Bangladesh J. Soil Sci. 2025, 41 (1): 49-64

EFFECTS OF SUGARCANE STRAW BIOCHAR, COW MANURE-DERIVED VERMICOMPOST AND NPK FERTILIZERS ON PHOSPHORUS BIOAVAILABILITY AND GROWTH OF RADISH

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Abstract

Organic amendments generated from natural organic sources, such as animal manure, compost, and plant wastes, improve soil nutrient availability, plant nutrient content, and plant growth when compared to inorganic amendments. Therefore, this experiment was carried out to compare the effects of sugarcane straw biochar (SSB) and cow manure-derived vermicompost (CMV) with inorganic fertilizers (NPK) on radish (*Raphanus sativus* L.) growth, phosphorus (P) content, and soil P availability. Radish was cultivated in pots with sandy loam surface soil amended with four rates of SSB (5, 10, 20, and 40 t ha^{-1}), four rates of CMV (5, 10, 20, and 40 t ha^{-1}), and four rates of NPK fertilizer (25, 50, 75, and 100%). The optimal dose for radish is 100% NPK (N-P-K = 137–32–70 kg ha^{-1}). The use of amendments in the growth media had a significant impact ($p < 0.05$) on the number of leaves, fresh and dry weights of leaves and bulbs, the concentration of P in radish leaves and bulbs, and P availability in soil. CMV and NPK treatments significantly enhanced the growth metrics, phosphorus uptake by radishes, and extractable phosphorus in the soil as application rates increased. Compared to the recommended amount of NPK fertilizers (100%), CMV at 20 and 40 t ha^{-1} significantly ($p< 0.05$) increased growth metrics, P uptake, and extractable P in the soil. The effect of 100% NPK fertilizers was comparable to 5 t ha^{-1} CMV in terms of extractable P. There was a significant positive correlation ($p < 0.001$) between available P and dry matter yield, P concentration in leaves, and available P extracted with three different extractants. The findings show that CMV 40-ton ha^{-1} is an amendment that enhances plant growth and plant P sources, while SSB, at its current rate, does not achieve these results.

Keywords: Biochar, vermicompost, NPK fertilizer, extractable soil P, plant growth, P concentration

1. Introduction

The need for food production rises along with the global population, placing tremendous strain on our finite natural resources. Due to the growing demand for food, studies have shown that conventional farming is ineffective at improving soil quality or productivity, and that alternative farming methods are required to preserve the environment and protect natural resources. One of the most well-liked alternative methods is organic farming, which strives to enhance ecosystem health and productivity by using less artificial fertilizers and pesticides (Ghimire *et al.* 2023). However, the market for organic foods and drinks is expanding quickly within the global food business. Compared to conventional farming, organic farming techniques are more profitable, friendly to the environment, and produce crops that are either as nutritious or more nutritious with fewer or no pesticide residues (Das *et al.* 2022). The need to implement environmentally friendly agricultural practices for sustainable food production is strongly highlighted by the state of the world today.

Chemical fertilizers have a significant negative impact on soil quality, alter soil pH, and hasten the loss of microbial richness and variety in agricultural fields (Hossain *et al.* 2022). However, the limitation of available resources and inorganic fertilizer P-caused environmental pollution are serious worldwide challenges in the field of agriculture (Wato *et al.* 2024). The adjustment of P input, reduction of P loss, and the recycling of P in agricultural wastes such as manure, vermicompost, sugarcane trash, etc., are deemed to be effective strategies to reduce inorganic P inputs globally (Hridi *et al.* 2023). However, the cost of inorganic fertilizers is also rising day by day (Islam *et al.* 2018).

The use of inorganic fertilizers on a large scale is related to high cost, regional restrictions, and secondary pollution, making organic fertilizers, like animal dung, a key alternative. Organic fertilizers offer benefits such as improved soil health, reduced nutrient leaching, and minimized environmental pollution, in contrast to synthetic fertilizers (Das *et al.* 2022).

In addition, organic farming has been suggested as an environmentally beneficial, low-intensity cultivation method that depends on organic amendment for plant nutrition and natural products for defense against plant diseases and pests (Kashem *et al.* 2015). Since organic manures typically improve the physical, chemical, and biological qualities of soil, using them to meet crop nutrient requirements will become a necessary practice for sustainable agriculture in the years to come (Wato *et al.* 2024). Organic waste has been used as manure for millennia throughout the world, but work still needs to be done to examine the possible benefits of vermicompost and biochar on soil chemical characteristics and crop productivity, as well as finding the required application rates (Das *et al.* 2022). The problems faced by the people of Bangladesh are immense and require multiple solutions. Biochar is an emerging multi-purpose innovation that is rapidly attracting the attention of researchers (Khatun *et al.* 2024). Biochar, a more resistant carbon-rich by-product of organic material obtained from the thermal breakdown of biomass, can be used as a soil amendment, a tool for improving soil fertility and productivity while also fighting the global challenge of climate change (Khatun *et al.* 2024). Amending the cropland with biochar might increase water holding capacity (WHC) and cation exchange capacity (CEC) and disease resistance of plants due to high surface area (SA) and high porosity. Biochar has been serving as an agent for both soil remediation and carbon sequestration. Numerous studies have demonstrated that adding biochar to soil can increase its microbial community (Zheng *et al.* 2018), improve soil aeration and structure (Zheng *et al.* 2018), improve water holding capacity and nutrient availability, and promote crop growth and grain yield. Besides other organic amendments, vermicompost has emerged as the most important and commonly used organic fertilizer in recent years. Vermicomposting is a bio-oxidative process in which earthworms actively engage with other fauna and microorganisms in the decomposer community to change the physical and biochemical properties of organic matter and speed up its stabilization (Nieto-Cantero *et al.* 2025). Regarding plant growth, it promotes root growth and structure, germination, plant growth, and crop yield (Das *et al.* 2022). By recycling waste on-site, it also contributes to closing the "metabolic gap" and lowering greenhouse gas emissions. Furthermore, vermicompost reduces the mobility and bioavailability of heavy metal ions in the soil, which has the passivation impact on these ions and can lessen their toxicity to plants (Bhatia *et al.* 2024). Microorganisms of vermicompost have the ability to generate antagonistic or inhibitory effects against a variety of harmful bacteria that improves plants' susceptibility to disease (Nieto-Cantero *et al.* 2025).

Vermicompost and biochar are currently major organic amendment materials used in agricultural production and have demonstrated a number of benefits, including improved crop yield, increased soil fertility, and improved agricultural product quality (Muthukannan *et al.* 2024). More research is needed to fully understand how the variable nature of organic amendments impacts plant growth compared to inorganic fertilizers, especially in terms of optimizing their use for improved crop yields. Therefore, the objective of this study was to compare the effects of sugarcane straw biochar (SSB) and cow manure-derived vermicompost (CMV) with inorganic fertilizers (NPK) on radish (*Raphanus sativus* L.) growth, phosphorus (P) content, and soil P availability.

2. Materials and Methods

2.1 Preparation of vermicompost and sugarcane straw biochar

Vermicompost is made by breaking down the digestive tracts of *Eisenia fetida* earthworms using techniques outlined by Das *et al.* (2022). Sugarcane straw was gathered from the Hathazari market in Bangladesh (22°30'N 91°48'E) in order to create sugarcane straw biochar according to Jonathan Pollnow and the Student House Intern (Pollnow 2014). The pyrolysis temperature was in the range of 350-450 ºC.

2.2 Characteristics of soil and organic amendments

The hydrometer method of Day (1965) was used to analyze the particle sizes of the soil samples, and the United States Department of Agriculture's Marshall's triangle coordinates (1951) were used to determine the textural classes of the soil samples. The field capacity of the soil and the moisture content of the soil and amendments were measured using the procedures outlined by Black (1965). Jenway glass electrode pH meter (Jackson 1958) was used to measure pH of soil at 1:2.5 soil to water and 1:10 organic amendments to water ratio.

The organic carbon content of the soil and amendments was determined by wet oxidation (Walkley and Black 1934), and the percentage of organic matter was estimated by multiplying the organic carbon percentage by the Van Bemmelen factor of 1.724 (Piper 1950). A UV-Vis spectrophotometer (Shimadzu, Japan) was used to measure the total P content of the soil and organic amendments following digestion with H_2SO_4 + H_2O_2 + $LiSO_4$ (Akinremi *et al.* 2003). Phosphorus in the soil extract and digests was determined colorimetrically using the ascorbic acid blue color method (Murphy and Riley, 1962). A scanning spectrophotometer (UV-1800, Shimadzu, Japan) was used to measure absorbance at wave wavelength of 882 nm. Important properties of amendments and soil characteristics are shown in Table 1.

2.3 Plant growth experiment

Five kilograms of air-dried soil were placed in a pot with three drainage holes at the bottom. The pots were marked in accordance with the treatments. Four rates of SSB (5, 10, 20, and 40 t ha^{-1}), four rates of CMV (5, 10, 20, and 40 t ha^{-1}), and four rates of NPK (25, 50, 75, and 100%) fertilizers were mixed with soil. The 100% NPK (N-P-K = 137-32-70 kg ha^{-1}) is considered as recommended dose for radish. The sources of NPK fertilizers were urea, triple super phosphate (TSP), and muriate of potash (MP), respectively. The treatments applied to the soil were mixed thoroughly and moistened with water for 7 days for proper equilibration. The pots were arranged in a Completely Randomized Design (CRD). Five seeds were sown in each pot, and water was applied up to the field capacity.

The seeds were completely germinated within 7 days of sowing, and 3 healthy seedlings were kept in each pot. The water content of the pots was added to pots occasionally. Earthen plates were placed under each pot to collect any leachate and return it to the pot.

Table 1. Characteristics of soil and experimental materials

Physical properties		Soil	Sugarcane straw biochar	Cow manure vermicompost
Moisture Content (%)		5.39	0.75	8.25
Field Capacity (%)		25	-	
Particle size distribution (%)	Sand	70	-	-
	Silt	16	-	-
	Clay	14	-	-
Textural class		Sandy loam	-	-
Chemical properties			-	-
Organic carbon (%)		0.37	-	-
Organic matter (%)		0.64	-	
CEC (cmol(+) kg^{-1} soil)		4.55	-	-
pH		5.08 (1:2.5)	6.98 (1:10)	8.95 (1:10)
Total N (%)		0.067	5.23	4.67
Total P (mg kg^{-1})		210	5800	5300
Total K (mg kg^{-1}))		390	587	900

Plants were harvested as shoots and root bulbs after 60 days of sowing. Maximum height (cm), number of total leaves, fresh and weight of leaves and root-bulb were recorded. To measure dry mass, the plant parts were dried at room temperature for several days to remove excess water prior to oven drying at 65°C for 72 h. The dried samples were powdered in a mechanical grinder before being digested with conc. $H_2SO_4 + H_2O_2 + LiSO_4$ digestion mixture (Akinremi *et al.* 2003). Soil samples were collected from each pot after harvest to measure soil pH and available P. Soil P was extracted using 0.5 M $NaHCO_3$ (Olsen 1954), Mehlich-3 (Mehlich 1984), and Bray & Kurtz extractants (Bray and Kurtz 1945) methods. As previously stated, the amount of P in the different extracts and plant tissue was determined using the ascorbic acid blue color method (Murphy and Riley 1962). The reagent blank was utilized for quality control throughout the experiment.

2.4 Statistical analysis

Statistical analyses were conducted using Microsoft Excel 2020 and MINITAB software (Minitab, 2020). Significant differences among means were determined using ANOVA followed by Tukey's simultaneous range test at $p < 0.05$. Pearson correlation analysis was used to evaluate relationships between measured parameters.

3. Results

3.1 Growth parameters of radish

Sugarcane straw biochar (SSB), cow manure-derived vermicompost (CMV) and NPK fertilizer application significantly ($p<0.05$) increased growth parameters of radish. The values of growth parameters such as number of leaves, height of leaves, height of root-bulb, fresh and dry weight of leaves and root-bulb are presented in Table 2.

Table 2. Effect of SSB, CMV, and NPK fertilizers on the total number of leaves, the height of shoots and root-bulbs of radish, fresh and dry weight of shoots and root-bulbs

Treatment and Rate	Number of leaves	Height of shoot	Height of root-bulb	Fresh weight of shoot	Fresh weight of root-bulb	Dry weight of shoot	Dry weight of root-bulb
		(cm)			(g)		
Control	5.23 ±1.15d	30.5±3.25d	9.2±1.07c	9.99±1.31c	1.04± 0.52e	1.92±0.22	0.24±0.14d
SSB 5 (t ha^{-1})	5.73 ±0.57d	31.2 ±4.69d	10.4±2.8c	10.98±1.41c	1.11 ± 0.43e	1.98±0.51	0.41 ±0.14d
SSB 10 (t ha^{-1})	6.33±1.15c	34.7 ±2.89d	11.0±1.25c	11.41±3.92c	1.93±0.61e	1.95±0.62	0.48±0.12cd
SSB 20 (t ha^{-1})	6.66 ±0.57c	41.3± 4.19c	12.0±1.43b	12.95±3.09c	2.83±0.45e	2.14±0.79	0.72± 0.1c
SSB 40 (t ha^{-1})	7.33 ±1.15bc	42.9± 4.34c	12.7±1.23b	13.29±3.14c	3.21±1.48e	2.85± 0.31	0.87± 0.17c
CMV 5 (t ha^{-1})	8.66±1.15b	47.5±3.38bc	12.3±0.77b	11.53±2.05c	7.98±2.91d	2.18± 0.24	1.47±0.47c
CMV 10 (t ha^{-1})	8.66 ±2.65b	55.7±2.1b	13.4±0.94ab	16.8 ±3.19b	16.07±2.54c	2.36± 0.38	2.62 ±1b
CMV 20 (t ha^{-1})	9.66 ±1.15a	57.8±4b	15.3±1.66ab	20.79±4.23b	24.62±4.67b	3.56± 0.35	3.17 ±0.28a
CMV 40 (t ha^{-1})	10.33 ±1.15a	67.4±3.22a	16.1±2.19a	33.63±5.74a	37.74±6.34a	5.94±0.77	4.92 ±0.17a
NPK 25%	7.67 ±2.08b	52.3±3.13b	12.5±1.29b	18.33±2.62b	2.39±0.15e	2.86±1.0	0.75±0.09dc
NPK 50%	8.33 ±1.1b	57.8±4.65b	13.1 ±0.52a	20.48±0.73b	6.41 ±0.52d	3.06±0.72	1.16 ±0.29c
NPK 75%	8.67 ±1.15ab	58.8±3.78b	13.9±0.71ab	21.2±3.42b	13.53±2.72c	3.76±0.56	2.19±0.26b
NPK 100%	9.66 ±1.15a	66.6±4.13a	15.4 ± 1.05a	32.71±2.46a	25.69±3.6b	5.78±1.54	3.58±1.07a

All values are presented in table are mean of three replications; ±: standard deviation. SSB: sugarcane straw biochar; CMB: cow manure derived vermicompost; NPK: nitrogen phosphorus and potassium fertilizer. Different letters in each column indicate the difference of soil amendments.

The total number of leaves per pot was the highest of 10.33 in the pot treated with 40 t ha^{-1} CMV and lowest of 5.23 in the control pot. In the SSB amendments, the number of leaves increased gradually from 5.73 to 7.33, but no significant difference was observed among 5, 10 and 20 t ha^{-1} treatments and also between 20 t ha^{-1} and 40 t ha^{-1} treatments of SSB. In the case of CMV amendment, the number of leaves increased from 8.66 in the 5 t ha^{-1} treatment to 10.33 in the 40 t ha^{-1} treatment. The number of leaves was similar between 5 t ha^{-1} and 10 t $ha^{-1,}$ and between 20 t ha^{-1} and 40 CVM t ha^{-1} treatments of CMV. The application of NPK fertilizer increased the number of leaves from 7.67 in the 25% treatment to 9.66 in the 100% treatment. Among the amendments, the number of leaves increased in the order of: CMV>NPK>SSB (Table 2). Almost similar result is found in the case of the height of the shoot, which also significantly increased with the increasing rate of amendments. Here, 40 t ha^{-1} CMV-treated pot had the maximum height of shoot per pot (67.4 cm), while the control pot had the lowest height (30.5 cm).

The height of shoots in the SSB amendments steadily grew from 31.2 cm to 42.9 cm; there was a discernible difference between the 5, 10, and 20 t ha^{-1} treatments of STB, but not between 20 t ha^{-1} and 40 t ha^{-1} treatments. The height of leaves in the CMV amendment increased from 47.5 cm in 5 t ha^{-1} treatments to 67.4 cm in 40 t ha^{-1} treatments. The height of leaves increased from 52.3 cm in the 25% treatment of NPK fertilizer to 66.6 cm in the 100% treatment of NPK fertilizer. The height of leaves was as follows: CMV>NPK>SSB. In the case of the height of the root-bulb, the control pot had the lowest of 9.2 cm while 40 t ha^{-1} CMV treated pot had the highest height of the root-bulb of 16.1 cm. There was no appreciable difference between the 5, 10, and 20 t ha^{-1} SSB treatments, nor between 20 t ha^{-1} and 40 t ha^{-1} treatments, in terms of height of the root-bulb in the STB amendments, which increased gradually from 10.4 cm to 12.7 cm. The height of the root-bulb in the CMV amendment increased from 12.3 cm in 5 t ha^{-1} treatments to 16.1 cm in 10 t ha^{-1} treatments. In NPK treatment, we found a range of 12.5 cm to 15.4 cm height of root bulb according to different doses. So, the highest height of the root bulb found in CMV treated pots and the lowest was found in SSB treated pots and NPK treated pots shows a medium result between CMV and SSB, irrespective of amendment.

It was found that a remarkably equivalent result that rose considerably with the amendment rates regarding the fresh weight of shoots. Here, 40 t ha^{-1} CMV treated pot had the highest maximal fresh weight of leaves (33.63 g), while the control pot had the lowest overall fresh weight of leaves (9.99 g). The fresh weight of leaves in the SSB amendments increased gradually from 10.98 g to 13.29 g, with no difference between 5 t ha^{-1} and 10 t ha^{-1} STB treatments, or between 20 t ha^{-1} and 40 t ha^{-1} treatments. The fresh weight of shoots in the

CMV amendment rises to 33.63 g in 40 t ha^{-1} treatments from 11.53 g in 5 t ha^{-1} treatments. The fresh weight of shoots in the NPK treatment varied from 18.33 g to 32.71 g depending on the dose. Thus, regardless of amendment rates, the highest root bulb height was discovered in pots treated with CMV, the lowest in pots treated with SSB, and a median result was reported in pots treated with NPK.

Fresh weight of bulb was a significantly influenced ($p < 0.001$) by the amendments. Fresh weight of bulb of radish was the highest of 37.74 g pot^{-1} in the CMV (40 t ha^{-1}) treated pot and was the lowest of 1.04 g pot^{-1} in the control treatment. Fresh weight of bulb of radish increased gradually with the rates of three different amendments. Fresh weight of bulb of radish varied from 7.98 g in 5 t ha^{-1} to 37.74 g in 40 t ha^{-1} of CMV, from 1.11 g in 5 t ha^{-1} to 3.21 g in 40 t ha^{-1} of SSB and from 2.39 g in 50% to 25.69 g in 100% of NPK fertilizer treated pots. Among the amendments, the fresh weight of bulb increase was in the order of: CMV>NPK>SSB. Dry weight of radish leaves and bulbs were significantly ($p<0.001$) influenced by amendments as was observed in the case of other growth parameters of radish plants as mentioned above. Similar to fresh weight of shoots, dry weight of shoots of radish was the highest of 5.94 g pot^{-1} in the CMV (40 t ha^{-1}) treated pot and was the lowest of 1.92 g pot^{-1} in the control treatment (Table 2). Dry weight leaves of radish ranged from 2.18 g in 5 t ha^{-1} to 5.94 g in 40 t ha^{-1} of CMV, from 1.98 g in 5 t ha^{-1} to 2.85 g in 40 t ha^{-1} of SSB and from 2.86 g in 50% to 5.78g in 100% of NPK fertilizer-treated pots. There was a significant increase in the dry weight of shoots with the rates of all amendments. Dry weight of root bulb of radish increased with the rates of different amendments as did with the dry weight of shoots. Dry weight of bulbs of radish was the highest of 4.92 g pot^{-1} in the CMV (40 t ha^{-1}) treated pot and was the lowest of 0.2 g pot^{-1} in the control treatment. Dry weight of bulb of radish varied from 1.47 g in 5 t ha^{-1} to 4.92 g in 40 t ha^{-1} of CMV, from 0.41 g in 5 t ha^{-1} to 0.87 g in 40 t ha^{-1} of SSB, and from 0.75 g in 50% to 3.58 g in 100% of NPK fertilizer treated pots. Dry weight of bulb of radish was 0.24 g pot^{-1} grown in the control pot. The result of 100% NPK fertilizers was comparable to the result of 40 t ha^{-1} of CMV.

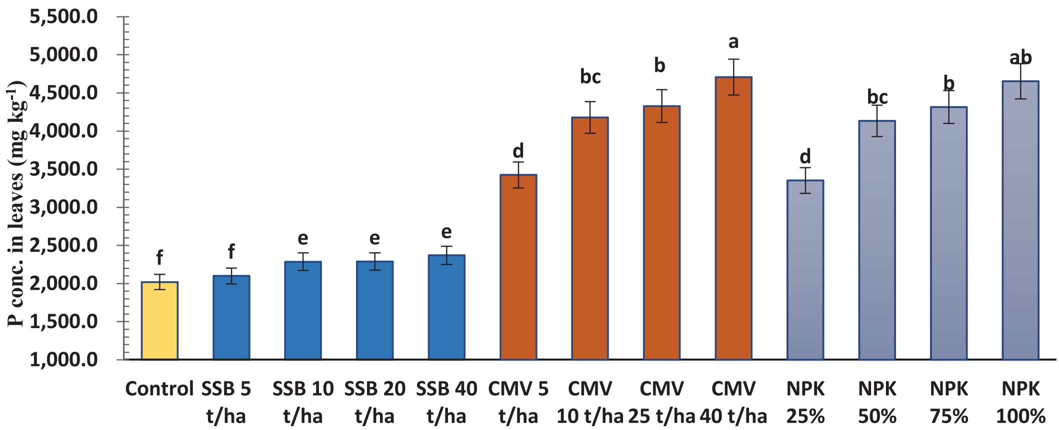
3.2 Phosphorus concentrations in plant parts of radish

Phosphorus concentrations in the radish leaves and root-bulbs were influenced significantly ($p < 0.001$) by the amendments. Concentrations of P gradually increased with the increase of their rates in both in leaves and in root-bulbs (Fig. 1) by the applications of CMV and NPK fertilizers, but not by the application of SSB amendments. Concentration of P in the leaves of radish was the highest of 4706 mg kg^{-1} in 40 t ha^{-1} of CMV-treated pot and was the lowest of 2021 mg kg^{-1} in the control treatment. Concentrations of P in the radish leaves increased from 3425 mg kg^{-1} in 5 t ha^{-1} to 4706 mg kg^{-1} in 40 t ha^{-1} of CMV, from 2100 mg kg^{-1} in 5 t ha^{-1} to 2370 mg kg^{-1} in 40 t ha^{-1} of SSB and from 3352 mg kg^{-1} in 50% to 4653 mg kg^{-1} in 100% of NPK fertilizer treated pots, respectively. Irrespective of rates, P concentrations were higher in the leaves of CMV and NPK-treated pots and lower in SSB-treated pots (Figure 1). The phosphorus concentration in the root-bulbs of radish reached a maximum of 3821 mg kg^{-1}

in pots treated with 40 t ha^{-1} of CMV, whereas the minimum was 1790 mg kg^{-1} in the control treatment. The phosphorus concentrations in radish leaves rose from 2563 mg kg^{-1} at 5 t ha^{-1} of CMV to 3821 mg kg^{-1} at 40 t ha^{-1}, from 1814 mg kg^{-1} at 5 t ha^{-1} to 2081 mg kg^{-1} at 40 t ha^{-1} of SSB, and from 2773 mg kg^{-1} at 50% to 3755 mg kg^{-1} at 100% of NPK fertilizer treated pots. Phosphorus concentrations rose in accordance with the rates of amendments.

2.3 Available P in amended soils after plant harvest

In this study, three different extractants were used to determine the available phosphorus concentration in soil after plant harvest. The extractants used were Olsen (Olsen *et al.,* 1954), Mehlich-3 (Mehlich, 1984) & Bray & Kurtz (Bray and Kurtz, 1945). The value of available phosphorus extracted after harvest is presented in Table 3. The amount of available P extracted with 0.5 M $NaHCO_3$ (Olsen), Mehlich-3 and Bray & Kurtz-1 methods ranged from 1.85 to 17.57 mg kg^{-1}, 3.24 to 21.78 mg kg^{-1}and 3.65 to 19.53 mg kg^{-1} respectively (Table 3). The amount of available P increased with the rates of treatments regardless of amendments and methods. Among the treatments, the maximum amount of available P extracted by three methods was observed in 40 t ha^{-1} CMV treatment, and the minimum in the control. The amount of available P varied markedly, depending on the treatments and extractants used. The mean values of P extracted by different extractants were in the order: Mehlich-3 P > Bray and Kurtz-1 P > Olsen P.



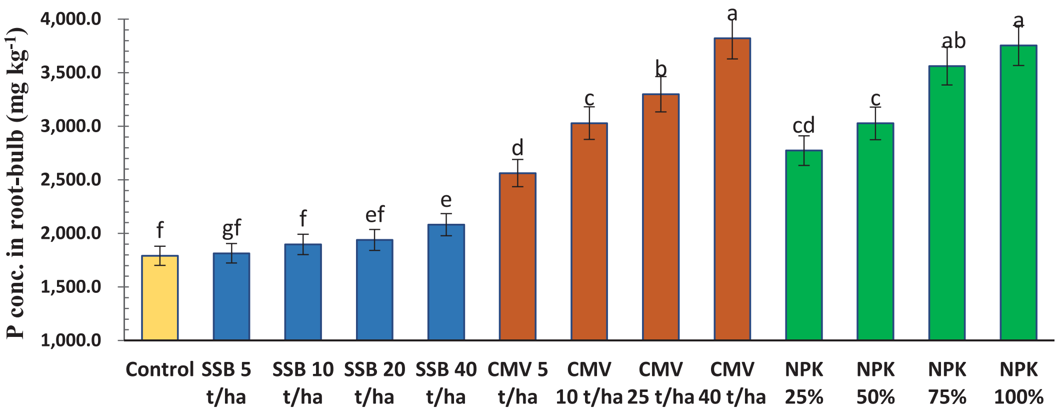


Fig. 1 Effect of SSB, CMV, and NPK fertilizers on P concentration in leaves and root-bulbs of radish. All values are presented in bars are mean of three replications; SSB: sugarcane straw biochar; CMB: cow manure derived vermicompost; NPK: nitrogen phosphorus and potassium fertilizer. Different letters in each bar indicate the difference of soil amendments.

3.4 Correlation among extractable P, dry matter yield, and P concentrations in radish

The P values extracted with different methods were significantly and positively correlated ($r = 0.573$ to 0.994, $P < 0.001$) with each other. The best correlation was found between Mehlich-3 P and Bray and Kurtz-1 P ($r = 0.994$). Extractable P measured from three extractants also showed positive relationship with P concentrations in plant tissue ($p<0.05$) (results are not shown) indicating that any of these extractants can be used to estimate bioavailable P. The level of significance was fitted to the graph as given in Figure 2 and 3. Regardless of extractants, extractable P showed a very strong positive correlation with dry matter yield and the same was true between plant P concentrations and dry matter yield of radish's plant parts (Fig. 2 and 3).

Table 3. Effect of SSB, CMV, and NPK fertilizers on bioavailable P in soils (mg kg^{-1})

Treatment	Rate	Olsen P	Mehlich-3 P	Bray & Kurtz P
Control	0	1.85 ± 0.59d	3.24 ± 0.37d	3.65 ± 0.31c
	5 (t ha^{-1})	2.77 ± 0.98d	5.15 ± 1.63c	3.81 ± 1.02c
	10 (t ha^{-1})	3.16 ± 0.54c	5.88 ± 0.87c	4.28 ± 0.3c
	20 (t ha^{-1})	3.15 ± 0.25c	6.91 ± 0.55c	4.96 ± 0.28c
	40 (t ha^{-1})	4.08 ± 1.43c	7.54 ± 2.04bc	5.13 ± 1.85c
CMV	5 (t ha^{-1})	5.33 ± 0.25b	7.96 ± 1.42b	6.78 ± 0.7bc
	10 (t ha^{-1})	6.56 ± 0.81b	10.78 ± 0.4b	8.36 ± 1.69b
	20 (t ha^{-1})	11.96 ± 0.75a	12.55 ± 3.7b	10.68 ± 2.41b
	40 (t ha^{-1})	17.57 ± 2.4a	21.78 ± 2.39a	19.53 ± 0.5a
NPK	25%	3.16 ± 0.61c	3.4 ± 0.55c	3.06 ± 0.4c
	50%	4.1 ± 0.78c	4.05 ± 0.39c	4.58 ± 0.36c
	75%	4.92 ± 0.5bc	5.33 ± 0.38c	5.18 ± 0.37c
	100%	5.23 ± 1.15b	7.95 ± 1.27b	6.15 ± 0.78bc

All values are presented in table are mean of three replications; ±: standard deviation. SSB: sugarcane straw biochar; CMB: cow manure derived vermicompost; NPK: nitrogen phosphorus and potassium fertilizer. Different letters in each column indicate the difference of soil amendments.

4. Discussion

This study assessed the impact of cow manure-derived vermicompost (CMV), sugarcane straw biochar (SSB), and NPK fertilizers on the growth performance and phosphorus (P) dynamics in radish (*Raphanus sativus* L.). The findings indicated that CMV, SSB and NPK applications behaved differently on the parameters studied. The type and rate of amendment applied significantly influenced the number of leaves per plant, shoot height, root-bulb height, and biomass production (both fresh and dry weight). The treatment with CMV at a rate of 40 t ha^{-1} yielded the greatest values across all growth parameters. This improvement is likely attributable to CMV's abundant organic matter and nutritional composition, which promote soil fertility and the availability of nutrients for plants (Das *et al.* 2022). Recent research indicates that vermicompost applications can markedly improve plant development characteristics by enhancing soil structure and nutrient availability (Muthukannan *et al.* 2024). The sugarcane straw biochar treatments demonstrated only marginal enhancements compared to the control and exhibited no substantial dose-dependent effects on growth parameters. The restricted impact may be ascribed to the protracted breakdown and nutrient release characteristics of biochar, especially when it is not enhanced nor amalgamated with additional nutrient sources (Hridi *et al.* 2023). Nevertheless, aged biochar has demonstrated superior efficacy in enhancing soil characteristics and promoting plant growth compared to fresh biochar (Enamul et al. 2025; Nyambo *et al.* 2023). Moreover, rice husk biochar has been documented to improve soil health and promote radish plant growth by enhancing soil pH, organic carbon levels, and microbial activity (Enamul *et al.* 2025; Gautam *et al.* 2024).

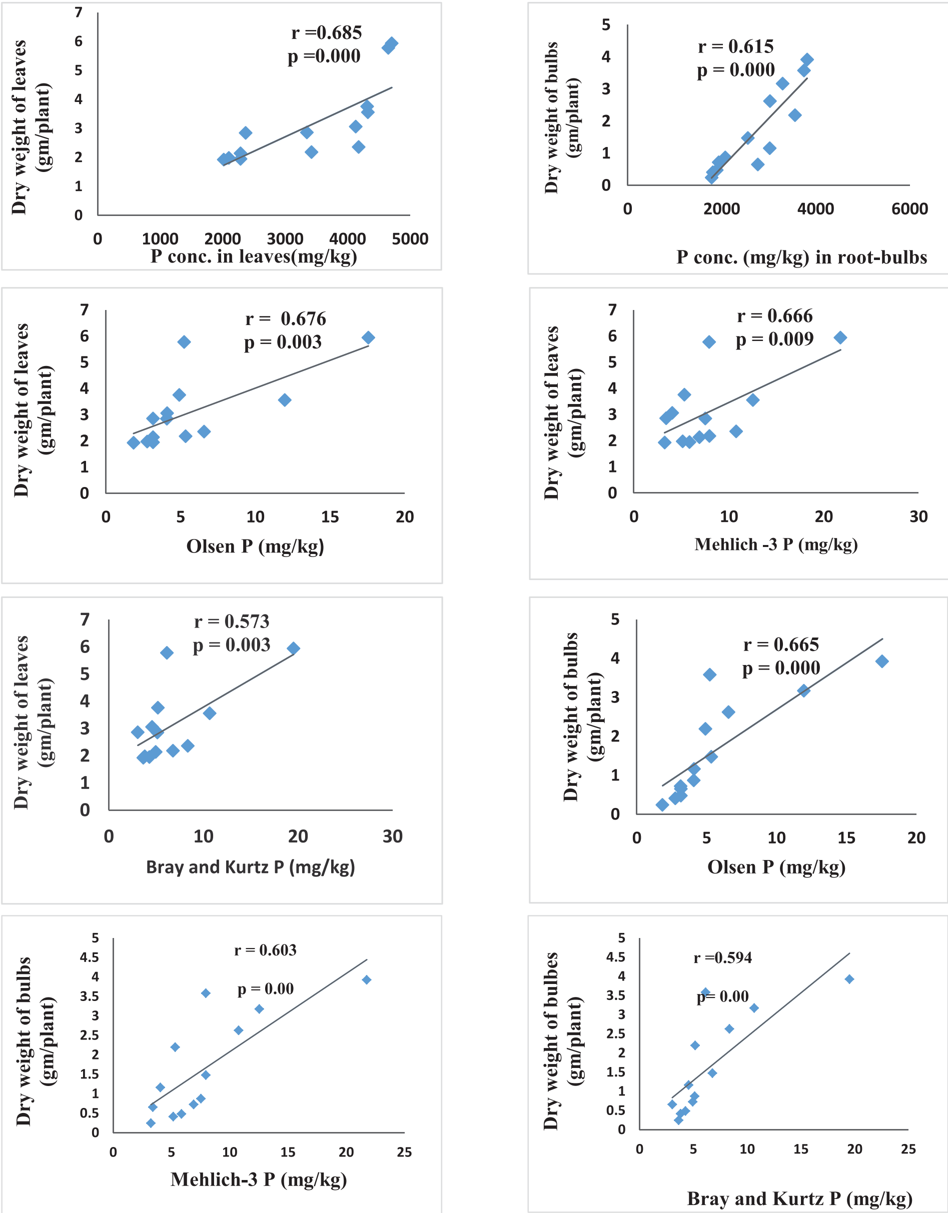


Fig. 2 Pearson correlation coefficient among dry matter yield, and P concentrations in radish

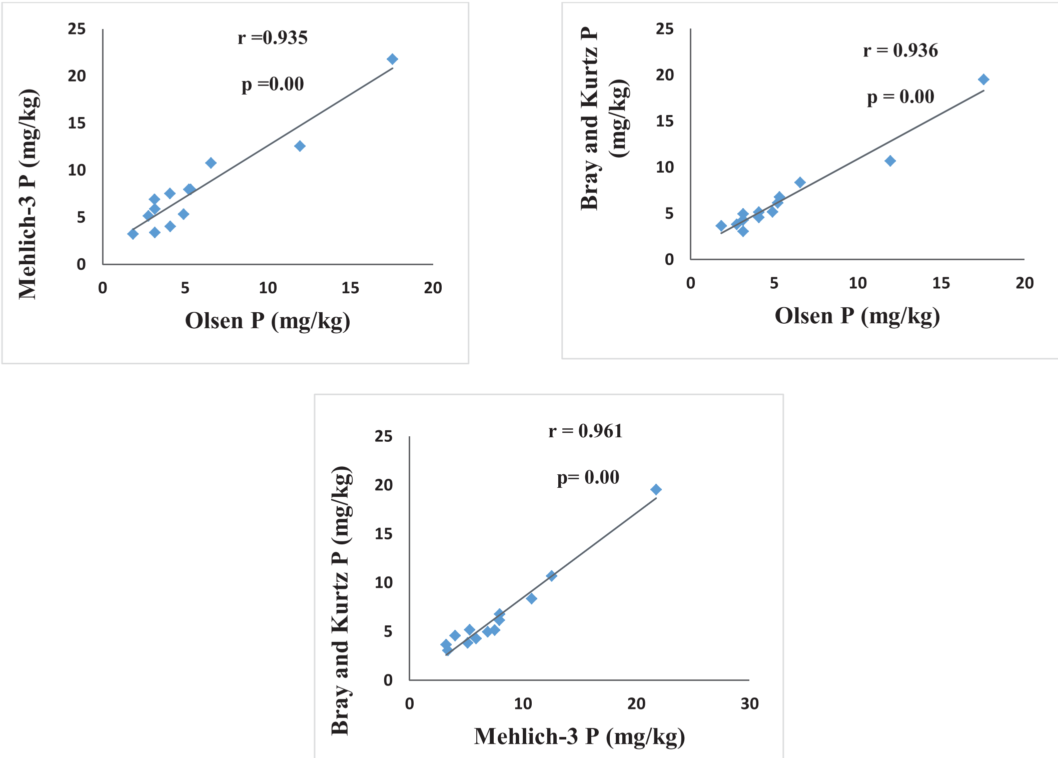


Fig. 3 Pearson correlation coefficient among extractable P.

The NPK fertilizers significantly enhanced plant growth but typically exhibited intermediate outcomes between CMV and SSB. Synthetic fertilizers, while accessible to plants, may lose efficacy over time due to leaching losses or insufficient enhancement of soil structure. Enhancing NPK fertilization rates has demonstrated an increase in production and nutrient use efficiency in radish agriculture (Choi *et al.* 2022). The advantage of CMV may be attributed to the presence of humic compounds and microbial activity that enhance nutrient mineralization and absorption. The application of vermicompost has been linked to enhanced biomass production in several crops, attributed to improved nutrient availability and soil health (Das *et al.* 2022; Muthukannan *et al.* 2024). These findings are similar to earlier research indicating enhanced crop growth and yield with organic nutrient management relative to the exclusive use of chemical fertilizers. The similar efficacy of 100% NPK and 40 t ha^{-1} CMV in certain parameters indicates the viability of organic supplements as sustainable substitutes for synthetic fertilizers. Organic amendment additions such as CMV not only supply nutrients directly but also enhance microbial activity and phosphorus mineralization in the rhizosphere. Applications of vermicompost have demonstrated an increase in phosphorus availability and absorption in plants (Das *et al.* 2022; Nieto-Cantero *et al.* 2025).

The limited effectiveness of SSB in enhancing phosphorus uptake may be attributed to its elevated carbon-to-nitrogen ratio or potential phosphorus adsorption on the biochar surface. Biochar additions have been shown to enhance phosphorus retention and availability in soils, especially when aged or used in conjunction with fertilizers (Ahmed *et al.* 2024).

Moreover, the application of biochar has demonstrated an enhancement in phosphatase activity, hence augmenting phosphorus availability via microbial activities (Zhang, 2025). The elevated phosphorus contents in CMV-treated plants correspond with findings that vermicompost improves nutrient solubility and phytoavailability owing to its fine texture, microbial load, and enzymatic activity. Consequently, CMV enhances development and facilitates food assimilation (Kashem *et al.* 2015; Das *et al.* 2022). These findings highlight the potential of CMV as an eco-friendly, nutrient-dense amendment capable of substituting or diminishing reliance on artificial fertilizers. The enhanced plant growth and phosphorus uptake underscore its significance in sustainable agriculture, particularly within organic or low-input farming systems. NPK fertilizers effectively increase short-term yield; however, their combination with organic sources such as CMV could improve long-term productivity and soil health.Conversely, whereas SSB may not demonstrate immediate advantages in short-cycle crops, its utilization may be more appropriate for long-term soil enhancement and warrants more investigation within integrated nitrogen management frameworks. Significant positive relationships P concentrations in plant parts with extractable P in soils indicates that any of the extractants could be used to assess available P in soil.

5. Conclusions

The use of cow manure derived vermicompost (CMV), sugarcane straw biochar (SSB), and NPK fertilizers significantly influenced on the growth parameters (the number of leaves, fresh and dry weights of leaves and root-bulbs), and P availability in the soil. The growth metrics and P uptake increased with increasing application rates of CMV and NPK amendments but not with SSB. Overall, these results suggest that CMV at 40 t ha^{-1} is a promising amendment for enhancing plant growth and P sources, while SSB, at its current rate and growth period, showed limited effectiveness in this regard. Our findings indicate that CMV at 40 t ha^{-1} is a potential amendment for improving plant growth and bioavailable P source.

Conflicts of Interest

The authors declare no conflicts of interest regarding publication of this paper.

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