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IMPROVING SOIL HEALTH THROUGH ORGANIC AGRICULTURE: EFFECTS ON PHYSICOCHEMICAL AND BIOLOGICAL PROPERTIES

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Abstract
Soil health is fundamental to sustainable agriculture and global food security. Organic farming practices are increasingly recognized for their ability to improve soil quality and crop productivity. This study assessed the impact of organic amendments—farmyard manure (FYM) and vermicompost (VC)—compared to conventional inputs, urea (U) and diammonium phosphate (DAP), on soil health indicators and wheat growth.The results showed significant ($P < 0.05$) enhancements in both soil physicochemical and biological properties under organic treatments relative to conventional fertilization. Organic amendments markedly increased soil organic matter (6.33-fold with VC and 5.70-fold with FYM), porosity (2.60-fold and 1.78-fold), and moisture content (1.93-fold and 1.81-fold). Conversely, bulk density and pH decreased by 1.19-fold and 1.12-fold under VC and FYM, respectively. Biological indicators, including microbial biomass carbon (MBC), nitrogen (MBN), and phosphorus (MBP), were also significantly elevated, showing 2.18-, 3.64-, and 4.10-fold increases with VC and 2.01-, 2.93-, and 3.08-fold with FYM. Additionally, populations of bacteria, fungi, and actinomycetes increased substantially under organic amendments.Correlation analyses highlighted strong interconnections between physicochemical and biological properties, emphasizing their collective role in sustaining soil health. Overall, organic amendments significantly enhanced soil fertility, microbial diversity, and biological activity compared to conventional fertilizers, reinforcing the critical role of organic agriculture in maintaining long-term soil productivity and ecological balance.

INTRODUCTION
Soil is a vital natural resource that supports agriculture, ecological balance, and environmental conservation (Hassan *et al.* 2022a). The essential properties of soils include their ability to support plant development, water, nutrients, and species, thus is central to sustainable agricultural system (Hore and Shoma 2024). But the latest techniques of integrated agricultural production involving intensive use of chemical inputs has made the situation worse with regard to soil, organic matter, and biological status (Hassan *et al.* 2022b). This disturbing practice requires the examination of other forms of agriculture; like organic agriculture to remedy and rebuild suitable soil quality (Krif *et al.* 2020). Organic agriculture founded on the principles of using organic material, biological activities and farm ecosystem to support production (Hassan and David 2018). Organic farming uses organic substance such as farm yard manure, vermiculture compost, green manure and crop residues (Kwiatkowski *et al.* 2020). These inputs do not only deliver essential nutrient to the crops, but

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also enhance the physic-chemical and biological property of the soil (Hassan *et al.* 2017). Modern technology has developed organic farming as a method of combating the adverse impacts of the traditional type of farming (Aulakh *et al.* 2022). These adverse impacts can be alleviated by enhancing soil biological resources, the proportion of organic materials in the soil, and by reducing pollution (Aulakh *et al.* 2022).

Most studies showed that soil health and its fertility depending on physicochemical indicators including bulb density (BD), porosity, organic matter (OM), moisture content and pH (Basak *et al.* 2020). It has been observed that FYM and VC has significantly enhanced the physical structure of the soil, water holding capacity (moisture), porosity and nutrients retention (Sharma, 2022). It has been examined that addition of FYM and VC significantly decreases the bulk density (BD) and pH, increases porosity, improves moisture and overall soil health index (Sivagamy *et al.* 2024). Organic agricultural practices use FYM and VC which served as source of food and energy for the microorganisms that are a major contributor in improving the OM, nutrient cycling and overall soil ecology (Sahu, 2023). Further, indices like microbial biomass carbon (MBC,), nitrogen (MBN) and phosphorus (MBP), and community variability i.e. bacteria, fungi and actinomycetes are important attributes of soil quality (Basak *et al.* 2020). Organic agricultural practices i.e. use of FYM and VC enhance microbial biomass and numbers through supply of organic substances (Gao *et al.* 2022). This improves the soil biological properties and overall soil ecology and health (Gao *et al.* 2022). Plant growth promoting microorganisms include bacteria, fungi, and actinomycetes are involved in nutrient mineralization, organic matter decomposition and biological control against diseases (Shah *et al.* 2021). The application of organic amendments such as VC and FYM not only increases the number of soil microorganisms, but also increases microbial biomass, and physico-chemical indexes (Sharma, 2022).

In contrast the traditional agricultural practices i.e. use of urea (U) and diammonium phosphate (DAP) has been linked to negative effects on soil physico-chemical and biological properties in the long-run (Fellet *et al.* 2022). Physico- chemical and biological properties, along with long-term soil health, are significantly enhanced by organic practices (Fellet *et al.*, 2022). In contrast, traditional practices, i.e. use of synthetic fertilizers (urea and DAP), often have transient positive effects and adverse long-term consequences (Kumar *et al.*, 2024). The effect of traditional agricultural practices (Urea and DAP) on the soil microbial biomass and community is negative, which kept aggravating with the time (Ramazanoglu *et al.* 2024). Traditional practices (Urae and DAP) always have detrimental impacts on the soil health and overall agro ecology (Teka *et al.* 2024). Arjjumend *et al.* (2021) concluded that effect of synthetic fertilizers is negative on the long-run. Omer *et al.* (2024) found that traditional practices i.e. use of synthetic chemicals and tillage have detrimental effects on the soil physical conditions and biological diversity. Despite growing evidence of the benefits of organic farming, further research is needed to quantify its effects on soil health indicators i.e. physical, chemical and biological properties. This study aims to fill this gap by analyzing firstly to assess the impact of organic practices on soil physico-chemical properties. Secondly to analyze its potential role in enhancing biological properties and microbial community and diversity of soil.

1. Material and Methods

1.1. Soil sampling

Samples (0-30 cm depth) were collected by using a hand auger. Filed-moist soil samples were sieved (<2 mm) and divided into two subsamples. One subsample was air-dried at room temperature and used for chemical analyses. Second subsample was stored at 4°C for the analysis of biological properties.

1.2. Experimental setup

Five treatments (Table 1) were performed in triplicate, following a randomized complete block design. Fifteen pots (8 ×12 cm) were filled with 5 kg of air-dried an
d sieved (2 mm) soil. Treatments i.e. VC (T1), FYM (T2), U (T3) and DAP (T4) were applied at the rate of 30 g kg^{-1} soil (Lhamu *et al.* 2024 and Ilker *et al.* 2016). After 60 days samples were collected from each pot for the analysis of physico-chemical properties i.e. OM, porosity, BD, moisture, pH and

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EC and biological properties i.e. MBC, MBN, and MBP and bacteria, fungi and actinomycetes respectively.

1.3. Physico-chemical properties of soil

Organic matter was determined by measuring convertible organic carbon contents (Hassan *et al.* 2014). Porosity was measured through soil bulk and particle density (Rehman *et al.* 2008). Moisture contents were assessed via gravimetrical method by weighing the soil before and after oven-drying (Hassan *et al.* 2014). The pH and EC were examined by using a soil-water ration of 1:5 with a calibrated and properly rinsed pH and EC meter (Hassan *et al.* 2014). Basic physico-chemical properties of experimental soil are given in Table 2.

1.4. Biological properties of soil

The method of fumigation-extraction was used to determine the microbial biomass carbon (MBC), nitrogen (MBN), and phosphorus (MBP) via pre-fumigated and un-

Table 1. Treatments of the experiment

Treatments	Level (g kg^{-1} soil)	Rate (g kg^{-1})
T1	VC	30
T2	FYM	30
T3	U	30
T4	DAP	30
T5	Control (CK)	0

fumigated soil samples (Hassan *et al.* 2014). Whereas, microbial population i.e. bacteria, fungi and actinomycetes were quantified through serial dilution and culturing on selective media plates, and incubating under pretermitted conditions (Hassan and David, 2018).

2. Statistical analysis

The ANOVA test was used to analyze the collected data, while LSD test was employed to estimate the differences among treatments.

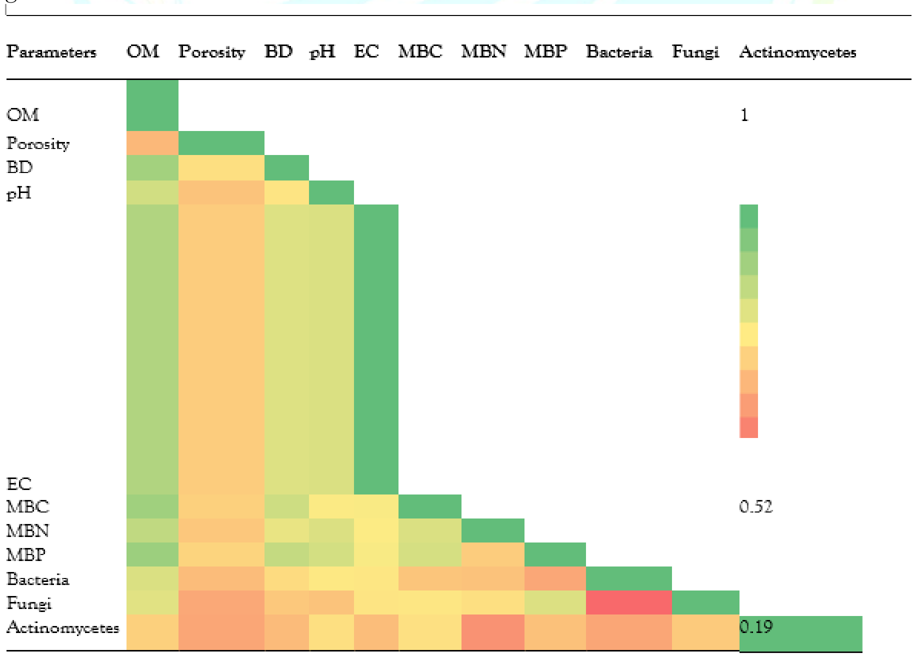

Figure 3. Pearson correlation heat map between the parameters

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3. Results

3.1. Effect of organic versus traditional agricultural practices on the physico-chemical properties of soil

The effect of organic versus traditional agricultural practices on the physico-chemical properties of soil is given in Table1. The organic inputs i.e. VC and FYM significantly ($P < 0.05$) increased all the measured soil physico-chemical properties compared to traditional practices and control. The increase in the OM via VC and FYM was 6.33-fold and 5.70-fold higher compared to control. Conversely, the increase in the OM via traditional practices, i.e. DAP and urea was 1.78- fold and 1.60-fold higher compared to control. Similarly, increase in porosity through organic practices i.e. VC and FYM was 2.60-fold and 1.78-fold compared to control. Whereas the increase in the traditional practices i.e. DAP and urea was 1.28-fold and 1.16-fold compared to control. On the contrary, in organic practices i.e. VC and FYM a decrease in the BD was observed i.e. 1.19-fold and 1.14-fold. Whereas increase in the BD owing to traditional practices i.e. DAP and urea was observed that was 1.11-fold and 1.07-fold higher compared to organic practices i.e. VC and FYM. Organic practices i.e. VC and FYM also significantly enhanced i.e. 1.93-fold 1.81-fold the moisture in the soil compared to control. Whereas traditional practices, i.e., DAP and urea also increased the soil moisture 1.34-fold and 1.19-fold, but this increase was significantly lower compared to organic practices. On the other hand, traditional practices increased the soil pH i.e. 1.12-fold and 1.08-fold compared to control. Whereas organic practices decreased the soil pH i.e. 1.19-fold and 1.12-fold compared to control.

3.2. Effect of organic versus traditional agricultural practices on the biological properties of soil

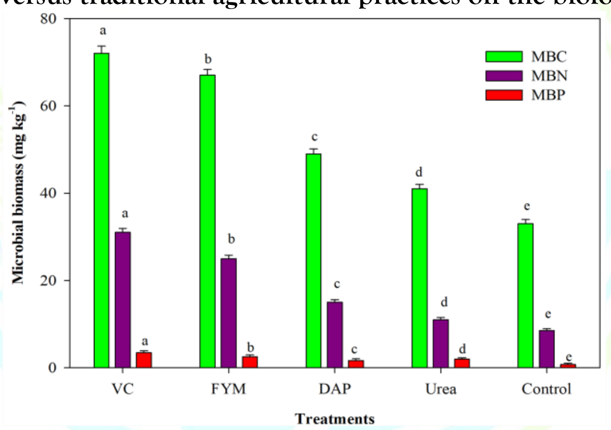

Figure 1. Effect of organic and traditional agricultural practices on the microbial biomass MBC, microbial biomass carbon, MBN, microbial biomass nitrogen, MBP, microbial biomass phosphorus, VC, vermicompost, FYM, farmyard manure; DAP, diammonium phosphate.

The effect of organic versus traditional agricultural practices on the biological properties of soil is given in Table 2. The organic inputs i.e. VC and FYM significantly ($P < 0.05$) increased all the measured biological soil properties compared to traditional practices and control. The increase in the MBC, MBN and MBP via VC i.e. 2.18-fold, 3.64-fold and 4.1-fold FYM i.e. 2.01-fold, 2.93-fold and 3.08-fold higher compared to control. Conversely, the increase in the MBC, MBN and MBP via traditional practices i.e. DAP and urea was 1.48-fold, 1.76-fold and 2.03-fold and 1.24-fold, 1.29-fold and 1.42-fold higher compared to control. Similarly, increase in microbial population i.e. bacteria, fungi and actinomycetes through organic practices i.e. VC and FYM was 3.45-fold, 6.36-fold and 4.0-fold and 3.45-fold, 6.36-

fold and 4.0-fold respectively compared to control. Whereas the increase in the traditional practices, i.e., DAP and uurea,was 1.91-fold, 1.36-fold and 2.0-fold and 1.36-fold, 1.81-fold and 1.33-fold correspondingly compared to control.

3.3. Correlation analysis

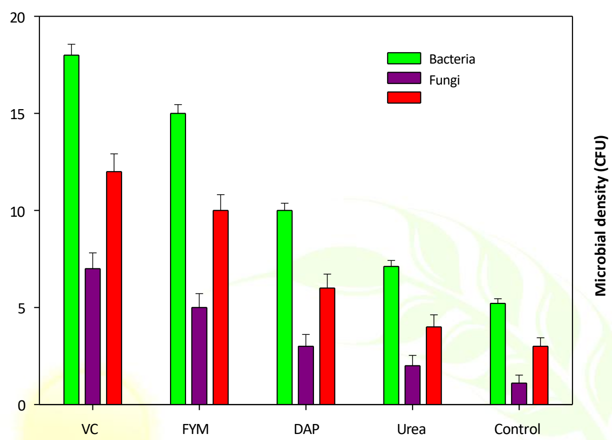

Figure 2. Effect of organic and traditional agricultural practices on the microbial density CFU, colony forming unit; VC, vermicompost; FYM, farm yard manure; DAP,

Table 2. Basic physico-chemical properties of experimental soil

Properties	Reading
Clay (g kg^{-1})	100.6
Silt (g kg^{-1})	176.3
Sand (g kg^{-1})	723.1
Textural class	Sandy loam
pH (1:2.5)	7.98
EC (µS cm^{-1})	11.5
CEC (C mol_C Kg^{-1})	6.49
OM (%)	0.51
Available N (mg kg^{-1})	5.21
Available P (mg kg^{-1})	3.61
Available K (mg kg^{-1})	97.4
Total P (g kg^{-1})	0.21
Total N (g kg^{-1})	0.32

biological properties of the soil is given in Fig. 3. It shows that both physico-chemical and biological indices are closely interlinked with each other. been observed that among physico-chemical Correlationbetween the physico and properties OM (0.847), pH (0.705) and EC (0.787) showed highly significant correlation with other physiochemical indices and also with biological indices.

Whereas, among biological indices MBC (0.833), MBN (0.751), MBP (0.847) and bacteria (0.681) and fungi (0.658) showed a highly significant correlation with other biological and physiochemical indices.

4. Discussion

The effect of traditional i.e. U and DAP and organic i.e. VC and FYM agricultural practices on soil physico-chemical properties i.e. OM, porosity, BD, moisture, pH and EC are given in. The use of organic agricultural practices i.e. VC and FYM significantly ($P < 0.05$) improved all the measured properties compared to traditional agricultural practices and control. The maximum increase in OM, porosity, moisture, pH and EC and maximum decrease in BD was observed at VC and then in FYM. Conversely the effect of traditional or non-agricultural practices i.e. U and DAP was significantly ($P < 0.05$) low compared to agricultural practices and control. Overall effect of treatments was in order VC < FYM < DAP < U < CK. Basak *et al.* (2020) found that organic inputs significantly improved soil physicochemical properties, including moisture, porosity, OM, and EC, enhancing overall soil health. Kindle *et al.* (2024) emphasized OM, porosity, BD, moisture, pH, and EC as key soil health indicators, highlighting the potential of organic practices to improve them. Sharma (2022) reported that VC and FYM notably enhanced OM, porosity, moisture, nutrient availability, and retention compared to traditional practices. Sivagamy *et al.* (2024) reported that VC and FYM significantly increased porosity, moisture, EC, and root penetration, while reducing BD, pH, and overall soil health index. Sahu (2023) found that

properties i.e. MBC, MBN and MBP and bacteria, fungi and actinomycetes are given in table Fig. 1-2. The use of organic agricultural practices i.e. VC and FYM significantly ($P < 0.05$) improved all the measured biological properties compared to traditional agricultural practices and control. The maximum increase in MBC, MBN and MBP and bacteria, fungi and actinomycetes was observed at VC and then in FYM. Conversely the effect of traditional or non- agricultural practices i.e. U and DAP was significantly ($P < 0.05$) low compared to agricultural practices and control. Overall effect of treatments was in order VC < FYM < DAP < U < CK. Basak *et al.* (2020) highlighted microbial biomass (MBC, MBN, MBP) and community diversity (bacteria, fungi, and actinomycetes) as key soil quality indicators, with organic practices positively influencing them. Gao *et al.* (2022) found that FYM and VC significantly increased microbial biomass and improved soil biology and ecology. Shah *et al.* (2021) emphasized that plant growth-promoting microorganisms aid in nutrient mineralization, organic matter decomposition, and disease control. Sharma (2022) reported that VC and FYM enhance microbial populations, biomass, and soil fertility, boosting crop yield. In contrast, Fellet *et al.* (2022), Ramazanoglu *et al.* (2024), and Teka *et al.* (2024) found that synthetic fertilizers (Urea and DAP) negatively impact microbial biomass, community structure, and enzyme activity, with effects worsening over time, ultimately harming soil ecology and agro-ecosystems. It has been examined that synthetic fertilizers have momentary positive effects but in the long-run highly negative impacts on the

Table 3. Effect of organic and traditional agricultural practices on the physico-chemical properties of soil

Treatment	OM (%)	Porosity (%)	BD (g/cm^{-3})	Moisture (%)	pH (1:1.5)	EC (1:1.5
VC	3.23±0.23a	66±1.41a	0.92±0.05e	62±1.87a	7.23±0.86d	10.2±0.56a
FYM	2.91±0.19b	57±1.21b	0.97±0.04d	58±1.56b	7.58±0.72c	8.61±0.45b
DAP	0.91±0.12c	41±1.11c	1.04±0.03bc	43±1.11c	7.87±0.52bc	6.01±0.31c
Urea	0.82±0.11d	37±1.01d	1.08±0.02ab	38±1.01d	7.94±0.41ab	4.04±0.26d
Control	0.51±0.09e	32±0.91e	1.10±0.01a	32±0.93e	7.98±0.32a	3.34±0.21e

organic practices improve soil properties and health by providing nutrients and energy for microorganisms, enhancing OM, carbon, and nutrient cycling. In contrast, Fellet *et al.* (2022) and Kumar *et al.* (2024) observed that synthetic fertilizers (Urea and DAP) negatively impact soil physico-chemical properties, with mostly transitory or harmful long-term effects.

The effect of traditional i.e. U and DAP and organic i.e. VC and FYM agricultural practices on soil biological overall soil health (Arjjumend *et al.* 202; Omer *et al.* 2024).

It has been observed that among the physico-chemical properties, organic matter (OM) (0.847), pH (0.705), and electrical conductivity (EC) (0.787) exhibit highly significant correlations with other physico-chemical indices as well as biological indices. Basak *et al.* (2020), in a study, demonstrated that soil health and fertility depend on physico- chemical indicators such as porosity, OM, EC, and pH, which are closely interrelated. Among the biological indices, microbial biomass carbon (MBC) (0.833), microbial biomass nitrogen (MBN) (0.751), microbial biomass phosphorus (MBP) (0.847), bacteria (0.681), and fungi (0.658) showed highly significant correlations with other biological and physico-chemical indices. Indices such as MBC, MBN, and MBP, along with community variability (e.g., bacteria, fungi, and actinomycetes), are critical attributes of soil quality and are interrelated with each other as well as with other indices (Basak *et al.*, 2020). Similarly, in an experiment, Shah *et al.* (2021) identified a significant ($P < 0.05$) correlation among physico-chemical and biological indices and further concluded that all these indices play a vital role in maintaining the soil health index.

5. Conclusion

In conclusion, organic agriculture practices demonstrate significant potential to enhance soil physico-chemical and biological properties. Thereby improving long-term soil health and food security, unlike traditional inorganic practices that offer only temporary benefits. Given the strong interconnections between soil properties (e.g., OM, pH and EC) and biological indices (e.g., MBC, MBN, MBP, bacteria and fungi), transitioning to organic farming is essential for maintaining a healthy and sustainable soil ecosystem, offering valuable insights for farmers, researchers, and policymakers.

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Conflict of Interest
The authors declare no conflict of interest.

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