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Synergistic Effects of Combined Organic and Inorganic Nitrogen on Wheat Nutrient Uptake and Soil Fertility in Inceptisol of Eastern Uttar Pradesh, India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

A pot experiment was conducted during the year 2020 at the Institute of Agricultural Sciences, BHU, Varanasi, to study the impact of organic and inorganic sources of nitrogen on nutrient content in wheat and soil physic-chemical properties of the Inceptisols of eastern Uttar Pradesh. The experiment was arrangedin completely randomized design with 10 treatment combinations having three replications. The experiment results indicated that use of 50% of the recommended nitrogen dose through urea along with 50% N through poultry manure in integration significantly enhanced the nitrogen, phosphorus and potassiumcontent in grain and straw compared to the control. The T_5 treatment, in which combined use of 50% RDN and 50% poultry manure recorded highest micronutrient concentrations (*i.e.* Zn: 14.3 and 21.41 mg kg^{-1}, Cu: 37.83 and 20.66 mg kg^{-1}, Mn: 20.03 and 3.65 mg kg^{-1}, and Fe: 231.73 and 54.31 mg kg^{-1}) in both straw and grain, respectively as compared to control (T_1). The use of organic source with fertilizers also increased the post-harvest soil fertility as available N, P, and K, along with DTPA-extractable micronutrients. Overall, the treatment incorporating poultry manure @ 50% RDN and 50% PM (5.26 t ha^{-1}) provided best results among all treatments in term of nutrient content of wheat and soil fertility.

Keywords: Sustainability; poultry manure; sewage sludge; farmyard manure; vermicompost.

1. INTRODUCTION

Wheat is a crop sensitive to temperature and photoperiod, requiring long days for optimal growth. It thrives across various conditions, experiencing significant seasonal fluctuations in temperature and precipitation during its growing period (Pandey, 2023). In India, wheat production reached over 107 million metric tonnes from 31.6 million hectares in 2021, contributing around 37% to the total food grain production. Wheat is a cornerstone of the country's economy and food security, (Singh and Beillard, 2021). itsproductivity increased dramatically after the Green Revolution as a result of the widespread use of plant protection measures and the expansion of irrigated regions.

The use of imbalanced amount of chemical fertilisers negatively affected soil, human health, and overall production metrics. The mineral fertilizers are essential for plant growth; their prolonged use poses risks to both the environment and human health, including surface and groundwater pollution (Poudel and Singh, 2023). Effective nitrogen (N) management is crucial for enhancing fertilizer efficiency, boosting crop yields, and mitigating global nitrogen-related challenges. Wheat, covering about 20% of the world’s arable land (237 million hectares), benefited significantly from the Green Revolution, particularly through fertilizer use, leading to increased yields from the 1960s to 2013, despite stable acreage (Feyisa et al., 2024). However, regional impacts varied. Nitrogen is vital for crop development, improving both yield and quality, and large amounts are applied globally to meet agricultural demands. In non-fertilized settings, nitrogen remains the primary factor limiting crop yields (Feyisa et al., 2024). However, despite the positive effect of N fertilizers on crops, there is an indirect negative effect on soil health in the absence of the proper use of N.Even with the extensive application of mineral nitrogen fertilizer, a considerable portion is lost or rendered inaccessible to plants within modern farming practices. Additionally, it exacerbates the degradation of soil physico-chemical and biological characteristics, as noted by (Iqbal et al., 2019). Moreover, the overreliance on chemical fertilizers induces soil acidification and diminishes soil microbial biomass, ultimately impairing soil fertility, as highlighted in studies by (Cai et al., 2018). Moreover, prolonged use of chemical fertilizers can compromise the soil's capacity to sustain healthy crop growth and productivity over time, as emphasized by (Singh, 2018). Therefore, the persistent dependence on chemical fertilizers for crop cultivation is unsustainable. Currently, there is extensive research on utilizing organic manures, biochar, and crop residues either alone or in combination to enhance soil fertility, nutrient provision, and overall soil quality, thereby promoting long-term crop growth and health (Dhaliwal et al., 2019). In South Asia's wheat-based systems, FYM is the most widely used organic manure, often applied to summer rice or maize, with a residual benefit for winter wheat. However, poultry manure (PM) mineralizes nitrogen faster than FYM due to its high uric acid and urea content, which readily release NH4-N. In a lab trial, PM showed a 45% mineralization rate in 4 weeks, compared to FYM's 12%. PM-N was as effective as urea-N in increasing rice yield and N uptake, with residual effects in wheat equivalent to 40 kg N/ha. Additionally, PM improved soil health and the resilience of wheat-soybean systems (Tehulie, 2020). Use of different manures in rice–wheat systems have been evidenced to increase the crop yield and DTPA-extractable micronutrient concentrations in soil in north-western India(Dhaliwal et al., 2019). Organic manure provides essential macro and micronutrients, boosts microbial activity, and improves soil properties. Its slow nitrogen release enhances nitrogen efficiency, rice yield, and quality, while also increasing soil organic carbon and sustaining nutrient availability. This study explored combining organic and inorganic fertilizers to improve soil quality, root growth, nitrogen uptake, and yield, aiming to find the most efficient and cost-effective mix for optimal nutrient content and soil fertility.

2. MATERIALS AND METHODS

2.1 Experimental Site

A pot experiment on wheat was carried out during 2020-2021 in the Net House of the department of Soil Science and Agricultural Chemistry, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi.Varanasi is situated at an altitude of 80.71 meters above mean sea level and located between 25°18' North latitude and 80°36' East longitudes. Varanasi experiences a humid subtropical climate with a mean average rainfall of about 1100 mm and potential evapotranspiration of about 1525 mm. The maximum and minimum temperature varied from 17.5ºC to 34.5ºC and 7.5ºC to 20.7ºC during wheat cultivation (December to March). The maximum and minimum relative humidity varied between 64-96% and 34-71%, respectively.

2.2 Experimental Setup

The experiment was conducted in alluvial soils of the Indo-Gangetic plains, characterized by sandy clay loam texture, slightly alkaline pH (7.3), low organic carbon (0.29%), and low available nitrogen (208.4 kg ha-1), phosphorus (24.8 kg ha-1), and potassium (148.6 kg ha^{-1}). The soil had DTPA-extractable concentrations of Zn, Cu, Fe, and Mn of 0.41, 1.27, 3.78, and 4.01, respectively. The treatment details are mentioned in Table 1. Ten treatments with three replications were tested using wheat (HD-2967) as the crop. The soil was collected from BHU Agro Farm, air-dried, sieved, and filled in pots. Treatments included four organic sources (FYM, PM, VC, SS) and nitrogen applied as 50% RDF & 50% organic N, 100% organic N, or 100% RDF. The recommended doses of N (118.56 mg), P_2O_5 (170.43 mg), and K_2O (45.45 mg) per kg soil were applied via Urea, SSP, and MOP, respectively (Table 1). Organic fertilizers were applied one week before sowing, and full inorganic fertilizers were applied before sowing. Wheat seeds were sown in each pot, leaving five plants for the experiment, with pots maintained at field capacity.

2.3 Soil and Plant Analyses

For laboratory analysis, all the three replicates of soil and plant sampleswere taken, and the mean of the three is given as final value. From every pot, post-harvest soil (PHS) was collected and the sample was processed by passing it through 2-mm and subsequently with 0.5-mm sieves and kept for chemical analysis. The moisture content was determined immediately by the gravimetric method. The soil samples were analyzed for pH by following the procedure as outlined in (Sparks et al., 1996), and the same solution/sample was used for measurement of electrical conductivity (EC). Potassium dichromate (1N $K_2Cr_2O_7$) oxidizable organic carbon was determined by the method of (Walkley and Black 1934), available N by alkaline potassium permanganate ($KMnO_4$) method (Subbiah and Asij,1956), available P by extracting the soil with sodium bicarbonate ($NaHCO_3$), and available K using neutral normal ammonium acetate extraction method (Jackson,1973). The micronutrient content in PHS was determined by DTPA extraction in 1:2 soil: extractant ratio (Lindsay et al., 1978) and analyzed by atomic absorption spectrophotometer (AAS), model Agilent 240FS-AA (Agilent Technologies, Santa Clara, USA). Dry plant tissue was finely grounded in a soil-processing lab and stored in zipped polythene bags. The nitrogen concentration was determined by digestion (H_2SO_4), distillation and titrimetric method, using a standard Kjeldahl autoanalyzer (Distyl-EM; Pelican) procedure. Total Phosphorus and potassium in plant were estimated by HNO_3: $HClO_4$(3:1) di-acid mixture as per the procedure of (Jackson, 1973). Finely grounded seed and straw samples were digested with di-acid mixture (HNO_3:$HClO_4$: 3:1, v/v) and analyzed for Zn, Cu, Fe, Mn, and Ni using AAS (Tandon, 1995).

Table 1. Treatment details of the experiment

Treatments	Treatment details
T_1	Control
T_2	100% RDF
T_3	50%RDN + 50% FYM (14 t ha^{-1})
T_4	50%RDN + 50% VC(5 t ha^{-1})
T_5	50%RDN + 50%PM(5.26 t ha^{-1})
T_6	50%RDN + 50% SS (7.5 t ha^{-1})
T_7	100% FYM (28 t ha^{-1})
T_8	100% VC(10 t ha^{-1})
T_9	100% PM(10.53 t ha^{-1})
T_{10}	100% SS (15 t ha^{-1})

RDF, Recommended Dose of Fertilizer; RDN*, Recommended Dose of Nitrogen through Urea; Recommended dose of fertilizer (RDF) for wheat crop, i.e., N, P_2O_5, and K_2O:120, 60 and 60 kg ha^{-1}, respectively; FYM (Farmyard Manure), VC (Vermicompost), PM (Poultry Manure) and SS (Sewage Sludge)*

2.4 Statistical Analysis

The research data were analyzed using statistical software SPSS 16.0 for ANOVA (complete randomized design). Duncan multiple range test (DMRT) at p≤0.05 levels of significance was used to evaluate the significant differences among mean values (Gomez and Gomez, 1984).

3. RESULTS AND DISCUSSION

3.1 Macronutrient and Micronutrient Content

The perusal data in Table 2 revealed that there was significant difference in N concentration in straw and grain yield of wheat crop in relation to applied treatments. Straw has a nitrogen content ranging from 0.65 to 1.01%. The highest nitrogen concentration was found in T5, followed by T6, T4, T3, and T2 at 0.97, 0.92, and 0.91% respectively. This meant that the concentrations of nitrogen were significantly higher than the control at 55.38, 49.23, 41.53, 40, and 35%. Grain had nitrogen contents ranging from 1.16 to 2.46%. T5 showed the highest N content in grain yield, while T1, the control, showed the lowest. T5 was at par differ with T6 having nitrogen 2.32%followed by T4, T3 and T2. These values represent a considerable increase of 182.81, 112, 100, 87.06 and 61.2% over control. The concentration of phosphorus in straw varied, with T5 (RDN50%PM50%) having the highest concentration and T1 control having the lowest value, ranging from 0.15 to 0.08. Following T2, which produced a statistically significant rise of 87.5, 50, and 37.5% over control, T5 and T6 differed statistically at par. The range of phosphorus levels in grain was 0.22 to 0.39, with T5 (RDN50%PM50%) exhibiting the highest concentration and T1 (control) exhibiting the lowest. This led to a significant increase above control of 77.27%. The data pertaining to Potassium concentration in wheat straw and grain have been presented in Table 2. Straw has a considerably wide range of potassium concentrations, from 1.16 to 1.65%. The lowest concentration was found in T1 (control), which differs considerably from T5, and the largest concentration was found in T5. T5 is statistically not comparable to T6, which is considerably higher than control by 42.24 and 29.31%, respectively. The highest concentration was found in grain at 0.62 and the lowest in 0.27. The same pattern was found in straw at T5 (RDN50%PM50%) and the lowest in T1 (control). T5 and T6 differed statistically, leading to a significant increase of 129.6 and 92.59% over control. The nutrient content in wheat was lower with sole inorganic fertilizers, but combining organic and inorganic fertilizers increased nutrient levels (Table 2). This supports the idea that organic fertilizers enrich soil and boost crop yields, as they provide key nutrients like N, P, and K, improving soil fertility and nutrient content in grains (Islam et al., 2018). The continuous use of organic fertilizer along with inorganic fertilizer increased the nutrient content and nutrient use efficiency of major nutrients than did the inorganic fertilizers alone (Islam et al., 2018). Nutrient uptake is crucial for fertilizer management, enhancing yield, nutrient-use efficiency, and reducing groundwater pollution. Organic fertilizers (FYM, SS, PM, VC) enriched with N, P, and K support microbial decomposition, providing these nutrients for wheat growth. Higher nitrogen uptake by wheat, as shown in Table 2, can enhance phosphorus and potassium content by promoting root and shoot growth. N increases P availability, while NO_3-N uptake can influence cation absorption, releasing OH- and HCO3- into the soil (Islam et al., 2018, Lawlor, 2004). This increases the pH in the rhizosphere and, hence, would promote P availability which, in turn, influences the P uptake by plants.

The data pertaining to the effect of organic and inorganic sources of Nitrogen on the quality of wheat crop on micronutrient (Zn, Fe, Mn and Cu) concentration in straw and grain of wheat has been presented in Tables 3 and 4. The Zn, Fe, Mn and Cu concentration in straw ranged from, 14.3 to 9.03, 231.73 to 124.5, 20.03 to 10.17 and 37.83 to 22.67 mg kg^{-1}. Similarly, in grain, the micronutrient concentration (Zn, Fe, Mn and Cu) varied from, 21.41 to 14.66, 54.31 to 30.72, 3.65 to 1.24 and 19.37 to 10.89 mg kg^{-1}. In straw and grain the Zn, Fe, Mn and Cu content were higher in T5 followed by T6, T4, T3 and T2. Micronutrient (Zn, Fe, Mn, and Cu) concentrations in straw and grain are highest in (14.3, 21.4), (231.73, 54.31), (20.03, 3.65) and (37.83, 20.66), with significant increases of 58.36 and 46.04%, 86.12 and 76.79%, 96.95 and 194.35%, and 66.87 and 77.86% over control being observed. Inorganic fertilizers and organic manures likely increased micronutrient uptake in wheat by enhancing their bioavailability in the soil compared to the control (Saha et al., 2019). Decomposition of organic waste releases nutrients, improving soil nutrient availability. Organic manures lower soil pH, enhancing micronutrient bioavailability compared to inorganic fertilizers alone. Dhaliwal's study also found higher micronutrient uptake with combined organic and inorganic fertilizers (Dhaliwal et al., 2019). Synergistic application provides sufficient nutrition for chlorophyll biosynthesis. Micronutrient uptake is influenced by nutrient interactions and soil properties. Nitrogen (N) and zinc (Zn) have a positive relationship, with increased N promoting Zn uptake and translocation in wheat. Similarly, N fertilizers enhance manganese (Mn) availability and uptake. Combined organic and inorganic fertilizers also increase copper (Cu) and iron (Fe) uptake (Dhaliwal et al.,2023).

3.2 Available Nutrient in Post-Harvest Soil

The data regarding physicochemical properties of post-harvest soil, such as pH, EC, and OC, varied from 7.50 to 7.77, 0.054 to 0.098 ds m^{-1} 0.31% to (0.46%) respectively in Table 5. The maximum pH (7.77) was recorded in T5 and T6 which was at par withT9, T10, T3, T8 and T7. However, the minimum pH was observed in control (7.5). The maximum EC (0.1 dS m^{-1}) was in T5 which was 3.6% higher than control (0.05 dS m^{-1}). The maximum OC was observed in T9 (0.46 g kg^{-1}) followed by T7, T8 and T10 which was significantly higher by 48.38, 41.93, 38.70 and 22.58% over control. Data on available N content in post-harvest soil has been presented in Table 5. It ranged from 199.68 to 300.51 kg ha^{-1}. The maximum N content (300.51kg ha^{-1}) was obtained with T5 followed by 278kg $ha^{-1}$with T6, 268 kg ha^{-1} with T4, 260.64 kg ha^{-1} with T3and 258.16 kg ha^{-1} with T2 which resulted a significant increase of 50.58, 39.28, 34.53, 30.52 and % over control (199.68 kg ha^{-1}), respectively. The lowest N content was recorded in control (199.68 kg ha^{-1}). Data on available P content in post-harvest soil has been presented in Table 5. It ranged from 8.98 to 22.76 kg ha^{-1}. The maximum P content (22.76 kg ha^{-1}) was obtained with T5 followed by 15.49 kg $ha^{-1}$with T6, 13.98 kg ha^{-1} with T4,13.91 kg ha^{-1} with T3 and 13.31kg ha^{-1} with T2 which resulted a significant increase of 153.45, 72.49, 55.67, 54.89 and 48.21% over control (8.98 kg ha^{-1}), respectively. Data on available K content in post-harvest soil has been presented in Table 5. It ranged from 182.27 to 300.33 kg ha^{-1}. The maximum K content (300.33 kg ha^{-1}) was obtained with T5 followed by 266.87 kg $ha^{-1}$with T6, 233.93 kg ha^{-1} with T4, 220.27 kg ha $^{-1}$ with T3 and 220 kg ha^{-1} with T2 which resulted a significant increase of 64.77, 46.41, 28.34, 20.84 and 20.7% over control (182.27 kg ha^{-1}), respectively. The data pertaining to DTPA-extractable Fe, Mn, Cu and Zn content significant variation range from 8.48 to 5.05, 4.67 to 2.3, 2.02 to 0.89 and 1.13 to 0.56 mg kg^{-1}(Table 5). The maximum DTPA Fe content (8.48 mg kg^{-1}) was observed in T5 followed by T3 (6.63), T6 (6.52) and T4(6.46) which was significantly higher by 40.44, 31.28, 29.1 and 27.92% than control. The highest DTPA Mn content (4.67 mg kg^{-1}) was observed in T5 followed by T6(4.24), T3(3.99) and T4(3.92) which significantly increased by 103, 84.34, 73.47 and 70.43% than control. The maximum DTPA Cu content (2.02 mg kg^{-1}) was in T5 followed by T6(1.95), T3(1.73) and T4(1.58) which was significantly increased by 126.9, 119.1, 94.38 and 77.52% than control. The maximum DTPA Zn content (1.13 mg kg^{-1}) was in T5 followed by T6(0.93 mgkg^{-1}), T4 (0.87 mg kg^{-1}) and T3(0.79) with respective increase of 101.78, 66.07, 55.35 and 41.07% over control. Organic carbon content increased by 10% compared to control when PM

Table 2. Effect of organic and inorganic sources of nitrogen on nitrogen, phosphorus and potassium concentration (%) in the straw and grain of wheat

Treatments	Nitrogen concentration		Phosphorus concentration		Potassium concentration	
	Straw	Grain	Straw	Grain	Straw	Grain
T1	0.65 ± 0.02 e	1.16 ± 0.09 e	0.08 ± 0.02 e	0.22 ± 0.01 b	1.16 ± 0.01 e	0.27 ± 0.06 d
T2	0.88 ± 0.02 bc	1.87 ± 0.05 c	0.11 ± 0 bc	0.3 ± 0.01 ab	1.4 ± 0.01 c	0.44 ± 0.05 bc
T3	0.91 ± 0.02 abc	2.15 ± 0.03 b	0.11 ± 0 bc	0.3 ± 0.01 ab	1.44 ± 0.01 bc	0.47 ± 0.06 bc
T4	0.92 ± 0.01 abc	2.17 ± 0.05 b	0.11 ± 0 bc	0.3 ± 0.01 ab	1.45 ± 0.01 bc	0.47 ± 0.01 bc
T5	1.01 ± 0.05 a	2.46 ± 0.03 a	0.15 ± 0 a	0.39 ± 0.01 a	1.65 ± 0.02 a	0.62 ± 0.02 a
T6	0.97 ± 0.02 ab	2.32 ± 0.04 ab	0.12 ± 0 b	0.32 ± 0.06 ab	1.5 ± 0.01 b	0.52 ± 0.05 ab
T7	0.71 ± 0.03 de	1.5 ± 0.1 d	0.08 ± 0 e	0.22 ± 0.06 b	1.22 ± 0.01 de	0.34 ± 0.03 cd
T8	0.73 ± 0.08 de	1.63 ± 0.03 d	0.09 ± 0 de	0.24 ± 0.07 ab	1.26 ± 0.01 d	0.34 ± 0.02 cd
T9	0.83 ± 0.03 cd	1.86 ± 0.04 c	0.11 ± 0 bcd	0.28 ± 0.06 ab	1.28 ± 0.09 d	0.43 ± 0.01 bc
T10	0.81 ± 0.01 cd	1.84 ± 0.04 c	0.1 ± 0 cde	0.27 ± 0.02 ab	1.27 ± 0.02 d	0.35 ± 0.03 cd

(mean of 3 replications± standard error)

Table 3. Effect of organic and inorganic sources of nitrogen on micronutrient concentration (mg kg^{-1}) in the grain of wheat

Treatments	Fe	Zn	Mn	Cu
T1	30.72 ± 0.29 f	14.66 ± 0.91 d	1.24 ± 0.36 c	10.89 ± 1.15 c
T2	33.86 ± 0.03 e	19.83 ± 0.8 ab	2.1 ± 0.06 bc	14.54 ± 0.23 b
T3	197.27 ± 0.27 b	16.42 ± 0.14 cd	3.54 ± 0.29 a	19.76 ± 0.4 a
T4	42.01 ± 0.01 c	18.64 ± 1.12 bc	2.87 ± 0.44 ab	18.9 ± 0.58 a
T5	54.31 ± 0.43 a	21.41 ± 1.04 a	3.65 ± 0.46 a	20.66 ± 0.96 a
T6	46.99 ± 0.14 b	20.1 ± 0.04 ab	3.52 ± 0.03 a	19.37 ± 0.71 a
T7	39.48 ± 0.24 d	15.05 ± 1.19 d	2.71 ± 0.29 ab	11.5 ± 1.3 c
T8	34.01 ± 0.05 e	15.06 ± 0.03 d	1.94 ± 0.52 bc	14.54 ± 0.23 b
T9	39.8 ± 1.73 d	15.34 ± 1.35 d	2.79 ± 0.29 ab	16.06 ± 0.35 b
T10	35.14 ± 1.16 e	15.31 ± 0.06 d	2.16 ± 0.1 bc	15.23 ± 0.49 b

(mean of 3 replication± standard error)

Table 4. Effect of organic and inorganic sources of nitrogen on micronutrient concentration (mg kg^{-1}) in the straw of wheat

Treatments	Fe	Zn	Mn	Cu
T1	124.5 ± 2.91 f	9.03 ± 0.47 e	10.17 ± 0.07 f	22.67 ± 0.88 e
T2	138.8 ± 0.5 e	12.8 ± 0.31 b	10.47 ± 0.09 f	28.33 ± 0.38 d
T3	197.27 ± 0.27 b	10.28 ± 0.03 d	13.87 ± 0.09 c	36.43 ± 1.22 ab
T4	175.93 ± 0.97 c	11.89 ± 0.05 c	12.53 ± 0.09 d	35.1 ± 0.12 b
T5	231.73 ± 10.23 a	14.3 ± 0.15 a	20.03 ± 0.12 a	37.83 ± 0.19 a
T6	198.47 ± 0.15 b	12.97 ± 0.02 b	18.73 ± 0.77 b	35.93 ± 0.38 b
T7	164.77 ± 0.3 d	9.17 ± 0.03 e	11.6 ± 0.12 e	23.63 ± 0.34 e
T8	139.27 ± 0.27 e	9.22 ± 0.05 e	10.33 ± 0.03 f	28.33 ± 0.38 d
T9	165.77 ± 0.9 d	9.5 ± 0.03 e	12.47 ± 0.24 d	30.7 ± 0.31 c
T10	144.63 ± 1.69 e	9.41 ± 0.07 e	11.37 ± 0.09 e	29.4 ± 0.35 cd

(mean of 3 replication± standard error)

Table 5. Effects of organic and inorganic sources of nitrogen on pH, EC, nitrogen, phosphorus, potassium and DTPA extractable micronutrient content in the post-harvest soil

Treatments	pH	EC	Organic carbon	Nitrogen	Phosphorus	Potassium	Zinc	Copper	Mn	Fe
T1	7.5 ± 0.15 a	0.05 ± 0.01 b	0.31 ± 0 g	199.68 ± 0.95 g	8.98 ± 0.49 f	182.27 ± 0.58 h	0.56 ± 0.02 g	0.89 ± 0.04 e	2.3 ± 1.04 b	5.05 ± 0.6 c
T2	7.6 ± 0.06 a	0.09 ± 0 a	0.34 ± 0.01 f	258.16 ± 2.86 d	13.31 ± 0.31 cd	220.1 ± 0.59 d	0.64 ± 0.06 fg	1.58 ± 0.02 cd	3.76 ± 0.3 a	5.64 ± 0.73 bc
T3	7.67 ± 0.17 a	0.09 ± 0 a	0.35 ± 0 ef	260.64 ± 0.79 d	13.91 ± 0.18 c	220.27 ± 0.19 d	0.79 ± 0.02 cd	1.73 ± 0.05 bc	3.99 ± 0.51 a	6.63 ± 0.24 b
T4	7.63 ± 0.03 a	0.09 ± 0 a	0.36 ± 0 de	268.64 ± 0.63 c	13.98 ± 0.45 c	233.93 ± 0.71 c	0.87 ± 0.05 bc	1.58 ± 0.09 cd	3.92 ± 0.26 a	6.46 ± 0.11 b
T5	7.77 ± 0.03 a	0.1 ± 0 a	0.38 ± 0.01 c	300.51 ± 1.62 a	22.76 ± 0.51 a	300.33 ± 0.33 a	1.13 ± 0.01 a	2.02 ± 0.06 a	4.67 ± 0.11 a	8.48 ± 0.28 a
T6	7.77 ± 0.03 a	0.09 ± 0 a	0.37 ± 0.01 cd	278.12 ± 0.95 b	15.49 ± 0.32 b	266.87 ± 0.88 b	0.93 ± 0.05 b	1.95 ± 0.11 ab	4.24 ± 0.2 a	6.52 ± 0.14 b
T7	7.67 ± 0.17 a	0.08 ± 0.02 a	0.44 ± 0.01 ab	246.35 ± 0.66 f	10.35 ± 0.36 e	182.6 ± 0.95 h	0.73 ± 0.02 def	1.45 ± 0.06 d	3.9 ± 0.38 a	6.36 ± 0.18 bc
T8	7.67 ± 0.17 a	0.08 ± 0 a	0.43 ± 0.01 b	251.68 ± 0.24 e	10.97 ± 0.12 e	187.67 ± 0.64 g	0.74 ± 0.01 def	1.43 ± 0.14 d	3.71 ± 0.13 a	5.87 ± 0.55 bc
T9	7.7 ± 0 a	0.09 ± 0 a	0.46 ± 0.01 a	254.25 ± 0.5 e	12.61 ± 0.31 d	197.87 ± 0.37 e	0.67 ± 0.04 ef	1.49 ± 0.01 d	3.79 ± 0.25 a	6.14 ± 0 bc
T10	7.73 ± 0.03 a	0.08 ± 0 a	0.39 ± 0.01 c	253.59 ± 0.46 e	10.98 ± 0.42 e	194.13 ± 0.48 f	0.78 ± 0.02 de	1.49 ± 0.04 d	3.89 ± 0.61 a	6.05 ± 0.57 bc

(mean of 3 replications± standard error)

and VC were applied at 10 and 10.53 t ha^{-1}. In tropical and sub-tropical climates, high temperature and humidity accelerate microbial decomposition, resulting in only a small increase in soil carbon despite high organic matter application. Liu et al., found that animal manure builds soil carbon more effectively than straw, due to higher humified and recalcitrant carbon forms (Liu et al., 2016) . Manure is also more resistant to microbial decomposition, leading to higher carbon storage (Alam et al., 2019). Poultry manure, with its high calcium content, was most effective in raising soil pH to 6.25, making it slightly acidic, as confirmed by other studies (Rahman, 2013). Organic matter improves soil pH and buffering capacity, enhancing cation exchange capacity and base saturation, which in turn boosts nutrient availability by improving the soil's physicochemical and biological properties. The application of organic manures increases soil content of OC, N, P, K, Ca, Mg, and S, while integrated organic and inorganic fertilizers improve soil structure and nutrient availability, leading to higher crop yields (Islam, 2018). Integrated treatments raised soil levels of N, P, K, and S compared to sole inorganic fertilizers (Zaman et al., 2018). Organic manures also promote soil bacterial populations, further enhancing fertility. Although total phosphorus increases with higher organic fertilizer application, its availability depends on slow mineralization, with only 2-3% mineralized per year. Soil pH plays a key role in controlling phosphorus availability through mineralization and adsorption-desorption processes (Hinsinger, 2000). Our results showed that soil pH under different organic treatments increased significantly in a favourable range for nutrient availability in soil; it might have a significant positive impact on the nutrient availability. Our results were also supported by many other researchers (Mahmud et al., 2020, Mengistu et al., 20117) who reported higher organic carbon, N, P, K, Ca, Mg, and S contents in post-harvest soils due to integrated organic and inorganic fertilizer treatment. Organic matter, in addition to macro-nutrients, also contains micro-nutrients that can promote and maintain a sustainable nutrient supply to the soil. Previous research has highlighted the positive impact of organic manure on soil nitrogen (N) supply. The present study showed that the highest increase in available phosphorus (P) was observed under combined treatment with recommended dose of fertilizer (RDF), farmyard manure (FYM), and poultry manure (PM) (Zaman et al., 2018, Adekiya et al., 2019). This was expected, as cereal crops typically utilize only a fraction of applied P, and manure helps reduce P fixation in soil, enhancing its availability (Makoto and Koike, 2007). Organic molecules from manure compete with phosphate ions (PO_4^{3-}) for retention sites, further increasing P availability (Xie, 1991) For potassium (K), its leaching loss due to percolating water, especially in irrigated areas, is a significant concern (Tandon and Sekhon, 1988). The study found higher available K under combined manure and mineral treatments, which can be attributed to the release of organic acids during decomposition (Timsina et al., 2013). These acids generate negative charges in the soil, reducing the fixation of K and improving its availability. Additionally, PM increased the content of essential nutrients such as N, P, K, calcium (Ca), magnesium (Mg), zinc (Zn), iron (Fe), and copper (Cu) in maize, consistent with previous studies showing that PM enhances both soil nutrient status and crop nutrient uptake (Ayeni and Adetunji, 2010).

This study found that integrating poultry manure (PM), farmyard manure (FYM), vermicompost (VC), and sewage sludge (SS) with 50% recommended nitrogen (RDN) effectively enhanced the nutrient content and physicochemical properties of wheat. The RDN50PM50 treatment (5.26 t ha^{-1}) showed the best results for both plant and soil nutrient content. Organic manures like PM, rich in nitrogen (N) and moderate in phosphorus (P) and potassium (K), are compatible with 50% RDN from urea, improving yield while reducing the need for chemical fertilizers, thus supporting sustainable agriculture. Combining manures with inorganic fertilizers offers a more balanced nutrient supply, promoting nutritional security and sustained crop productivity. Further research is needed to explore the long-term effects of this integration on soil fertility, particularly in terms of soil physical and biochemical properties.

4. CONCLUSION

This study found that integrating poultry manure (PM), farmyard manure (FYM), vermicompost (VC), and sewage sludge (SS) with 50% recommended nitrogen (RDN) effectively improved nutrient content and physicochemical properties of wheat. The RDN50PM50 treatment (5.26 t ha^{-1}) showed the best results for both plant and soil nutrients. Organic manures like PM, rich in nitrogen (N) and moderate in phosphorus (P) and potassium (K), are well-suited for integration with chemical fertilizers, enhancing yield and reducing fertilizer usage for more sustainable agriculture. Combining manures with fertilizers provides a more balanced nutrient supply, improving crop productivity and nutritional security. However, the study focused primarily on nitrogen levels, and further research is needed to assess the interactive effects of manures and fertilizers on soil micronutrients and biochemical properties for long-term soil fertility.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

The author(s) confirm that no generative AI technologies, including Large Language Models (such as ChatGPT, Copilot, etc.) or text-to-image generators, were utilized in the writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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