



ORIGINAL RESEARCH

Impact of Long-Term Organic Manure Application on Yield, Zinc, and Copper Uptake in Maize, Peas, and Mungbean (*Vigna radiata* L.) Cropping System

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ABSTRACT: To evaluate the impact of the long-term application of organic manures on yield, uptake of zinc and copper in maize, peas and summer mungbean cropping systems, a field study was conducted at the integrated farming system of Punjab Agricultural University, Ludhiana. The treatment combinations were; T₁: 50% N through recommended NPK + 50% N was substituted through FYM, T₂: 100% N through FYM, T₃: T₂ + intercropping (marigold in pea, cowpea in maize), T₄: T₂ + agronomic practices for weed and pest control, T₅: 50% N as FYM + rock phosphate to substitute the P requirement of crops + phosphate solubilizing bacterial cultures (PSB), T₆: T₂ + biofertilizer (consortium) containing N and P carriers and T₇: 100% Recommended NPK through chemical fertilizers. Significant increases in the yield, micronutrient content and uptake were recorded due to the application of 50% nitrogen through farmyard manure (FYM) and 50% of the recommended dose of fertilizers (T₁) followed by 100% N through FYM + biofertilizer containing N and P carriers (T₆). The highest grain yield of maize (5.72 t ha⁻¹), pea (16.2 t ha⁻¹) and summer mungbean (11.6 t ha⁻¹) were recorded in treatment T₁, surpassing the 100% recommended dose of fertilizer (T₇) by 13.7%, 20% and 10.4 %, respectively. The concentration of copper (Cu) and zinc (Zn) in the grains of maize, pea and summer mung bean was 38.3%, 14.1%, 29.6% and 53.4%, 22.8 % and 19.8% higher in treatment T₁ as compared to treatment T₇. Moreover, the concentration of copper and zinc in the grains of maize, pea and summer mung bean was 32.1%, 24.2% and 29.5 % and 21.7%, 17.6% and 11.6% higher in treatment T₁, respectively, compared to treatment T₇. Similarly, the increase in the uptake of Cu and Zn was observed in both grain and straw of maize, pea and summer mung bean. The study concluded that the integrated nutrient management (INM) treatment is to substitute a portion of chemical fertilizers with a more sustainable and environmentally safe organic compost in order to mitigate soil degradation, improve crop production, and protect the environment.

KEYWORDS: Maize, peas; mungbean, micronutrients, cropping system, organic manure, integrated farming

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1. Introduction

Organic matter plays a crucial role in increasing micronutrients availability and mitigating the adverse effects of free cations

(Rani et al., 2023). Due to their limited mobility, plants face challenges in obtaining micronutrients from the solid phase of the soil to their roots (Dhaliwal et al., 2019;

Bhatla et al., 2018). The addition of organic matter to the soil enhances its physical, chemical, and biological properties, resulting in increased DTPA-extractable (diethylenetriaminepentaacetic acid) content of iron (Fe), copper (Cu), zinc (Zn), and manganese (Mn) in the soil (Dhaliwal et al., 2013; Ali et al., 2020). This increase occurs through various processes, such as chelation (Sharma et al., 2014), helping overcome micronutrients deficiencies.

Chelating agents form soluble complexes with metallic micronutrients, increasing the carrying capacity of soil solutions, and are being developed, potentially accounting for the positive effects of organic manures (Sinegani et al., 2015; Sharma et al., 2014). Biofertilizers, living microorganisms applied to soil, seeds, or plant surfaces, colonize the rhizosphere or the interior of the plant (Hernández et al., 2023), promoting growth by enhancing the supply or availability of primary nutrients to the host plant (Daniel et al., 2022). The activity of phosphate-solubilizing bacteria and vesicular-arbuscular mycorrhizal fungi also increases with organic matter addition, further enhancing zinc uptake (Masrahi et al., 2023; Lehmann et al., 2014). These activities support biochemical processes in the soil, such as nitrogen fixation, phosphorus mobilization, solubilization, zinc solubilization, and overall plant growth (Silva et al., 2023).

By mobilizing micronutrients, biofertilizers not only accelerate plant development but also reduce micronutrients deficiency (Mandal et al., 2023). The availability of nutrients in the soil depends on the chemical equilibrium between nutrient ions in the soil solution and solid phases.

Several variables, including soil type, crop species, fertilizer supplier, and the yield potential of the variety, affect how well various crops absorb secondary nutrients (Aulakh et al., 2022). According to Choudhary et al. (2018), different cropping systems that received combined applications of organic manures and chemical fertilizers showed better micronutrients uptake. Furthermore, Rutkowska et al. (2014) reported that the integrated use of organic manures and chemical fertilizers improved the availability of micronutrients to plants.

Despite the positive effects of predominant cropping systems like rice-wheat, cotton-wheat, and maize-wheat on building soil organic matter and nutrient status (Sharman et al., 2023), the rice-wheat system is also associated with the appearance of iron deficiency in rice and manganese and zinc deficiency in the subsequent wheat crop (Yadav et al., 2023). The inclusion of deep-rooted crops and pulses in the cropping system helps overcome nutrient deficiencies by mobilizing zinc, copper, iron, and manganese, thus reducing micronutrients deficiencies (Kumar et al., 2020). Pulses contribute to organic matter through litter fall and have higher root biomass, serving as a crucial source in redistributing soil micronutrients and secondary plant nutrients (Edwards et al., 2022).

However, certain cropping systems like moongbean-wheat, soyabean-wheat, and moongbean-raya play a pivotal role in building nutrient status and ameliorating deficiencies. In intensive agricultural systems where, high nitrogen levels are applied without organic additions, such as in rice-wheat systems, micronutrients depletion

occurs (Ali et al., 2019; Gupta et al., 2000). Organic manures, containing both macro and micronutrients, contribute to soil improvement by significantly enhancing nitrogen fixation. They establish a positive nutritional balance and improve soil physical qualities by providing an excellent substrate for microorganism growth (Kumar et al., 2011). The incorporation of organic manures into the soil supplies valuable nutrients to plants and the soil, contributing to the maintenance of soil fertility (Prasad et al., 2002). Farmyard manure, acting as a reservoir of nutrients, is known to improve soil productivity on a sustainable basis (Chaudhary and Narwal, 2005). Long-term application of farmyard manure has been shown to increase DTPA-extractable micronutrients in the soil (Richards et al., 2011; Wang et al., 2016).

Given the pivotal role of organic manures, this experiment was conducted to assess the long-term impact of organic manure application on the yield, micronutrients content, and uptake in a cropping system involving maize, peas, and summer mung beans. The investigation aims to provide valuable insights into the sustained effects of organic manures on overall productivity and nutrient dynamics within this agricultural context

2. Materials and methods

2.1 Experimental location and design

The field experiment was carried out at School of Organic Farming, PAU, Ludhiana by choosing maize - pea - summer mungbean as the testing cropping system, comprised of seven treatments, replicated thrice in a randomized block design. In each treatment, different organic and integrated nutrient

sources were applied. The various organic and inorganic combination treatments were; T₁: 50% N through recommended NPK + 50% N was substituted through FYM, T₂: 100% N through FYM, T₃: T₂ + intercropping (marigold in pea, cowpea in maize), T₄: T₂ + agronomic practices for weed and pest control, T₅: 50% N as FYM + rock phosphate to substitute the P requirement of crops + phosphate solubilizing bacterial cultures (PSB), T₆: T₂ + biofertilizer (consortium) containing N and P carriers and T₇: 100% Recommended NPK through chemical fertilizers.

2.2 Measurement and analysis

The basic soil sample was collected before the start and harvest of crops by giving a V-shaped cut. The samples were collected from 3-4 places and thereafter, soil samples were mixed together to obtain a representative sample for analysis. The chemical properties of surface soil were determined using the standard analytical procedures (Jackson 1973). Plant samples were collected after harvesting of maize, pea and summer mungbean. Grain and straw samples of cropping system were collected, dried in the sun, and then oven-dried. Grain and straw samples of maize, pea and summer moong were digested in a di-acid mixture of nitric acid (HNO₃) and perchloric acid (HClO₄) in the ratio of 3:1 for the analysis of Fe, Mn, Zn and Cu. The concentration (ppm) of Fe, Mn, Zn and Cu were determined by using the Atomic Absorption Spectrophotometer method (Lindsey and Norvell 1978). The grain and straw yield of maize, pea, and summer mung bean was reported in ton hectare.

2.3. Statistical analysis

The effects of several treatments on yield and micro nutrients concentration were assessed using the ANOVA technique in Statistics 8.1 (Analytical Software Tallahassee, FL, USA). First, the data were subjected to routine testing to meet the normality assumptions. Furthermore, before analyzing the data, the percentages were arcsine transferred to normalize the variables. Tukey's post hoc test was used to compare means for parameters with significant treatment effects

3. Results

The results of this study showed that the various organic and INM treatments played an important role in regulating several soil chemical properties. The impact of different types and rates of organic compost application, either solely or in combination with chemical fertilizers on crop yield, micronutrients content, and uptake by plant were presented in different sections.

3.1 Grain and straw yield of maize

Results showed that maize grain yield was significantly affected by different treatments (Figure 1A). Among the treatments, T_1 treatment increased the grain yield of maize (5.72 t ha^{-1}) compared to all other treatments followed by T_6 . In contrast, the lowest grain yield (4.17 t ha^{-1}) of maize was recorded in treatment T_5 (50% N as FYM + Rock phosphate + PSB). Whereas the treatment T_7 with 100% recommended NPK recorded 5.03 t ha^{-1} of grain yield.

Maize residue has economic significance since it is given to the animals as feed. The maize stover yield was significantly influenced by different treatments (Figure 1A). The highest stover yield of maize (9.78 t ha^{-1}) was observed in treatment T_6 followed

by treatment T_1 (9.48 t ha^{-1}). Whereas the lowest stover yield (7.03 t ha^{-1}) was observed in the treatment T_5 , having 50% N applied through FYM, rock phosphate and PSB.

3.2 Pea pod and stover yield

Pea pod yield varied from 10.6 to 16.2 t ha^{-1} under various organic and integrated treatments, significantly increased the pea pod yield (Fig. 1B). Among the different treatments, the highest pod yield (16.2 t ha^{-1}) of peas was observed under the treatment T_1 where 50% N was substituted through FYM and 50% recommended NPK were applied followed by treatment T_6 (15.8 t ha^{-1}) which include 100% nitrogen through FYM along with biofertilizer. The lowest pod yield (10.6 t ha^{-1}) was observed under the treatment T_5 having 50% N was substituted through FYM and rock phosphate and PSB was applied.

The pea stover yield varied from 0.152 to 0.196 t ha^{-1} (Fig. 1C). The results showed that different organic and integrated treatments significantly improved the pea stover yield. The highest stover yield of pea (19.6 t ha^{-1}) was observed in treatment T_1 where 50% N was substituted through FYM and 50% recommended NPK were applied, followed by treatment T_6 (19.0 t ha^{-1}), which included 100% nitrogen through FYM along with biofertilizer. Thereafter, the lowest stover yield (15.2 t ha^{-1}) was observed in the treatment T_5 with 50% N as FYM and rock phosphate and PSB.

3.3 Grain and straw yield of summer mung bean

Grain yield of summer mung bean varied from 0.88 to 11.6 t ha^{-1} (Figure 1C). Among the different treatments, the highest grain yield of mung bean (1.16 t ha^{-1}) was observed in the treatment T_1 where 50% N was

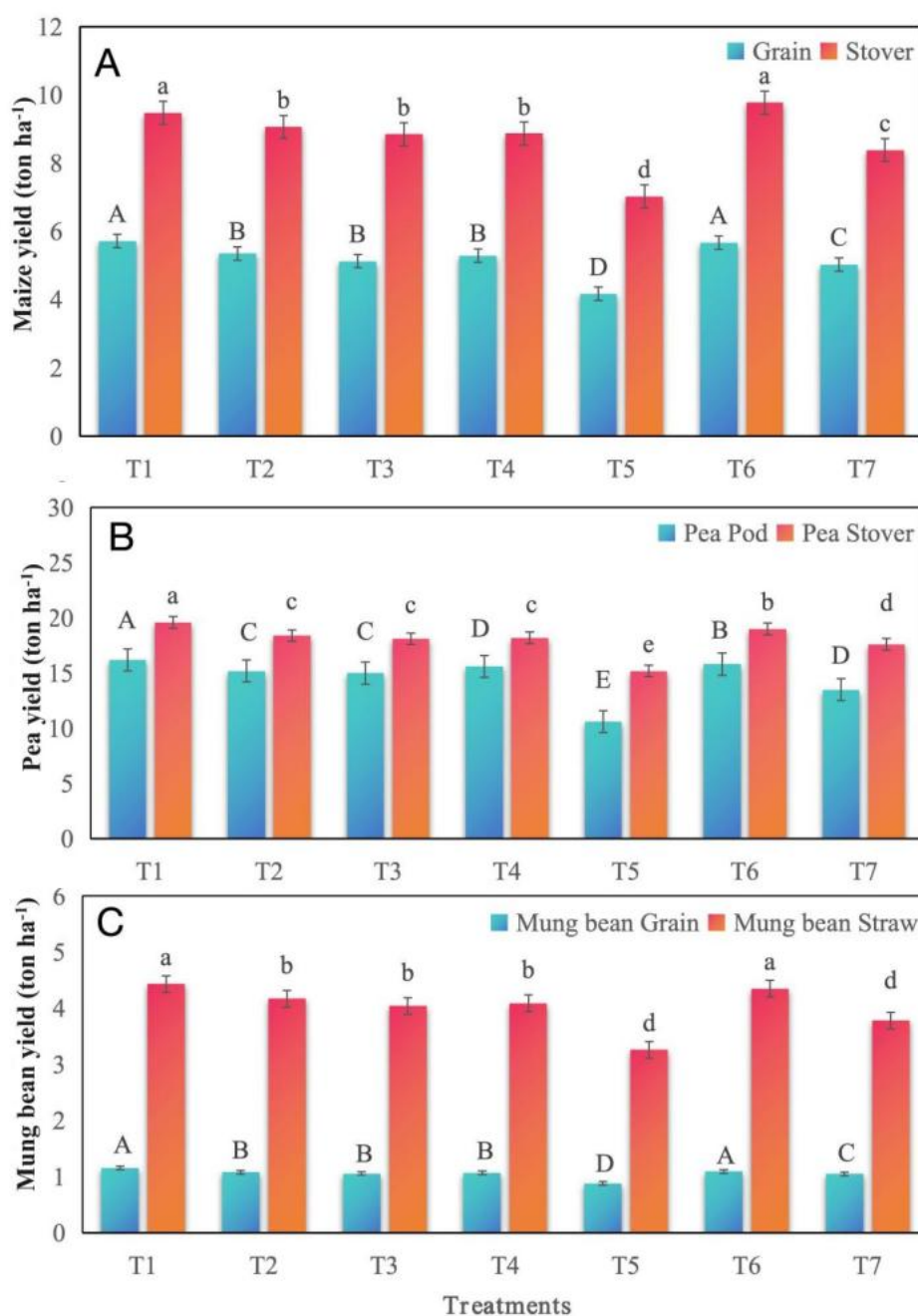


Figure 1. Effect of long-term application of organic manures on the (A) maize, (B) mung bean and (C) pea grain and straw yield (ton ha⁻¹). Note-lowercase and upper-case letters indicate significant differences ($P < 0.05$) among the treatments of grain yield and straw yield respectively. T₁- 50% of the recommended, NPK + 50% N through FYM; T₂ - 100% N through FYM; T₃ - 100% N through FYM + intercropping; T₄ - 100% N through FYM+ agronomic measures for weed and pest management; T₅ - 50% N as FYM + Rock phosphate + PSB; T₆ - 100% N through FYM + biofertilizer, containing N and P, carriers; T₇ - 100% recommended NPK

substituted through FYM and 50% recommended NPK were applied, followed by treatment T₆ (1.09 t ha⁻¹), which included 100% nitrogen through FYM along with biofertilizer. The lowest grain yield (0.88 t ha⁻¹) was observed in the treatment T₅ with 50% N substituted through FYM, rock phosphate, and PSB. The straw yield of the summer mung bean among different treatments varied from 3.26 to 4.43 t ha⁻¹ (Figure 1C). The highest straw yield of mung bean (4.43 t ha⁻¹) was observed in treatment T₁, where 50% N was substituted through FYM and 50% recommended NPK was applied followed by treatment T₆ (4.35 t ha⁻¹), which included 100% nitrogen through FYM along with biofertilizer and the lowest stover yield (3.26 t ha⁻¹) was observed under the treatment T₅ having 50% N as FYM with rock phosphate and PSB.

3.4 Copper and zinc content of maize grain

The effect of the long term application of organic manures on the micronutrients concentration of maize grain is given in Table 1. The Cu concentration of maize grain varied from 1.98 to 2.74 mg kg⁻¹. Among all the treatments highest Cu content (2.74 mg kg⁻¹) was observed under treatment T₁, where 50% N was substituted through FYM and 50% recommended NPK was applied, followed by T₆ (2.55 mg kg⁻¹) where 100% nitrogen through FYM along with biofertilizer was applied. The lowest content of Cu (1.98 mg kg⁻¹) was observed in the treatment T₇ having 100% recommended NPK. The integrated treatment significantly increased the Cu content of maize grain as compared to the recommended dose of fertilizer. The Zn concentration in maize grain under different treatments varied from

14.6 to 22.4 mg kg⁻¹. The highest Zn content (22.4 mg kg⁻¹) was recorded in the T₁ where 50% N through FYM and 50% recommended NPK were applied followed by T₆ (20.0 mg kg⁻¹) which included 100% nitrogen through FYM along with biofertilizer and the lowest content of Zn (14.6 mg kg⁻¹) was observed in the treatment T₇. The integrated treatment significantly increased the Zn content of maize grain as compared to the treatment with 100% recommended dose of fertilizer.

3.5 Copper and zinc content of pea grain

The copper concentration of pea grain varied from 5.40 to 6.16 mg kg⁻¹. Among all the treatments, the highest Cu content (6.16 mg kg⁻¹) was observed under treatment T₁ where 50% N was substituted through FYM and 50% N through recommended NPK, followed by T₆ (6.10 mg kg⁻¹) where 100% nitrogen was substituted through FYM along with biofertilizer was applied which was higher than the treatment T₄ (5.75 mg kg⁻¹) where 100% N through FYM and agronomic measures for weed and pest management were adopted. The lowest content of Cu (5.40 mg kg⁻¹) was observed in the treatment T₇ with 100% recommended NPK. The integrated treatment significantly increased the Cu content of pea grain as compared to the 100% recommended dose of fertilizers. The Zn concentration in pea grain varied from 29.7 to 36.5 mg kg⁻¹. Highest Zn content (36.5 mg kg⁻¹) was recorded in the T₁ where 50% N was substituted through FYM and 50% recommended NPK were applied followed by T₆ (34.4 mg kg⁻¹). Lowest content of Zn (29.7 mg kg⁻¹) was observed in the treatment T₇. The integrated treatment management treatment significantly increased the Zn content of pea grain as--

Table 1. Effect of long term application of organic manures on micronutrients concentration (mg kg⁻¹) of maize, peas and summer

Treatment	Maize				Pea				Summer Mung bean			
	Cu		Zn		Cu		Zn		Cu		Zn	
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
T ₁	2.74 a	5.43 a	22.4 a	30.2 a	6.16 a	8.96 a	36.5 a	41.9 a	3.28 a	6.75 a	39.8 a	50.9 a
T ₂	2.32 d	4.98 b	17.8 c	25.6 c	5.69 d	7.9 d	32.4 c	38.9 c	2.98 c	6.14 c	34.4 c	49.9 b
T ₃	2.25 d	4.23 c	16.1 d	25.2 c	5.63 e	7.48 e	30.9 d	38.2 c	2.76 d	5.68 d	34.4 c	47 c
T ₄	2.43 c	5.17 b	19.9 b	27.2 b	5.75 c	8.53 c	32 c	41.1 b	3.05 c	6.28 c	36.8 b	50.2 a
T ₅	2.14 e	4.2 c	14.7 e	24.9 c	5.53 f	7.47 e	29.8 e	37.7 d	2.64 e	5.44 e	34.3 e	46.8 c
T ₆	2.55 b	5.36 a	20 b	27.6 b	6.1 b	8.75 b	34 b	41.5 d	3.17 b	6.53 b	38.9 a	50.9 a
T ₇	1.98 f	4.11 c	14.6 e	24.8 d	5.4 g	7.21 f	29.7 e	35.6 e	2.53 f	5.21 f	33.2 d	45.4 d
LSD (0.05)	0.09	0.21	1.12	0.71	0.01	0.03	0.9	0.8	0.1	0.21	0.93	0.81

mung bean.

Note-lowercase letters indicate significant ($P < 0.05$) difference among the treatments. T₁- 50% of the recommended, NPK + 50% N through. FYM; T₂ - 100% N through FYM; T₃ - 100% N through FYM + intercropping; T₄ - 100% N through FYM+ agronomic measures for weed and pest management; T₅ - 50% N as FYM + Rock phosphate + PSB; T₆ - 100% N through FYM + biofertilizer, containing. N and P, carriers; T₇ - 100% recommended NPK

compared the treatment where 100% recommended dose of fertilizer was applied.

3.6 Copper and zinc content of summer mung bean grain

Copper concentration of mung bean grain was varied from 2.53 to 3.28 mg kg⁻¹. Among all the treatments highest Cu content (3.28 mg kg⁻¹) was observed in the treatment T₁ where 50% N through FYM and 50% recommended NPK were applied, followed by T₆ (3.17 mg kg⁻¹) where 100% nitrogen through FYM applied with biofertilizer. The lowest content of Cu (2.53 mg kg⁻¹) was observed in the treatment T₇ having 100% recommended NPK. The Zn concentration of mung bean varied from 33.1 to 39.5 mg kg⁻¹. Among different treatments, highest Zn content (39.5 mg kg⁻¹) was observed under the treatment T₁ where 50% N through FYM and 50% recommended NPK were applied followed by T₆ (38.9 mg kg⁻¹) which include 100% nitrogen through FYM along with biofertilizer. The content was 36.8 mg kg⁻¹ in treatment T₄ where 100% NPK was applied through FYM along with agronomic measures for weed and pest management was followed and the lowest content of Zn (33.2 mg kg⁻¹) was observed in the treatment T₇. The integrated treatment significantly increased the Zn content of mung bean grain as compared to the treatment with 100% recommended dose of fertilizer.

3.7 Copper and zinc content of maize straw

Micronutrients concentration of maize stover is presented in the table 1. The Cu concentration in maize varied from 4.11 to 5.43 mg kg⁻¹. Highest Cu content (5.43 mg kg⁻¹) was observed in the treatment T₁ where 50% N through FYM and 50% recommended NPK were applied followed by T₆ (5.36 mg

kg⁻¹) where 100% nitrogen was applied through FYM along with biofertilizer was applied. The lowest content of Cu (4.11 mg kg⁻¹) was observed in the treatment T₇ where 100% recommended NPK was applied through chemical fertilizers. Zn content varied from 24.8 to 30.2 mg kg⁻¹. The highest stover Zn concentration (30.15 mg kg⁻¹) was observed under the treatment T₁ where 50% N through FYM and 50% recommended NPK were applied followed by T₆ (27.6 mg kg⁻¹) which included 100% nitrogen through FYM along with biofertilizer was applied. The lowest content of Zn (24.8 mg kg⁻¹) was observed in the treatment T₇ having 100% recommended NPK through chemical fertilizers were applied. The integrated nutrient management treatments (T₁, T₄, T₆) increased the maize stover zinc concentration as compared to the chemical fertilizer alone.

3.8 Copper and zinc content of pea straw

Copper concentration in pea straw showed variation among different treatments from 7.21 to 8.96 mg kg⁻¹ (Table 1). Highest Cu content (8.96 mg kg⁻¹) was observed in the treatment T₁ where 50% N through FYM and 50% recommended NPK were applied followed by T₆ (8.75 mg kg⁻¹) where 100% nitrogen was applied through FYM along with bio fertilizer. The lowest content of Cu (7.21 mg kg⁻¹) was observed in the treatment T₇ where 100% recommended NPK was applied through chemical fertilizers. The Zn content of pea straw varied from 35.6 to 41.9 mg kg⁻¹. The highest straw Zn concentration (41.9 mg kg⁻¹) was observed under the treatment T₁ where 50% N through FYM and 50% recommended NPK were applied followed by T₆ (41.5 mg kg⁻¹) which included 100% nitrogen through FYM along with

biofertilizer was applied. The lowest content of Zn (35.5 mg kg^{-1}) was observed in the treatment T_7 where 100% recommended NPK through chemical fertilizers were applied. The integrated nutrient management treatments increased the pea stover zinc concentration as compared to the chemical fertilizer alone.

3.9 Copper and zinc content of mung bean straw

Micronutrients concentration of mung bean straw showed significant variation among different treatments ranging from 5.21 to 6.75 mg kg^{-1} (Table 1). Higher Cu content (6.75 mg kg^{-1}) was observed in the treatment T_1 where 50% N through FYM and 50% recommended NPK were applied, followed by T_6 (6.53 mg kg^{-1}) where 100% nitrogen was applied through FYM along with biofertilizer. The lowest content of Cu (5.21 mg kg^{-1}) was observed in the treatment T_7 where 100% recommended NPK was applied through chemical fertilizers. The Zn concentration of mung bean straw varied from 45.4 to 50.9 mg kg^{-1} . The highest straw Zn concentration (50.9 mg kg^{-1}) was observed in the treatment T_1 where 50% N through FYM and 50% recommended NPK were applied followed by T_6 (46.8 mg kg^{-1}) which included 100% nitrogen through FYM along with biofertilizer. The lowest content of Zn (45.4 mg kg^{-1}) was observed in the treatment T_7 where 100% recommended NPK through chemical fertilizers alone.

3.10 Micronutrients uptake of maize grain and straw

Micronutrient uptake of maize grain and straw are presented in the table 2. Variation in Cu uptake by maize grain varied from 8.7 to 15.4 g ha^{-1} . Among all the treatments,

highest Cu uptake (15.4 g ha^{-1}) was observed in the treatment T_1 where 50% N was substituted through FYM and 50% N through recommended NPK were applied followed by 14.2 g ha^{-1} in treatment T_6 where 100% nitrogen through FYM along with biofertilizer was applied. The lowest uptake of Cu (8.7 g ha^{-1}) was observed in the treatment T_5 where 50% N was applied through FYM along with rock phosphate and PSB. The integrated treatment significantly increased the Cu uptake of maize grain as compared to the recommended dose of fertilizers. Zn uptake by maize grain varied from 60.1 to 125.7 g ha^{-1} . The highest Zn uptake (125.7 g ha^{-1}) was recorded in T_1 where 50% N through FYM and 50% recommended NPK were applied followed by T_6 which included 100% nitrogen through FYM along with biofertilizer was applied. The lowest uptake of Zn (60.1 g ha^{-1}) was observed in the treatment T_5 where 100% N through FYM and rock phosphate and PSB were applied. The integrated treatment except T_5 significantly increased the Zn uptake by maize grain as compared to the application of 100% recommended dose of fertilizer.

3.11 Micronutrient uptake of pea grain and Straw

Data on effect of long term application of organic manures on the micronutrient uptake of pea grain and straw is presented in the table 2. Variation in the Cu uptake by pea grain was observed in the different treatments from 60.1 to 100 g ha^{-1} . Among all the treatments, highest Cu uptake (100 g ha^{-1}) was observed in treatment T_1 where 50% N through FYM and 50% recommended NPK were applied followed by 93.2 g ha^{-1} in treatment T_2 where 100% nitrogen through

FYM was applied. The lowest uptake of Cu (60.1 g ha^{-1}) was observed in the treatment T_5 where 50% N was applied through FYM along with rock phosphate and PSB. The integrated treatments except T_5 significantly increased the Cu uptake of pea grain as compared to the recommended dose of fertilizer alone. The Zn uptake by pea grain varied from 332 to 598 g ha^{-1} . The highest Zn uptake (598 g ha^{-1}) was recorded in T_1 where 50% N was substituted through FYM and 50% N was substituted through recommended NPK followed by (523 g ha^{-1}) in T_2 which received 100% nitrogen through FYM. The lowest uptake of Zn (332 g ha^{-1}) was observed in the treatment T_5 where 100% N through FYM, rock phosphate and PSB was applied. The integrated treatment significantly increased the Zn uptake by pea grain as compared the treatment with 100% recommended dose of fertilizer. The increase in micronutrients uptake might be due to the fact that application of organic manures decreases the soil pH and increases the availability of the plant available forms of micronutrients.

3.12 Micronutrient uptake of summer mung bean grain

Copper uptake of mungbean grain was observed in the different treatments varied from 2.56 to 3.68 g ha^{-1} (Table 2). Among all the treatments, highest Cu uptake (3.68 g ha^{-1}) was observed in treatment T_1 where 50% N was applied through FYM and 50% recommended NPK were applied. The lowest uptake of Cu (2.56 g ha^{-1}) was observed in the treatment T_5 where 50% N was applied through FYM along with rock phosphate and PSB. The integrated treatment significantly increased the Cu uptake of mungbean grain

as compared to the recommended dose of fertilizers. The Zn uptake by mungbean grain varied from 28.9 to 44.6 g ha^{-1} . The highest Zn uptake by moonbean grain (44.6 g ha^{-1}) was observed in T_1 where 50% N was substituted through FYM and 50% N was substituted through recommended NPK followed by 40.9 g ha^{-1} in T_6 which received 100% nitrogen through FYM along with biofertilizer containing N and P carriers was applied. The lowest uptake of Zn (29.0 g ha^{-1}) was observed in the treatment T_5 where 100% N through FYM and rock phosphate and PSB was applied. The integrated treatment except T_5 significantly increased the Zn uptake by mungbean grain as compared to the treatment with 100% recommended dose of fertilizers.

3.13 Micronutrient uptake of maize straw

Variation in the Cu uptake by maize straw observed in different treatments varied from 29.9 to 53.2 g ha^{-1} (Table 2). Among all the treatments, highest Cu uptake (53.2 g ha^{-1}) was recorded in T_6 where 100% nitrogen was applied through FYM along with biofertilizer followed by treatment T_1 (52.1 g ha^{-1}) where 50% N through FYM and 50% recommended NPK were applied followed by 46.5 g ha^{-1} in T_4 where 100% nitrogen through FYM and agronomic measures for weed and pest management were adopted. The lowest uptake of Cu (29.9 g ha^{-1}) was observed in the treatment T_5 where 50% N was applied through FYM along with rock phosphate and PSB. The integrated treatment significantly increased the Cu uptake of maize stover as compared the recommended dose of fertilizer.

The Zn uptake by maize straw varied from 177.1 to 289.7 g ha^{-1} . The highest Zn uptake

Table 2. Effect of long term application of organic manures on micronutrients uptake (g ha^{-1}) of maize, peas and summer mung bean.

Treatments	Maize				Pea				Summer Mung bean			
	Cu		Zn		Cu		Zn		Cu		Zn	
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
T ₁	15.4 a	52.2 a	125 a	289 a	100 a	176 a	598 a	836 a	3.68 a	30.8 a	44.6 a	232 a
T ₂	12.2 c	45.8 b	93.2 d	235 b	93.3 b	146 d	523 b	726 b	3.09 c	26.3 b	35.7 d	214 a
T ₃	11.3 d	38 c	80.9 e	226 c	86.5 d	135 e	485 b	700 c	2.82 d	23.6 b	35.2 d	195 b
T ₄	12.6 c	46.5 b	103 c	245 b	89.3 c	156 c	512 b	761 b	3.14 c	26.4 b	37.9 c	211 b
T ₅	8.7 f	29.9 d	60.1 g	177 e	60.1 f	114 f	332 e	584 e	2.23 f	18.2 d	29 f	157 c
T ₆	14.2 b	53.2 a	111 b	273 a	87.8 c	167 b	475 c	801 a	3.32 b	29.2 a	40.9 b	228 a
T ₇ -	9.81 e	35 c	72 f	210 d	73 e	127 e	404 d	635 d	2.56 e	20.2 c	33.5 e	176 c
LSD (0.05)	0.91	4.72	8.5	20.1	2.7	8.3	42.5	58.5	0.09	3.2	1.01	19.3

Note-lowercase letters indicate significant ($P < 0.05$) difference among the treatments. T₁- 50% of the recommended, NPK + 50% N through. FYM; T₂ - 100% N through FYM; T₃ - 100% N through FYM + intercropping; T₄ - 100% N through FYM+ agronomic measures for weed and pest management; T₅ - 50% N as FYM + Rock phosphate + PSB; T₆ - 100% N through FYM + biofertilizer, containing. N and P, carriers; T₇ - 100% recommended NPK

(289.7 g ha⁻¹) was recorded in T₁ where 50% N through FYM and 50% recommended NPK were applied followed by (273 g ha⁻¹) in T₆ which included 100% nitrogen through FYM along with biofertilizer was applied. The lowest uptake of Zn (177 g ha⁻¹) was observed in the treatment T₅ where 100% N through FYM, rock phosphate and PSB were applied. The integrated treatments except T₅ significantly increased the Zn uptake of maize stover as compared to the treatment with 100% recommended dose of fertilizer.

3.14 Micronutrient uptake of pea straw

The Cu uptake by pea grain was varied in the different treatments from 60.1 to 100 g ha⁻¹ (Table 2). Among all the treatments, highest Cu uptake (100 g ha⁻¹) was observed in treatment T₁ where 50% N through FYM and 50% recommended NPK were applied followed by 93.2 g ha⁻¹ in treatment T₂ where 100% nitrogen through FYM was applied. The lowest uptake of Cu (60.1 g ha⁻¹) was observed in the treatment T₅ where 50% N was applied through FYM along with rock phosphate and PSB. The integrated treatments except T₅ significantly increased the Cu uptake of pea grain as compared to the recommended dose of fertilizer. The Zn uptake by pea grain varied from 332 to 598 g ha⁻¹. The highest Zn uptake (598 g ha⁻¹) was recorded in T₁ where 50% N through FYM and 50% recommended NPK were applied. The lowest uptake of Zn (332 g ha⁻¹) was observed in the treatment T₅ where 100% N through FYM, rock phosphate and PSB was applied.

3.15 Micronutrient uptake of mungbean straw

The Cu uptake by mung bean straw in different treatments varied from 18.2 to 30.7

g ha⁻¹. Highest Cu uptake (30.7 g ha⁻¹) was in T₁ where 50% N through FYM and 50% recommended NPK were applied followed by (29.2 g ha⁻¹) T₆ in which 100% N through FYM along with biofertilizer containing N and P carriers was applied. The lowest uptake of Cu (18.2 g ha⁻¹) was observed in the treatment T₅ where 50% N was applied through FYM along with rock phosphate and PSB. The integrated treatment significantly increased the Cu uptake of mungbean straw as compared to the recommended dose of fertilizers. The Zn uptake by mung bean straw varied from 157 to 232 g ha⁻¹. The highest Zn uptake (232 g ha⁻¹) was in T₁ where 50% N through FYM and 50% recommended NPK were applied followed by 228 g ha⁻¹ in T₆ which included 100% nitrogen through FYM along with biofertilizer followed by (214 g ha⁻¹) in treatment T₂ where 100% NPK was applied through FYM and the lowest uptake of Zn (157 g ha⁻¹) was observed in the treatment T₅ where 100% N through FYM, rock phosphate and PSB was applied. The integrated treatment significantly increased the Zn uptake of mungbean straw as compared to the treatment with 100% recommended dose of fertilizer.

4. Discussion

The application of an integrated nutrient dose, combining organic and inorganic fertilizers, not only boosts nutritional supply for higher grain yield but also induces changes in the physical and chemical properties of the soil, thereby promoting improved crop growth and yield (Urmi et al., 2022). Gao et al.'s (2020) documented that an increase in maize grain yield was reported with integrated nutrient management.

Similarly, Geng et al. (2019) and Elduma et al. (2020) also observed heightened maize grain yield with the application of organic manures.

The present study revealed significant effects of various organic and integrated nutrient management (INM) treatments on maize, pea and mung bean stover yields and the increase in stover yield can be attributed to the addition of organic matter to the soil, potentially leading to increased nutrient solubilization and availability. This, in turn, contributes to an amplified stover yield. Furthermore, the combination of organic manures with inorganic fertilizers enhances the vegetative growth of the plant, as noted by Elduma et al. (2020) regarding an increase in maize stover yield with the application of organic manures.

This enhancement in yield might be attributed to various factors, such as the addition of organic matter in a legume-based system, root activity, and nutrient mobilization influencing the soil microenvironment (Kumar et al., 2018). Consequently, the crop may extract a higher amount of nutrients from the soil, leading to increased grain yield. Kishore et al. (2021) observed an increase in mung bean grain yield with 100% RDF + FYM at the rate 5 t ha⁻¹ + Rhizobium. Similarly, Isha et al. (2021) also reported an increase in mung bean yield was observed with the application of FYM applied at the rate 5 t ha⁻¹.

Essential micronutrients, such as copper (Cu) and zinc (Zn), play vital roles in enzymatic activities, photosynthesis, cell wall formation, and overall plant growth and development (Norouzi et al., 2014).

Our study highlighted substantial variations in micronutrient concentrations, particularly copper (Cu) and zinc (Zn), across diverse treatments. Treatment T1, integrating 50% nitrogen through farmyard manure (FYM) and 50% recommended NPK, consistently demonstrated elevated Cu and Zn levels in maize grain. For peas, T1 displayed the highest Cu and Zn content in grain, with integrated treatment T6 also exhibiting significant improvement over 100% recommended NPK. Similarly, in summer mung beans, treatments T1 and T6 consistently revealed superior Cu and Zn concentrations in both grain and straw, outperforming the treatment relying solely on 100% recommended NPK. Maize stover and pea straw exhibited varying Cu and Zn concentrations, with T1 and T6 consistently leading in content. These findings underscore the positive influence of integrated nutrient management on micronutrient concentrations in crop residues, emphasising its potential for sustainable agricultural practices. This enhancement can be attributed to the application of organic manures, which lowers soil pH and increases the availability of plant-accessible forms of micronutrients. The use of FYM and the consortium further increased micronutrients mobility, thereby raising their concentration. In legume-based systems, the addition of organic matter and nutrient mobilization in the soil contributed to higher nutrient acquisition by plants (Norouzi et al., 2014).

The variation in Cu and Zn uptake across treatments underscores the impact of different nutrient management strategies. Treatment T1, involving a combination of 50% N through FYM and 50% recommended

NPK, consistently exhibited superior micronutrients uptake in pea grain and mungbean straw. In contrast, T5, which relied on 50% N through FYM with rock phosphate and PSB, demonstrated lower uptake. Notably, the integrated treatments outperformed the sole application of 100% recommended NPK, emphasizing the efficacy of combining organic and inorganic approaches in enhancing micronutrients uptake. These findings suggest the potential for optimizing nutrient management practices to promote sustainable and efficient crop production. The observed increase in micronutrients uptake can be linked to the application of organic manures, which not only decreases soil pH but also enhances the availability of plant-accessible forms of micronutrients. The application of organic manures increased plant biomass and micronutrients concentrations, resulting in elevated micronutrients uptake in both organic and integrated treatments. The integrated use of organic manures and inorganic fertilizers significantly boosted grain and straw micronutrients uptake, attributed to the release of micronutrients during the decomposition of organic matter (Dhaliwal et al., 2023).

5. Conclusion

The various organic and integrated fertilizer treatments significantly influenced crop yield and micronutrients uptake by grain and straw. Treatment T1 consistently yielded the highest maize grain, pea pod, and mung bean grain, while T5 exhibited the lowest yields. Micronutrients concentrations in grain and straw increased with organic and integrated nutrient management, with T1 and T6 displaying the highest Zn and Cu

concentrations, and T7 the lowest. This pattern was consistent for all crops, with micronutrients concentration following the order $Zn > Cu$ in both straw and grains. The assimilation of micronutrients in grain and straw indicate concentration trends, with T1 and T6 leading in uptake, and T5 showing the lowest values. This pattern was observed across all crops. Organic manure application enhanced plant biomass, micronutrients concentration, and subsequent micronutrients uptake in the organic and integrated treatments. Overall, the application of organic manures not only boosted plant biomass but also elevated micronutrients concentrations, resulting in enhanced micronutrients uptake in the organic and integrated treatments. These findings emphasize the potential of sustainable agricultural practices in optimizing crop performance and nutrient dynamics.

Author Contribution

NR, SSW, conceptualized and designed the research work. NR, SSW, SR: Execution of field/lab experiments and data collection, analysis, interpretation of results and preparation of rough draft of manuscript was prepared by all authors edited the manuscript, read and approved the final version.

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