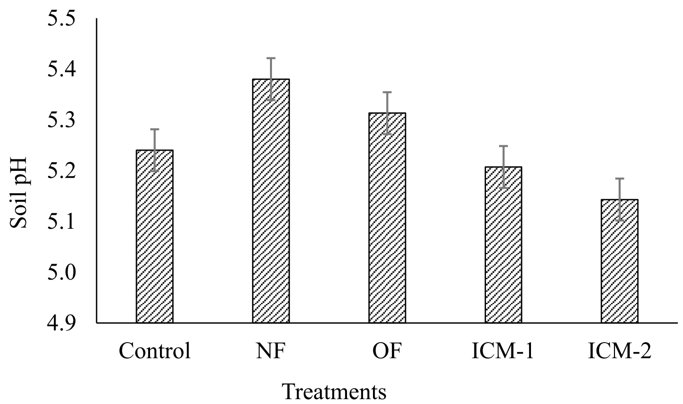

Figure 1. Effect of crop and soil

Management practices on pH in 0-15 cm depth of soil.

EC-Electrical conductivity; NF-natural farming; OF-organic farming; ICM-1-Integrated crop management practice with organic nutrient and pest management; ICM-2-Integrated crop management practice with organic nutrient management and inorganic pest management. Error bars indicate standard error of mean.

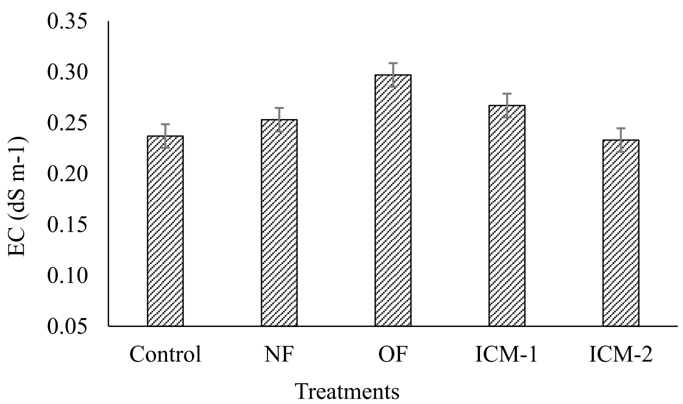

Figure 2. Effect of crop and soil management practices on electrical conductivity (dS m^{-1}) in 0-15 cm depth of soil

EC-Electrical conductivity; NF-natural farming; OF-organic farming; ICM-1-Integrated crop management practice with organic nutrient and pest management; ICM-2-Integrated crop management practice with organic nutrient management and inorganic pest management. Error bars indicate standard error of mean.

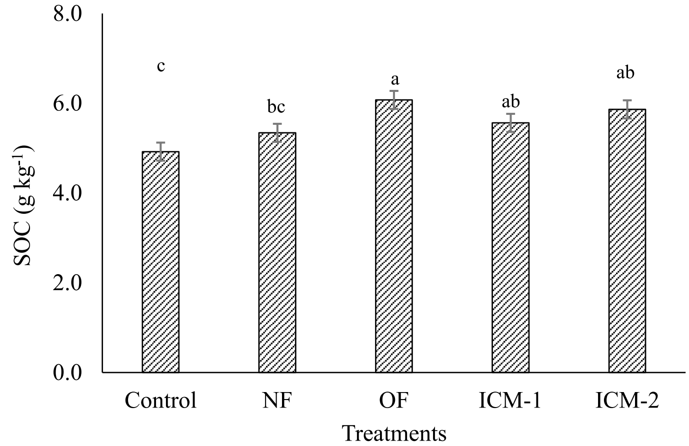

Figure 3. Effect of crop and soil management practices on soil organic carbon (SOC) (g kg^{-1}) in 0-15 cm depth of soil.

EC-Electrical conductivity; NF-natural farming; OF-organic farming; ICM-1-Integrated crop management practice with organic nutrient and pest management; ICM-2-Integrated crop management practice with organic nutrient management and inorganic pest management. Error bars indicate standard error of mean.The same letter(s) after the means indicate no significant difference at *p*< 0.05. LSD, Fisher Least Significant Difference.

Effect of crop management practices on soil available macronutrients

The application of various inputs significantly (p≤0.05) increased soil available nitrogen content compared to the control (67.2 mg kg^{-1}) (table 1). The highest available nitrogen was recorded in ICM-2 (86.0 mg kg^{-1}) plots followed by organic farming (85.9 mg kg^{-1}) plots, however, no significant difference was recorded across these two treatments. Natural farming and ICM-1 plots soil also showed similar values (80.3 mg kg^{-1}) of available N content. Organic farming and ICM-2 practices increased soil nitrogen availability by 6.97% and 7.09%, respectively, over natural farming. Soil available phosphorus ranged from 23.2 mg kg^{-1} (control) to 31.6 mg kg^{-1} (ICM-2) across different treatments. ICM-2 plots showed a significant (p≤0.05) increase (36.2%)in soil available P content over control plots, and it was 17.9% higher over natural farming and 8.9% higher over organic farming plots. However, ICM-2 plots recorded almost a similar amount of available P as compared to ICM-1 plots. Organic farming plots had the highest soil available potassium content (104 mg kg^{-1}), followed by natural farming plots (89.8 mg kg^{-1}) (Table 1). The available K in organic farming plots showed significant (p≤0.05) increment of 33.7%, 18.2%, 22.1% and 16.1% over control, ICM-2, ICM-1, and natural farming plots, respectively.

Table 1. Effect of crop and soil management practices on soil macronutrients at 0-15 cm depth of soil.

Crop management practices	Available N	Available P	Available K
	(mg kg^{-1})		
Control	67.2^{C}	23.2^{D}	78.0^{C}
NF	80.3^{B}	26.8^{C}	89.8^{B}
OF	85.9^{A}	29.0^{BC}	104.3^{A}
ICM-1	80.3^{B}	31.3^{AB}	85.4^{B}
ICM-2	86.0^{A}	31.6^{A}	88.2^{B}
LSD (p≤0.05)	5.6	2.4	7.4

NF-natural farming; OF-organic farming; ICM-1-Integrated crop management practice with organic nutrient and pest management; ICM-2-Integrated crop management practice with organic nutrient management and inorganic pest management. The same letter(s) after the means indicate no significant difference at p< 0.05. LSD, Fisher Least Significant Difference

Effect of crop management practices on DTPA-extractable micronutrients

Data of DTPA- extractable micronutrients (Zn, Cu, Fe, and Mn) in soil are illustrated in table 2. Among the treatments, the highest soil DTPA-extractable zinc (Zn) was recorded in organic farming plots (1.85 ppm), and it was 65.1%, 27.5%, and 20.9% higher over control, ICM-1, and ICM-2 plots, respectively. However, it was statistically similar ($p \leq 0.05$) to natural farming plots (1.71 ppm). Natural farming plots had the highest soil DTPA-extractable copper (Cu) (4.24 ppm), followed by organic farming (4.07 ppm) plots. Natural farming plots recorded a significant ($p \leq 0.05$) increase in Cu content in soil compared to the control, ICM-2, ICM-1, and organic farming plots, the increment was 9.56%, 6.26%, 5.73%, and 4.17%, respectively. DTPA-extractable iron (Fe) ranged from 67.2 ppm (control) to 75.4 ppm (organic farming) among the treatments. The DTPA-Fe in soil was increased in all the treatments (except natural farming) over control. DTPA-extractable manganese (Mn) was highest in ICM-2 (102 ppm) plots, followed by organic farming (101 ppm) and natural farming (101 ppm) plots. All treatments showed significant ($p \leq 0.05$) increments in DTPA-Mn content in soil over the control plots.

Table 2. Effect of crop and soil management practices on soil DTPA-extractable micronutrients at 0-15 cm depth of soil

Crop management practices	Zinc	Copper	Iron	Manganese
	(mg kg^{-1})			
Control	1.12^{C}	3.87^{C}	67.2^{C}	79^{B}
NF	1.71^{AB}	4.24^{A}	73.4^{BC}	101^{A}
OF	1.85^{A}	4.07^{B}	75.4^{AB}	101^{A}
ICM-1	1.45^{B}	4.01^{BC}	80.0^{A}	97^{A}
ICM-2	1.53^{B}	3.99^{BC}	80.5^{A}	102^{A}
LSD (p≤0.05)	0.32	0.15	6.4	12

NF-natural farming; OF-organic farming; ICM-1-Integrated crop management practice with organic nutrient and pest management; ICM-2-Integrated crop management practice with organic nutrient management and inorganic pest management. The same letter(s) after the means indicate no significant difference at *p*< 0.05. LSD, Fisher Least Significant Difference.

Effect of crop management practices on yield of rice

Grain yield, straw yield, and harvest index of rice were significantly ($p \leq 0.05$) affected by crop management practices (table 3). The highest grain yield (3.12 Mg ha^{-1}), straw yield (4.50 Mg ha^{-1}), and harvest index (41.0%) were recorded under ICM-1 plots, while the lowest values were observed in the control plots (2.28 Mg ha^{-1}, 3.86 Mg ha^{-1}, 37.2%, respectively). Although natural farming showed a significant ($p \leq 0.05$) increase in grain yield (17.3%) compared to control, it yielded 14.0% less than ICM-1 plots. Similarly, straw yield in natural farming was significantly ($p \leq 0.05$) lower than ICM-1 (7.11%) and ICM-2 (6.49%) plots. The harvest index of rice was significantly higher in ICM-1 plots compared to other treatments. The harvest index of rice in ICM-1 treatment was 3.54%, 4.86%, 5.40%, and 10.2% higher over organic farming, natural farming, ICM-2, and control treatments.

Table 3. Effect of crop and soil management practices on grain yield, straw yield and harvest index of rice

Crop management practices	Grain yield (Mg ha^{-1})	Straw yield (Mg ha^{-1})	Harvest index (%)
Control	2.28^{C}	3.86^{B}	37.2^{C}
NF	2.67^{B}	4.18^{AB}	39.1^{B}
OF	2.79^{AB}	4.27^{AB}	39.6^{B}
ICM-1	3.12^{A}	4.50^{A}	41.0^{A}
ICM-2	2.93^{AB}	4.47^{A}	38.9^{B}
LSD (p≤0.05)	0.39	0.49	1.1

NF-natural farming; OF-organic farming; ICM-1-Integrated crop management practice with organic nutrient and pest management; ICM-2-Integrated crop management practice with organic nutrient management and inorganic pest management. The same letter(s) after the means indicate no significant difference at *p*< 0.05. LSD, Fisher Least Significant Difference

Discussion

Alfisols, typically fertile soils, face several chemical challenges, including soil acidity, nutrient deficiencies, and toxicity. Acidification, often resulting from leaching, can lower soil pH, which in turn reduces the availability of essential nutrients, particularly phosphorus, which becomes less accessible due to fixation with iron and aluminum oxides. Although Alfisol generally has a high cation exchange capacity (CEC), a low pH can reduce this capacity, negatively affecting nutrient retention. Additionally, the depletion of organic matter and erosion can further degrade soil health by lowering nutrient levels and deteriorating topsoil quality. To maintain stable crop yields, it is crucial to supplement the soil with adequate nutrients from both organic and inorganic sources. This balanced approach helps to correct nutrient deficiencies, enhances nutrient use efficiency, and preserves the soil's chemical properties. Soil pH is a critical factor that significantly influences various soil properties and processes affecting plant growth [17]. In neutral to alkaline soils, the availability of most micronutrients is limited, while in acidic soils like Alfisol, certain nutrients may reach to toxic levels. Therefore, managing soil pH is essential for optimizing nutrient availability and promoting healthy plant growth.

Soil reaction and soil organic carbon

Our results indicated that the application of different inputs did not significantly alter the soil pH or electrical conductivity (EC). [18,19], also observed similar types of findings. However, a marginal increase in both pH and EC was observed in the organic and natural farming plots compared to the ICM practices and control plots. The slight increase in soil pH under organic and natural farming treatments may be attributed to the long-term moderating effects of organic inputs. These inputs can chelate exchangeable iron and aluminum ions through various organic compounds, thereby reducing their hydrolysis [20,21] and thus decreasing the release of H^+ ions. Another contributing factor could be the high rainfall intensity characteristic of the humid climate, which may leach soluble basic ions to the subsoil, leading to a reduction in surface soil pH. Similarly, electrical conductivity showed a marginal increase in organic farming plots compared to the control. The decomposition of large amounts of organic inputs may solubilize native minerals, resulting in higher concentrations of total soluble ions or electrolytes in the soil [22]. Soil organic carbon (SOC) is a key indicator of soil health and fertility, representing the carbon content in soil organic matter [23]. SOC is primarily derived from the decomposition of plant residues, manures, and other organic materials.

It plays a crucial role in improving soil structure, enhancing water retention, and promoting nutrient availability. Additionally, SOC supports a diverse microbial ecosystem that contributes to vital soil functions such as nutrient cycling and disease suppression. In the present study, organic farming plots exhibited the highest SOC in soil, followed by ICM-2 plots. Application of organic inputs such as vermicompost, farmyard manure, and other organic resources (e.g., *jeevamrit, ghanjeevamrit, beejamrit*) significantly increase SOC levels compared to conventional inorganic practices [24,25,26]. Furthermore, the slower decomposition rate of organic matter (due to reduced and consistent mineralization) and the increased presence of both above and below-ground organic residues from enhanced crop growth are likely contributing factors to the higher SOC build-up observed in the organically managed plots [27].

Available nutrients

Available nitrogen was higher in both organic farming and ICM-2 plots, followed by natural farming and ICM-1 plots. In the present study, plots receiving organic inputs had higher soil organic matter (SOM) compared to control plots. This could be attributed to the faster mineralization of organic nitrogen, facilitated by increased microbial activity under organic management [28]. In the present study, the correlation between soil organic carbon (SOC) and available nitrogen (figure 4) is notably strong, suggesting that the higher levels of SOC in organic farming plots contribute to increased available nitrogen. The higher available nitrogen in the ICM plots may be due to the application of inorganic nutrients, which are more readily mineralized and thus become quickly available to plants. In contrast to available nitrogen, higher available phosphorus (P) was recorded in the integrated crop management (ICM) plots. The direct application of inorganic phosphorus sources, such as di-ammonium phosphate (DAP), in combination with manures, not only makes inorganic phosphorus more readily available to plants but also reduces its fixation by forming chelates with other compounds, particularly iron (Fe) and aluminum (Al) oxides [29,25]. Additionally, humate or fulvate ions released during manure decomposition can facilitate the release of fixed phosphorus into the soil solution through anion exchange reactions [30], making it more accessible to plants. These ions may also form phospho-humic complexes, which are easily assimilated by plants. However, short-term increases in soil pH due to organic matter addition can reduce the availability of metal cations like Fe^{2+} and Al^{3+} by altering their solubility, thus reducing phosphorus sorption. In contrast, lower available phosphorus in the natural farming plots may be attributed to the fact that organic matter application can sometimes decrease P availability by increasing the specific surface area of Fe and Al oxides, which, through reduced crystallinity, can fix more phosphorus on their surfaces. Furthermore, lower P content in natural farming inputs compared to ICM practices caused lesser available P in these plots. Higher potassium (K) availability was observed in the organic farming plots compared to other treatments. This finding aligns with the study of [31], who also reported higher K availability in organic farming soils compared to natural farming. The increased K availability in organic farming can be attributed to the higher production of carbon dioxide (CO_2) and organic acids during the decomposition of soil organic matter (SOM), which may have enhanced the release of K from native mineral sources.

Similar to available nitrogen, the present study observed a weak but positive correlation between soil organic carbon (SOC) and available potassium (figure 4), suggesting that organic farming plots have higher availability of potassium. In contrast, the relatively small quantities of supplements used in natural farming may result in lower available potassium levels [32].

The higher levels of DTPA-extractable Zn, Cu, and Mn in the natural and organic farming plots can be attributed to the increased application of farmyard manure and other organic inputs, such as *jeevamrit* and *ghanjeevamrit*, which enhance soil microbial activity and, in turn, improve the availability of these micronutrients. The elevated DTPA-Mn and Cu in the natural farming plots may be linked to the high concentrations of Cu and Mn in natural farming inputs like *beejamrit* and *jeevamrit* [33]. In contrast, DTPA-extractable Fe content was found to be higher in organic farming, ICM-1, and ICM-2 plots compared to the control and natural farming plots. This increase could be due to the release of native Fe from iron-bearing minerals following the application of various organic inputs, which may be more effective than natural farming inputs in mobilizing Fe.

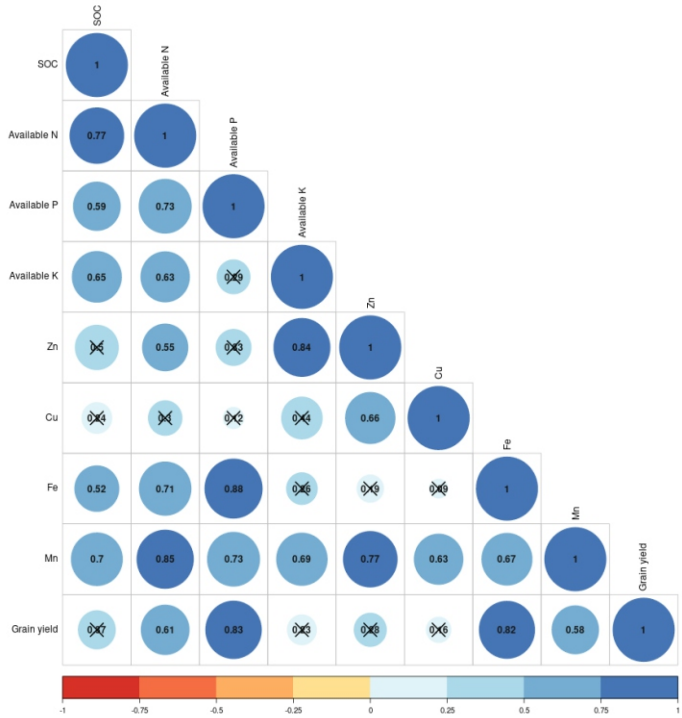

Figure 4. Correlation matrix of different soil properties in 0-15 cm depth of soil

The scale below with colour from deep red to deep blue represents correlation coefficient scale. Higher values towards blue colour means parameters are positively correlated and low or negative values towards red colour means parameters are less or negatively correlated. Significance is provided at 0.05 level.

Yield of crop

Integrated crop management scenario-1 (ICM-1) plots recorded the highest rice grain yield (), which was 37.0%, 16.8%, 11.8%, and 6.5% higher over control, natural farming, organic farming and ICM-2 plots, respectively. The higher availability of nutrients in the ICM-1 plots, particularly available phosphorus and DTPA-extractable iron, which are strongly correlated with grain yield (figure 4), contributed to the higher grain yield observed in these plots compared to the others. In addition, the highest straw yield and harvest index were recorded under the ICM-1 treatment.

This indicated that rice crops under ICM-1 are more efficient in partitioning photosynthates [34] that may have allocated higher biomass to reproductive parts of plants.

Conclusion

Crop and soil management practices significantly influence soil properties, nutrient availability, and rice productivity. While soil pH and electrical conductivity showed no significant differences across treatments, organic farming and ICM-2 had the highest soil organic carbon (SOC) content. Integrated and organic practices also increased nitrogen, phosphorus, and potassium availability, with ICM-2 and organic farming leading in nitrogen levels. Organic farming had the highest DTPA-extractable Zn, Fe, and Mn, while natural farming showed superior Zn, Cu and Mn content. In terms of rice yield, ICM-1 outperformed all other treatments, recording the highest grain yield, straw yield, and harvest index, followed by organic farming. The results indicate that integrated crop management, combining organic and inorganic inputs, is most effective for improving rice yield, while organic practices contribute positively to soil organic carbon and nutrient content, thereby improving soil health. Overall, integrated approaches offer the best outcomes for sustainable rice cultivation.

Future scope

Long-term studies are needed to assess the sustainability and environmental impact of natural farming prcatices, including their role in carbon sequestration and mitigation of greenhouse gas emissions. Additionally, exploring the adaptability of integrated and organic practices across diverse agro-climatic regions, rice varieties and different crops could provide valuable insights for broader implementation.

Conflict of interest

There is no conlict of interest while undertaking research.

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