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Research Article

Evaluation of phosphorus-enriched organic amendments to enhance soil phosphorus availability

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ABSTRACT

The primary issue confronting the majority of farmers is a lack of phosphorus (P) in soil. A research study involving composting of city waste with organic and inorganic amendments was conducted to assess the impact of these amendments on P availability in soil. Experimental treatments included: City Waste (CW), CW + Single Super Phosphate (SSP), CW + Farmyard Manure (FYM) (EC1) + SSP, CW + Poultry Litter (PL) + SSP (EC2). Two enriched composts were selected based on P content to grow the maize crop under greenhouse conditions to assess the impact of compost on soil and plant growth. Greenhouse experiment consisted of six treatments, viz., control, enriched compost 1 (EC1)@125kg P2O5 /ha, EC2@125kg P2O5 /ha, SSP@125kg P2O5 /ha, ½ EC1+ ½ SSP, ½ EC2+ ½ SSP at recommended rate. Soil samples were analyzed for pH, EC, and macronutrients (N, P, K), before and after crop harvest. Plant samples were also subjected to macro and micronutrient to evaluate the impact of compost on plant nutrient contents. Plant agronomic parameters, viz., plant height, fresh biomass weight, were also recorded Analytical results revealed that application of ½ EC2+ ½SSP (CW+PL+SSP) significantly increased P availability in compost (3.26%), plant (0.69%), and soil (15.5 mg kg^{-1}). Plant height ranged from 149 cm to 172 cm. Addition of enriched compost (EC) showed better results compared to control. Application of ½ EC2+ ½ SSP resulted in an 84.3% increase in plant P (1.4%). This work highlighted that aerobic composting of city waste with PL and SSP had the potential to produce good-quality compost, which could enhance the availability of P in soil and plants.

Keywords: Phosphorus; municipal waste compost; enrichment; Single superphosphate.

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INTRODUCTION

Municipal waste (MW) management in Pakistan is a serious problem. According to the report of the Environmental Protection Agency, around 20 million tons of solid waste are produced every year, and it is increasing by 2.4% annually (Mamo et al., 2021). Globally, the waste generation is estimated to be 27 billion tons per year by 2050 (Kaza et al., 2018). Increasing urbanization and a lack of MW management are the reasons behind this upward trajectory. MW collection in developing countries is almost half (40%) of what exists in developed countries (90%). The remaining uncollected waste in urban areas is often thrown in empty plots, sewage channels, and on streets, creating environmental issues. Natural decomposition of MW produces carbon dioxide, methane, and various greenhouse gas (GHG) emissions (Liu et al., 2024). Similarly, improper management of MW can also lead to contamination of oceans, choking of drainage system, occurrence of floods, and breeding place of diseases (Hoang and Fogarassy, 2020). Burning of MW, which is often practiced in poor countries, it can endanger human health by releasing noxious fumes into the atmosphere. Landfill and dumping sites can lead to odor emission, contamination of groundwater due to leachate, and vector-borne diseases (Ferronato and Toretta, 2019).

Keeping in view all above issues of MW management, composting of MW has gained a lot of attention as a safe option for waste management. Through composting MW, we can protect our environment, save landfill areas, reduce incineration, and get a good organic product for crop production. This waste could be an effective source of providing soil organic matter if handled properly.

Problem with compost use is that they are not a rich source of nutrients, and it has to be supplemented with chemical fertilizer to fulfill the requirements of normal plant growth. Addition of compost/organic amendments enhances water retention in soil (Alam et al., 2023). Both organic and inorganic amendments have been used to improve the nutrient content of compost (Torkashvand, 2010). For sustainable agriculture, organic fertilizers must be used along with inorganic fertilizers like iron nanoparticles (Alam et al., 2025; Jahiruddin et al, 2012). Dependence on chemical fertilizers alone is not good for soil health. In the present study, enriched MW composts were prepared by using both organic (FYM, PL) and inorganic amendments (single super phosphate). Addition of organic amendments to increase P in soil is important, especially in arid and semi-arid areas having low organic matter content (Mousavi et al., 2023). Phosphorus is a major limiting nutrient in soil for crop growth (Zhu et al., 2018). 90% of soils in the arid region of Pakistan are deficient in P (Shakoor et al., 2023; NFDC, 2006). Phosphorus-enriched compost could be useful to overcome this P deficiency in soil, along with its role as a waste management technique. P-enriched compost is likely to enhance P-use efficiency and decrease P losses by runoff and erosion (Fatima et al., 2025; Horta et al., 2018).

Previous reports have shown that application of rock phosphate-enriched MW composts improved soil P content as compared to conventional P fertilizer (SSP) application (Beura et al., 2022). The main objective of the current research was to improve the P content of MW/compost by adding inorganic fertilizer (SSP) during composting and to improve the P availability in soil and enhance crop growth and yield.

MATERIALS AND METHODS

Preparation of Composts

The experiment was conducted in PMAS-Arid Agriculture University, Rawalpindi. Municipal solid waste used in this study was prepared manually and consisted of potato peels, tomatoes, different fruit waste, green waste such as grass, and plant residues. FYM was collected from the animal sheds of the university, while poultry litter was collected from the Poultry Research Institute, Rawalpindi. After the collection of all organic waste, it was chopped into small pieces for the composting process.

Four cemented pits (4x4x4 feet) were constructed for compost preparation, with a storage capacity of 1000 kg. All the organic waste was mixed thoroughly and filled into pits. A layer of leaves and grass was placed at the bottom of each pit to absorb leachate. The following compost treatments were applied:

T1. City waste (CW)
T2. CW+SSP @ 3% (w/w)
T3. CW+FYM @ 1:1+ SSP@ 3%(w/w) (EC1)
T4. CW+PL @ 1:1+ SSP@ 3%(w/w) (EC2)

Turning of composting material was done weekly. Moisture was kept around 50% through measuring with a digital hygrometer, and this process continued for 3 months. After 3 months, there was no increase in compost temperature even after turning, which was an indicator that the compost had matured. Pre-analysis of composting materials is shown in Table 1.

Greenhouse Experiment

A pot experiment was carried out under greenhouse conditions to evaluate the effect of P-enriched compost application on soil and plants. The soil was collected from the research area of the university. Soil was air-dried, grinded, sieved through a 2mm sieve, and filled in pots @ 5kg. Soil sampling was done before crop sowing and after crop harvest. Soil samples were analyzed for pH, EC, and macronutrients (N, P, K). For plant analysis, fresh and healthy maize leaves were collected. These leaves were oven dried at 65℃ for 24 hours, grinded and stored in plastic containers for chemical analysis. Growth parameters of maize, like fresh weight and plant height, were noted. Chemical properties of the soil

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used were pH 7.8, EC 0.32 dS/m, OM 0.75%, nitrate nitrogen (N) 4 mg kg^{-1}, available P 8.24 mg kg^{-1}, extractable K 127 mg kg^{-1}, Zn 1.74 mg kg^{-1}, Fe 2.24 mg kg^{-1}, Mn 1.82 mg kg^{-1}, Cu 1.16 mg kg^{-1}. The experiment was laid out

Parameter	City waste	FYM	PL
pH	6.50	7.40	8.80
EC (ds/m)	3.10	3.20	3.40
Moisture	37%	43%	30%
Nitrogen	0.73%	0.92%	3.30%
Phosphorus	0.93%	0.80%	4.02%
Potassium	0.35%	0.65%	4.2%

Table 1. Pre-analysis of composting materials.

Following treatments were applied in greenhouse experiment:

T1: Control

T2: EC1@125kg P2O5 /ha

T3: EC2@125kg P2O5 /ha

T4: SSP@125kg P2O5 /ha

T5: ½ EC1+ ½ SSP

T6: ½ EC2+ ½ SSP

Basal dose of N (225 kg/ha) and K (125 kg/ha) was applied in every treatment except control.

Analytical Methods

Soil pH and EC were determined by using method of Mclean (1982) and Richards (1954), respectively. Soil OM was determined by Walkley-Black method (Walkley, 1947). Soil NO_3-N and extractable K were determined by Soltanpour & Workman (1979). Phosphorous was determined by the Olsen and Sommers (1982) method. Plants and compost samples were oven dried at 70oC followed by wet digestion using a di-acid mixture of nitric acid and perchloric acid (1:2). Nitrogen content of plant and compost samples was determined by the Kjeldahl method (Bremner & Mulvaney, 1996), while P by the method of Watnabe & Olsen (1965). Potassium (K) was determined by the method mentioned in Handbook 60 (Method 18, P 100, Handbook 60). Micronutrients were evaluated using Atomic Absorption Spectrophotometer (Rashid, 1986).

Statistical Analysis

Analysis of variance (ANOVA) was calculated for all sets of data (Steel et al., 1997) using software Statistics 8.1. Comparison of means was done using the LSD test.

RESULTS AND DISCUSSION

Plant Growth Attributes

Plant height and fresh biomass weight are important growth parameters of a crop. Plant height, shoot, and root weight were affected significantly by the application of various treatments, as shown in Table 2. The highest shoot weight (25g), root weight (27.23g), and plant height (172cm) were noted in ½ EC2+ ½ SSP, followed by ½ EC1+ ½ SSP and SSP treatment. Increase in shoot weight, root weight, and plant height were 41%, 53%, and 13% respectively over control.

Application of compost alone (EC1 and EC2) gave values of above plant growth parameters above lesser the combined application of compost with SSP. So, for EC1 (FYM compost) and EC2 (PL compost), EC2 gave better results, which indicates higher nutrient content of PL compost.

Macronutrient Contents in Plants

Data regarding the effect of various treatments on plant nutrient content have been presented in Figures 1-3. The treatments SSP, ½ EC1+ ½ SSP, ½ EC2+ ½ SSP resulted in higher N uptake. Nitrogen content in these treatments was 1.18 %, 1.25 %, and 1.3 %, respectively. These three treatments were statistically non-significant. Better N content of combined treatments could be due to improved N uptake triggered by better P availability. The lowest N content (0.6%) was noticed in control. Barus et al. (2019) reported that application of rice straw compost improved plant N by

31% as compared to control. Farooq et al. (2024) reported similar results that N content was increased during the process, and compost volume decreased.

Similarly, the P and K content of plants was higher with the application of SSP, ½ EC1+ ½ SSP, and ½ EC2+ ½ SSP. The P content of plants in these treatments was above 0.5%, which shows a sufficient range of P in plants. While in control plant, P content and K content were 0.35 % and 0.87 % respectively. Potassium content is in the deficient range. Even with the application of combined treatments, the highest K content of plants was around 1.4 %. It shows that application of compost alone is not enough to meet the K requirement of cereal crops. However, few researchers have shown significant improvement in plant K by the application of compost. Haque et al. (2021) reported a 17 % increase in plant K content by the application of rice straw compost.

Table 2. Effect of treatments on plant growth parameters.

Treatments	Fresh shoot weight (g)	Dry shoot weight (g)	Fresh root weight (g)	Dry root weight (g)	Plant height (cm)
Control	14.7 e	7.13 d	12.7 d	0.57 b	149 c
EC1	16.7 d	8.14 d	14.7 c	0.90 ab	158 bc
EC2	21.2 b	10.6 bc	19.2 b	1.30 ab	165 ab
SSP	20.4 c	9.70 c	18.4 bc	1.20 ab	168 ab
1/2EC1+ 1/2SSP	21.7 b	11.5 b	19.7 b	1.26 ab	169 a
1/2EC2+1/2SSP	25 a	14.5 a	27.2 a	1.56 a	172 a

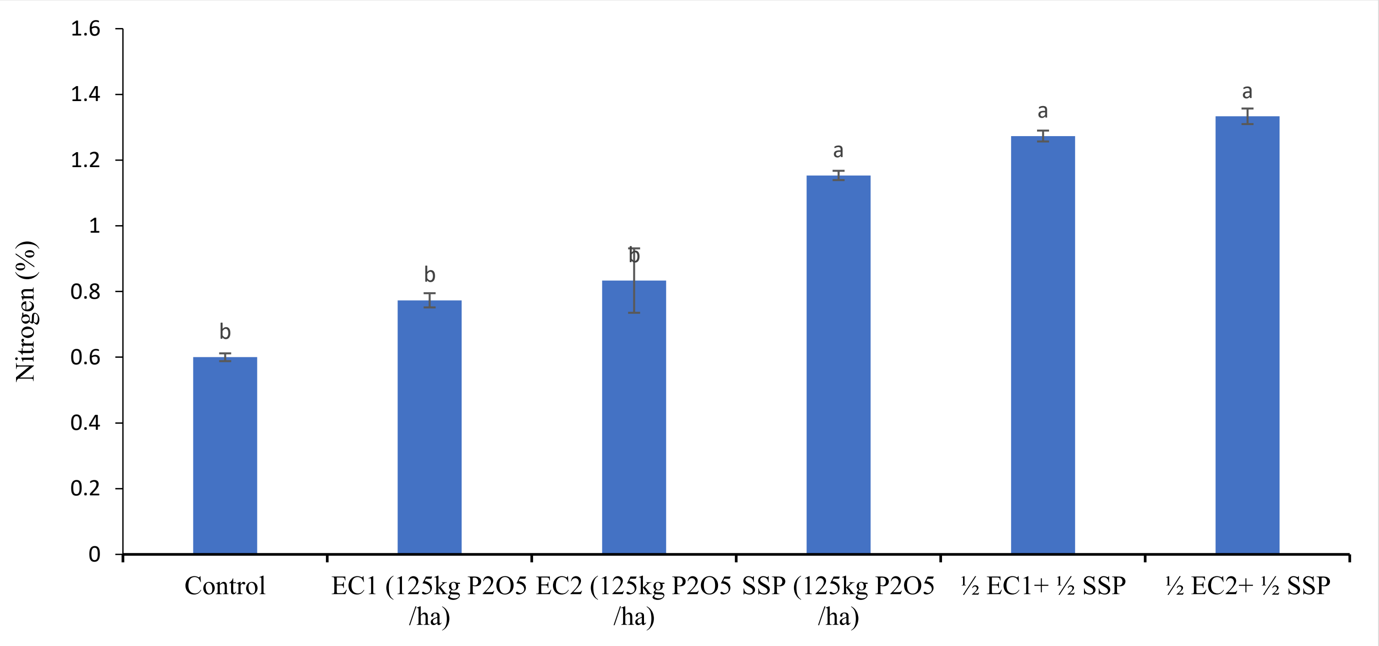

Figure 1. Effect of various treatments on plant nitrogen content.

Micronutrients in Plants

Table (3) shows the effect of application of compost treatments on plant micronutrient content. Application of enriched compost, whether applied alone or combined with SSP fertilizer, has improved micronutrient uptake in plants as compared to control where no amendment was added. The highest Cu (77.6 mg kg^{-1}), Zn (104.3 mg kg^{-1}), Fe (75.8 mg kg^{-1}), and Mn (90.6 mg kg^{-1}) content in plants was noted with the application of ½ EC2+ ½ SSP, followed by ½ EC1+ ½ SSP. Application of EC2 (PL) was more effective than EC1 (FYM) in improving micronutrient status of plants, which is an indication that PL compost is a good source of micronutrients.

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in SSP treatment was comparatively less as it was not a source of micronutrients. However, in this treatment micronutrient content of plants is better compared to control, which could be due to chemical fertilizer application. Micronutrient content was comparatively higher with the combined application of SSP with compost.

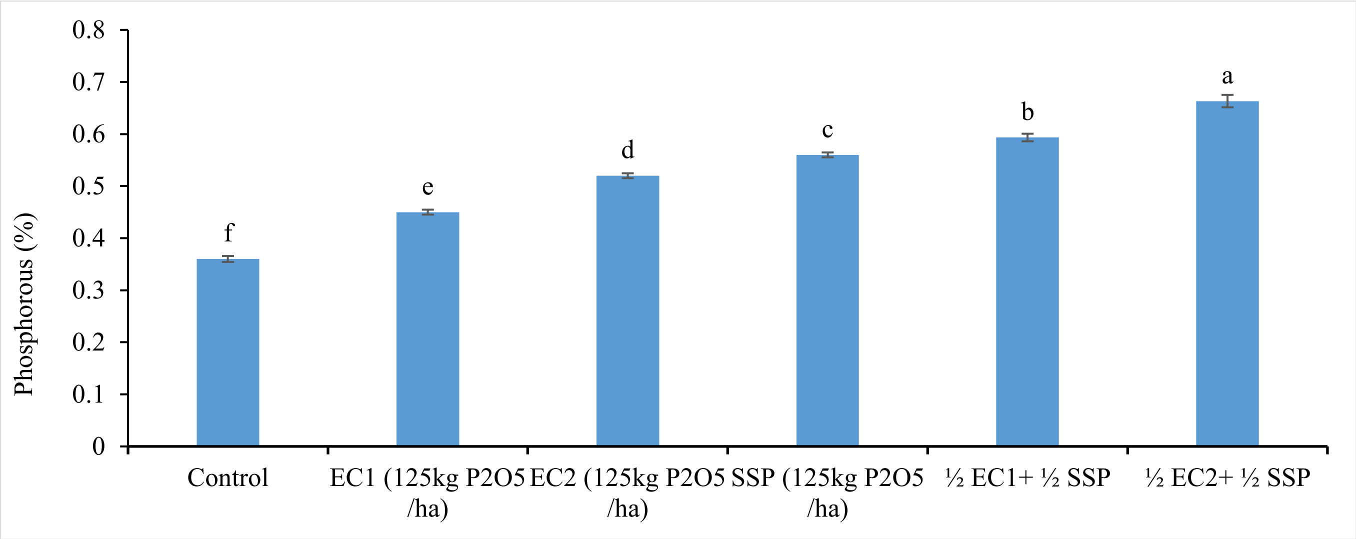

Figure 2. Effect of various treatments on plant phosphorus content.

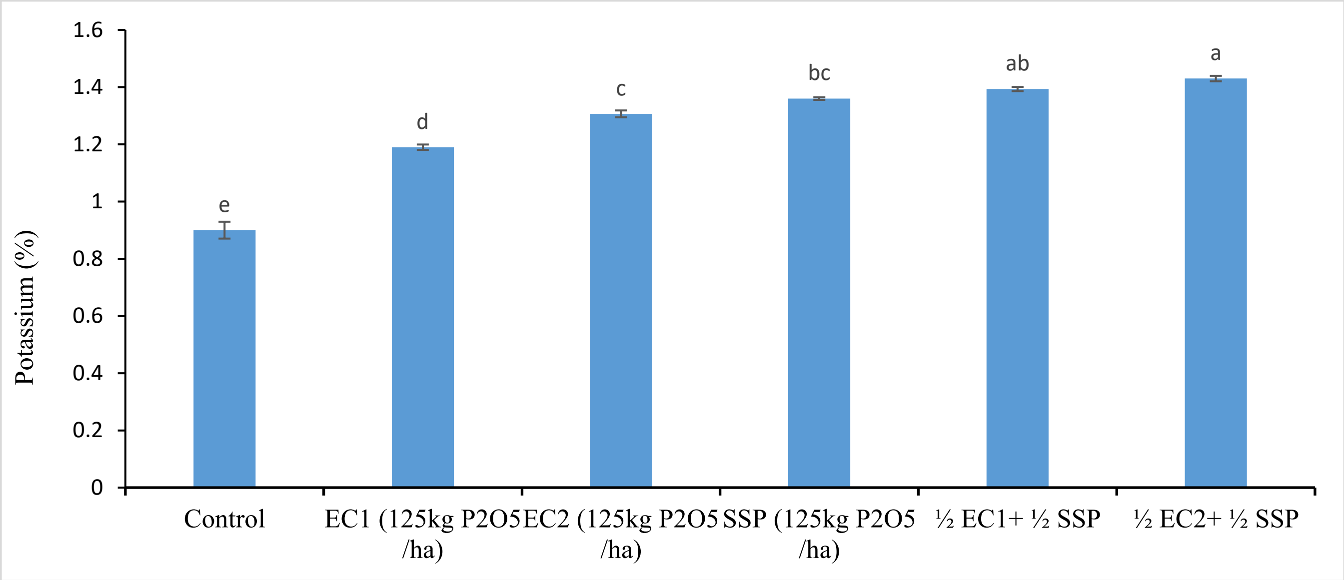

Figure 3. Effect of various treatments on plant potassium content.

Table 3. Effect of various treatments on plant micronutrients.

Treatments	Copper (Cu)	Iron (Fe)	Manganese (Mn)	Zinc (Zn)
Control	35.1 e	41.4 e	56.1 d	59.7 d
EC1	59.6 d	53.2 d	72.4 c	80.2 c
EC2	66.2 c	59.2 d	79.4 bc	95.1 b
SSP	64.1 c	55.8 c	76.3 b	91.1 b
½ EC1+1/2 SSP	73.8 b	70.4 b	86.5 a	102.6 a
½ EC2+1/2 SSP	77.6 a	75.8 a	90.6 a	104.3 a

This could be due to enhanced root growth because of the availability of NPK along with an organic source of nutrients. Better root growth is likely to result in better nutrient uptake (Iqbal et al., 2014). Sufficient availability of micronutrients is essential for plant growth. Reduced availability of any micronutrient can hinder normal growth (Alam et al., 2023; Manna et al., 2016). Zn content was higher than Cu, a fact corroborated by the findings of Carbonell et al. (2011).

Order of accumulation of micronutrients in plants was found to be Zn> Mn> Cu> Fe. In alkaline soils availability of micronutrients is a problem, especially Zn and Mn. (Reisenauer, 1988). Reduced Mn content of plants in our study could be due to alkaline, calcareous nature of soil. Our findings are supported by Mbarki et al. (2008), who reported improvements in micronutrient uptake by the application of MW compost. They reported a 3-fold increase in Cu uptake and 4-5-fold increase in Zn uptake by the application of MW compost.

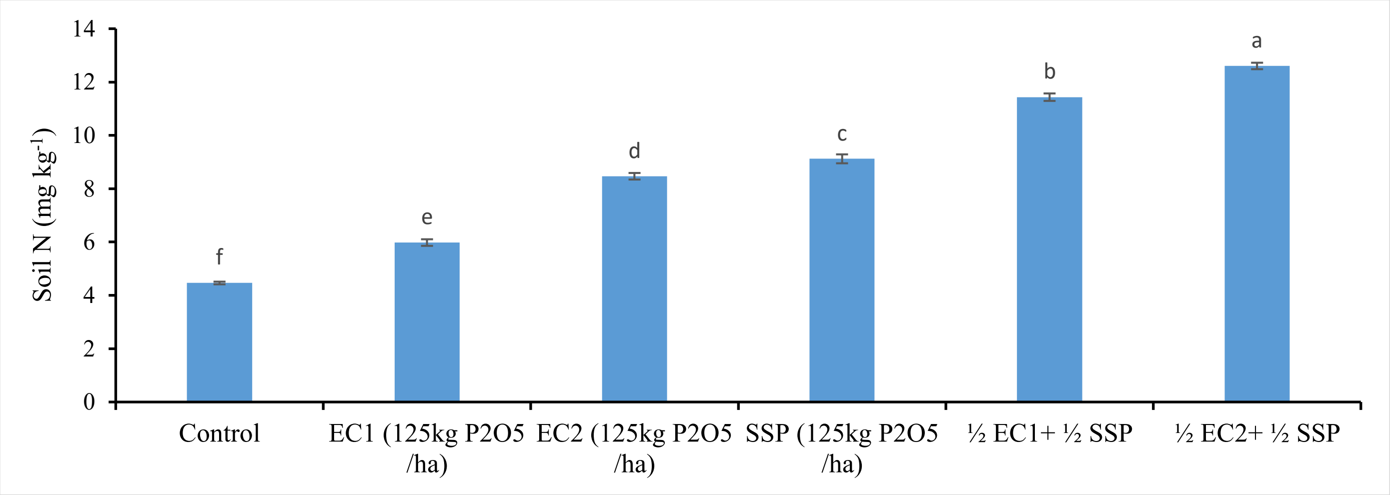

Figure 4. Effect of different compost treatments on soil nitrogen.

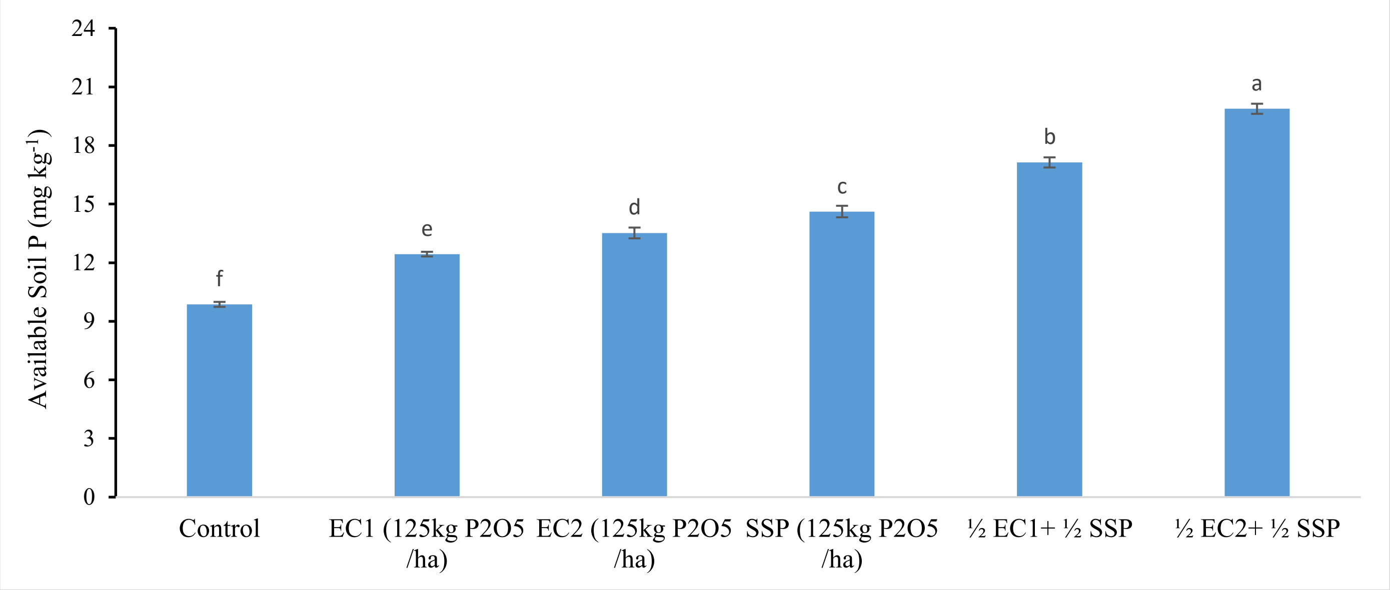

Figure 5. Effect of different compost treatments on soil phosphorus.

Macronutrients in soil

Soil P, NO_3-N, and extractable K are important components of soil fertility. These were also positively affected by the application of compost alone and compost with inorganic fertilizer (Figure 4-6). Soil NO_3-N varied from 4.5 to 12.3 mg kg^{-1}, with the lowest value in control and the highest value in EC2+½SSP, followed by EC1+½SSP (11.2 mg kg^{-1}). With EC1 and EC2 application soil NO_3-N concentration was 6 mg kg^{-1} and 8.2 mg kg^{-1}, respectively. Soil NO_3-N by the application of EC1 and EC2 was 25 % and 61 % higher than control, while the application of EC2+½ SSP resulted in a 63 % increase in soil NO_3-N over control. Available soil P ranged from 10 mg kg^{-1} to 20 mg kg^{-1}, with the lowest (10 mg kg^{-1}) in control, while the highest (20 mg kg^{-1}) was in EC2+½ SSP. In EC1 (FYM) and EC2 (PL) soil-P was 12.5 mg kg^{-1} and 14 mg kg^{-1}, respectively. With the SSP application, soil P (15 mg kg^{-1}) was less than ½ EC1+ ½ SSP and ½ EC2+ ½ SSP, respectively. Poultry litter is a rich source of N and P, so its application improved soil P and N. Furthermore, application of organic manure is known to reduce nutrient loss through soil fixation and leaching, so the availability of nutrients in soil is enhanced. Sole application of SSP gave a lesser value of Soil P, which could be due to its interaction with Ca in alkaline soils and Fe, Al in acidic soils. Similar trend was also noted for extractable soil K, where application of EC2+ ½ SSP resulted in improved soil K (160 mg kg^{-1}) followed by EC1+ ½ SSP (153 mg kg^{-1}).

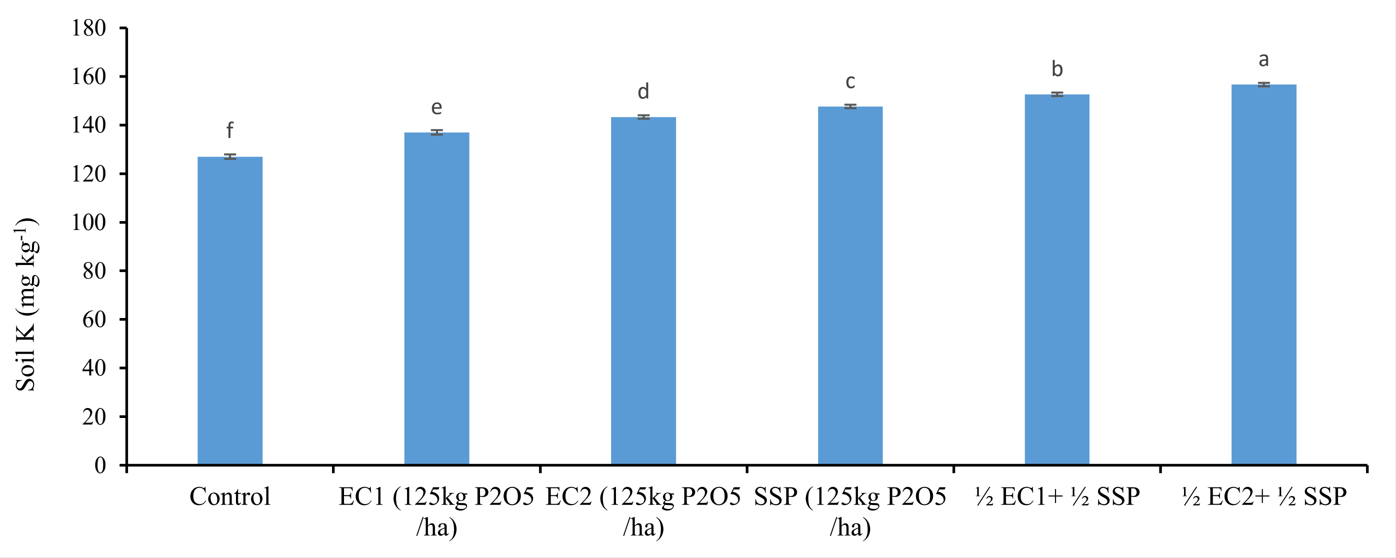

Figure 6. Effect of different compost treatments on soil potassium.

Application of composts, whether applied alone or in combination with inorganic fertilizer, has improved soil K, which could be due to the K content of organic sources and their ability to reduce losses of inorganic nutrients. Similar results were observed by Aziz et al. (2023), where they found that application of compost integrated with chemical fertilizers significantly improved soil NO_3-N content by 34 % compared to control. Turrion et al. (2018) observed that adding compost to the soil increases the available P reservoir in the long term.

CONCLUSION

The current study exhibited the impact of compost on the plant growth of maize as well as on soil physicochemical properties. Application of ½ EC2+ ½SSP (CW+PL+SSP) significantly increased P availability in the plant and soil. Compost application enhanced maize growth attributes, which ultimately enhanced the grain yield. This study highlights that aerobic composting of city waste with PL and SSP has the potential to produce good-quality compost, which could enhance the availability of P in soil and plants. Findings of the current study encourage farmers to adopt P-enriched organic amendments, viz., compost or fortified manure with P sources, to increase soil P availability and crop productivity. Such amendments not only provide readily available P but also improve microbial activity and soil health. Regular application, particularly before planting, can decrease reliance on inorganic fertilizers, reduce production costs, and enhance long-term soil fertility. Additionally, it is recommended to test soil P status periodically and adjust rates of amendment accordingly. This study provides a cost-effective and sustainable solution to address P deficiency in soils, the most common challenge to farmers. By utilizing P-enriched amendments, farmers can improve the fertility of soil, increase crop yields, and decrease reliance on expensive inorganic fertilizer.

AUTHOR'S CONTRIBUTION

MSK: Conceptualization, Methodology, Investigation, Data curation, Formal analysis, Writing. TI: Conceptualization, Data curation, Visualization, Software, Review & editing. TA: Conceptualization, Visualization, Software, Data curation, Review & editing. MA: Conceptualization, Visualization, Review & editing. IM: Review & editing. AA: Review & editing. IA: Review & editing. TH: Review & editing. MQ: Review & editing. MBR: Review & editing.

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AVAILABILITY OF DATA AND MATERIAL

All the data is provided in the manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE
Not applicable.

CONSENT FOR PUBLICATION
Consent has been given by all authors to publish this article.

CONFLICT OF INTERESTS
All authors attest to the validity of the manuscript contents and agree to its submission.

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