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Vermichar as nutrient supplement for soil improvement and glutinous corn productivity

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Abstract

This study evaluated the effects of vermichar on soil chemical properties, growth, yield, and economic returns of glutinous corn (*Zea mays* L.). It aimed to determine the optimal vermichar application rate and compare its performance with conventional NPK fertilizers. Treatments included vermichar at 5, 10 and 15 bags per hectare, alone or combined with NPK. Results showed that vermichar significantly improved soil pH, organic matter, and nutrient levels especially nitrogen, phosphorous, and potassium when applied with commercial NPK. The best soil improvement and highest yields were observed with 10-15 bags per hectare. Growth metrics such as plant height, ear size, and biomass increased with these treatments. While combining vermichar with NPK boosted yields, the highest return on investment was achieved with vermichar alone at 10 bags per hectare, outperforming the sole use of commercial fertilizer. This highlights vermichars potential as cost-effective and sustainable soil amendment. The study recommends using vermichar at optimized rates, particularly 10 bags per hectare for improved soil health, yield and profitability in glutinous corn production.

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Introduction

Agricultural production in the country is low and cannot sustain its growing population. Climate change-induced high rainfall variability and temperature fluctuations are blamed for the low agricultural productivity amongst smallholder farmers. Additionally, land degradation had resulted in shrinkages in the cultivated land and abandonment of crop fields which is worsened by the anthropogenic activities that lead to the depletion of soil organic carbon, a vital constituent of soil quality. Most farmers in the continent are resource-poor and therefore practice low input agriculture, continuous crop monoculture and use heavy soil tilling methods that enhance the decomposition of the already low soil organic carbon. Researchers have devised several interventions like conservation agriculture, but adoption remains poor owing to various associated issues like trade-offs. In addition, the response of soil to these interventions requires several years in most cases, and most smallholder farmers are not patient for that long. Researchers have recently been calling for other supplementary and climate-smart strategies that increase soil organic matter, nutrients and reduce greenhouse gas emissions.

Vermicomposts as soil amendment has multiple benefits such as improving soil health, minimizing the disease threat, and controlling soil erosion. Vermicompost is produced by the effective interaction of microbes and earthworms that could be used to improve soil fertility. During the vermicomposting, microbes are mainly involved in the biochemical decomposition of organic matter; whereas earthworms drive the process by acclimatizing the substrate which produces a stable soil conditioner called vermicompost. They boost the availability of mineral nutrients including nitrogen, phosphorus (seven-folds), potassium (eleven-folds), and magnesium (two-folds) in the soil. On the other hand, biochar has been accepted as a sustainable approach because it possesses properties such as high binding capacity and environmental safety. Known as black carbon, biochar is a fine-grained porous and carbonaceous solid material synthesized from waste biomass residues under limits oxygen conditions and low to medium temperatures by slow pyrolysis. Biochar can be produced by thermal decomposition of various kinds of organic feedstocks such as crop biomass, wood, agricultural residues (cereal straw, hazelnut, and peanut shell, wheat straw), and industrial organic waste (sewage sludge and de-inking paper sludge.

The potential of vermchar (combination of vermicompost and biochar) as viable soil amendments and nutrient sources for hybrid corn production is explored in this study. Specifically, to assess the impact of vermichar application soil chemical properties such as pH, organic matter including its macro and micro nutrients. Another is to determine the optimal rate of vermichar and compare it's on conventional fertilizer application for maximizing the growth and yield performance of glutinous corn. Lastly, to conduct a cost and return analysis of using vermichar as a soil supplement in glutinous corn cultivation compared to traditional methods.

Materials and methods

Production of vermichar

Biochar was produced via pyrolysis using poultry manure-corn cobs at a ratio of 60:40. The vermicompost was obtained from the vermicomposting facility of the University. VermiChar was produced by mixing homogeneously the vermicompost and biochar in equal amount (50:50). One-half kilogram sample of the vermichar products were brought to Regional Soil Analytical Laboratory, Tuguegarao City for analysis of pH, organic matter content, total nitrogen, available phosphorus, exchangeable potassium and other micronutrients.

Collection of soil aamples and analysis

Soil samples were randomly collected from the experimental area before the land preparation. The soil samples were processed by pulverizing, air drying, grinding, and screening. A one-kilogram of the composite soil sample was set aside and will also be submitted at the Integrated Soils Laboratory –

Cagayan Valley Research Center, City of Ilagan, Isabela for the analysis of pH, OM, N, P, K, Ca, Mg S, and micronutrients.

Land preparation

The experimental area of 450.50 square meters was cleared of grasses, stubbles, and other foreign materials to facilitate thorough land preparation. The area was plowed initially by tractor, and it was left idle for one week for the weeds to decay, second plowing and harrowing using an animal drawn plow was two days before planting. Furrows were constructed at 75 centimeters apart.

Construction of furrows and planting

After the final harrowing, furrows were constructed using an animal-drawn plow at distance of 75 centimeters apart. Glutinous corn (IES Glut) was used in the study. Two seeds were planted in each hill at a distance of 20 centimeters. The seeds were covered with fine soil and was lightly pressed to ensure full contact of seeds and soil. After 5 days, replanting of missing hills was done to ensure that there is no missing hill and maintain the same number of plants per plot.

Experimental design and treatments

The experimental area was divided into three blocks and each block have a dimension of 5 meters x 36 meters. An alley way of one meter between blocks was provided. Each block was further subdivided into six equal plots. Each experimental unit has an area of 20 square meters with a dimension of 5 m x 4 m and were spaced one half meter apart. The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications.

The following treatments were evaluated in this study:

Treatment 1- Control

Treatment 2- RR NPK using traditional fertilizer

Treatment 3- RR (inorganic) + 0.5 RR of amendment (vermichar)

Treatment 4- RR (inorganic) + RR of amendment (vermichar)

Treatment 5- RR (inorganic) + 1.5 RR of amendment (vermichar)

Treatment 6- RR of amendment (vermichar)

Application of fertilizer

Results of the soil analysis were the basis for the amount and kind of fertilizers applied in all the treatments. The reference fertilizers for this study were complete fertilizer (14-14-14), ammonium phosphate (16-20-0) and urea (45-0-0). One-half of the recommended amounts of nitrogen and full amount of the phosphorus and potassium was applied as basal (10 DAT) while the remaining one-half of nitrogen were side dressed during hilling-up at 25 days after planting. For the biochar, vermicast and vermichar, soil amendments were applied within the furrows before planting at the rate of 3 ton/ha^{-1}.

Care and management of the crop

Off baring was done three weeks after planting that is when the corn plants was at knee level. Hand weeding was done to control weeds during the period of the trial. Cultivation was done 30 days after planting using a spade. Regular monitoring of the plants was done to prevent disease outbreaks. Infected plants showing unusual signs and symptoms were immediately removed from the area. Insect infestation was managed by applying insecticides to the target insect pest following the manufacturer's recommendation.

Harvesting

The green corn was harvested at soft dough stage. Twelve representative plant samples were randomly selected from each plot for data gathering. All the corn ears obtained from the 12 sample plants removed for length, diameter, and weight while the whole plant was cut at ground level. These sample plants were set aside for biomass weight and corn ear yield per net plot. The number of plants per net plot of 9 m^2 was counted.

Results and discussion

Characteristics of vermichar

The formulated vermichar products were analyzed for soil organic matter (SOM) and nitrogen (N), phosphorous (P), and potassium (K). Table 1 summarizes the nutrient content of the soil amendments. Vermichar derived from a mixture of vermicast and biochar exhibited high organic matter content with 11.86%. Organic matter serves as a reservoir of nutrients and water in the soil, thus reducing compaction and surface crusting, and also enhances water infiltration. Organic matter plays a crucial role in soil health by serving as a reservoir of nutrients and water, reducing compaction and surface crusting, and enhancing water infiltration. It significantly contributes to plant growth by positively influencing the soil's physical, chemical, and biological properties. The presence of organic carbon in compost further improves these properties.

Table 1. Nutrient composition of vermichar

	SOM (%)	N (%)	P (%)	K (%)	NPK
Vermichar (50:50)	11.86	0.59	4.41	0.45	5.45

The total nitrogen content of the vermichar was relatively low at 0.59%, while phosphorus and potassium levels were 4.41% and 0.45%, respectively. The combined NPK content of 5.45% exceeds the minimum 5% threshold required for a material to be classified as organic, according to the Philippine National Standards (PNS) for Organic Fertilizer. The carbon-to-nitrogen (C/N) ratio of the product was 11.64, which is considered narrow and indicates that the product is well-matured and suitable for agricultural use. Ratios below 20 suggest adequate maturity, with values of 15 or lower being preferable (Inbar *et al.*, 1990).

Organic amendments with lower C/N ratios decompose more rapidly than those with higher ratios, promoting faster nutrient release. This low C/N ratio suggests that the vermichar and its resulting soil organic matter fractions are relatively rich in nitrogen and lower in carbon.

The potential increase in soil organic matter will depend on the total biomass produced by the vermichar, its C/N ratio, and how it is managed. Additionally, the vermichar contains essential micronutrients such as copper (35 ppm), zinc (247.50 ppm), manganese (555 ppm), and iron (38,337 ppm), and likely includes other micronutrients not captured in the current analysis. These trace elements are often absent in standard formulations of inorganic fertilizers available in the market.

Effect of vermichar on selected soil properties

Soil pH

The effects of vermichar application on soil pH across various treatment groups is shown in Table 2. The control group (T1) exhibited a soil pH of 6.02, indicating slightly acidic conditions. The application of NPK fertilizer alone (T2) increased soil pH to 8.01, reflecting a shift toward alkalinity. Subsequent treatments involving vermichar at application rates of 5 (T3), 10 (T4), and 15 (T5) bags per hectare, either alone or in combination with NPK, resulted in pH values of 7.90, 7.92, and 8.03, respectively. Notably, vermichar applied alone at 10 bags per hectare (T6) produced the highest pH reading of 8.15.

Table 2. Soil pH as influenced by vermichar application

Treatments		Soil pH
T_1	Control	6.02 b
T_2	90-60-30 kg ha^{-1} NPK	8.01 a
T_3	90-60-30 kg ha^{-1} NPK + 5 bags ha^{-1}	7.90 a
T_4	90-60-30 kg ha^{-1} NPK + 10 bags ha^{-1}	7.92 a
T_5	90-60-30 kg ha^{-1} NPK + 15 bags ha^{-1}	8.03 a
T_6	Vermichar @10 bags ha^{-1}	8.15 a

Means with common letters are not significantly different with each other using Tukey's HSD.

Statistical analysis revealed that Treatments T2 through T6 significantly increased soil pH compared to the control (T1). However, no significant differences were observed among T2 to T6, indicating that the addition of vermichar at varying rates does not further increase soil pH beyond the effect achieved with NPK fertilizer alone.

These results are consistent with previous studies emphasizing the role of biochar-based amendments, such as vermichar, in enhancing soil pH. For example, Ahmad *et al.* (2024) reported that the application of vermichar at 10 bags per hectare raised soil pH from 6.15 (control) to 7.69, demonstrating its ability to neutralize acidic soils. Similarly, Khan *et al.* (2024) found that vermichar application alone increased soil pH by 1.65 units, further confirming its effectiveness in pH modification.

The absence of significant differences among vermichar-amended treatments suggests that a moderate application rate—specifically 10 bags per hectare—is sufficient to attain optimal soil pH levels. This finding has practical implications for agricultural management, as it implies that higher application rates may not yield additional benefits for pH adjustment and could lead to unnecessary input costs. Moreover, improving soil pH through vermichar application can enhance nutrient availability, promote microbial activity, and ultimately contribute to better soil health and crop productivity.

Organic matter, nitrogen, exchangeable phosphorous and potassium

The changes in organic matter content following the application of three rates of vermichar are presented in Table 3. Soil organic matter (SOM) levels varied significantly across the treatments. The control treatment (T1) exhibited the lowest SOM value at 1.90%, indicating limited organic enrichment in the absence of amendments. All treatments that included NPK fertilizer (T2 to T5) resulted in substantial increases in SOM, with the highest value of 6.72% observed in T4 (NPK + 10 bags vermichar ha^{-1}). This finding suggests that the combined application of NPK and a moderate rate of vermichar is more effective in enhancing soil organic carbon than either input used alone. While the application of vermichar alone (T6) also improved SOM to 3.40%, this value was significantly lower than those observed in the integrated treatments, highlighting the greater efficacy of combined nutrient management strategies in improving soil organic matter content.

Table 3. Macronutrient composition of soil applied with vermichar

Treatment	Chemical properties			
	SOM (%)	N (%)	P (ppm)	K (ppm)
T_1 Control	1.90 c	0.10 c	10.22 c	111.30 c
T_2 90-60-30 kg ha^{-1} NPK	4.73 abc	0.24 abc	240.15 b	1762.66 ab
T_3 90-60-30 kg ha^{-1} NPK + 5 bags ha^{-1}	4.31 abc	0.22 abc	256.28 b	1225.12 abc
T_4 90-60-30 kg ha^{-1} NPK + 10 bags ha^{-1}	6.72 a	0.34 a	396.81 ab	1945.16 ab
T_5 90-60-30 kg ha^{-1} NPK + 15 bags ha^{-1}	6.01 ab	0.30 ab	438.01 a	2287.17 a
T_6 Vermichar @10 bags ha^{-1}	3.40 bc	0.17 bc	272.53 b	1096.54 c

Means with common letters are not significantly different with each other using Tukey's HSD.

Table 3 also reveals significant differences in the nitrogen content between the organic-treated soils and the control. The pattern of nitrogen accumulation closely mirrored that of soil organic matter. The control plot (T1) recorded the lowest nitrogen level at 0.10%.

Treatments involving NPK (T2 to T5) significantly increased nitrogen content, with T4 (NPK + 10 bags vermichar ha^{-1}) exhibiting the highest concentration at 0.34%. This highlights the synergistic effect of combining vermichar with NPK in promoting nitrogen accumulation in the soil. Although vermichar alone (T6) improved nitrogen content to 0.17%, it was still notably lower than the integrated treatments, reinforcing the idea that the combination of vermichar and NPK enhances nitrogen availability—likely through improved microbial activity and enhanced mineralization of organic nitrogen.

Among the macronutrients assessed, phosphorus showed the most substantial increase. The control (T1) had the lowest phosphorus concentration at 10.22 ppm, whereas T5 (NPK + 15 bags vermichar ha^{-1}) recorded the highest level at 438.01 ppm, followed by T4 (396.81 ppm), indicating a clear dose-dependent response. Vermichar alone (T6) also contributed appreciably to phosphorus availability (272.53 ppm), but its combination with NPK significantly amplified phosphorus levels. This suggests that vermichar may improve phosphorus availability by reducing fixation and enhancing microbial mobilization, particularly when supplemented with phosphorus-rich chemical fertilizers.

Potassium content followed a similar trend. The lowest value was observed in the control (T1) at 111.30 ppm, while the highest was recorded in T5 (2287.17 ppm), reflecting the cumulative impact of high vermichar rates and NPK fertilization. Vermichar alone (T6) yielded a potassium level of 1096.54 ppm—substantially higher than the control but lower than NPK-inclusive treatments. These results underscore vermichar's role as a valuable source of potassium, with its nutrient contribution maximized when applied alongside conventional fertilizers.

Micronutrient content of soil

Table 4 presents the micronutrient composition of soil treated with vermichar, focusing on copper (Cu), iron (Fe), manganese (Mn), and zinc (Zn) concentrations. The results show that the control treatment (T1) had relatively low micronutrient levels, with Cu at 1.67 ppm, Fe at 90.82 ppm, Mn at 5.27 ppm, and Zn at 1.30 ppm. The application of NPK fertilizer (T2) did not significantly increase Cu, Fe, Mn, or Zn levels compared to the control, although Fe levels were notably reduced to 41.00 ppm.

Table 4. Micronutrient composition of soil applied with vermichar

Treatment		Chemical properties (ppm)			
		Cu	Fe	Mn	Zn
T_1	Control	1.67 b	90.82 a	5.27 c	1.30 d
T_2	90-60-30 kg ha^{-1} NPK	1.68 b	41.00 b	8.67 bc	5.20 cd
T_3	90-60-30 kg ha^{-1} NPK + 5 bags ha^{-1}	2.09 ab	55.60 b	8.87 bc	6.13 bcd
T_4	90-60-30 kg ha^{-1} NPK + 10 bags ha^{-1}	3.75 a	66.93 ab	14.40 a	10.13 abc
T_5	90-60-30 kg ha^{-1} NPK + 15 bags ha^{-1}	4.01 a	54.53 b	13.20 ab	11.60 a
T_6	Vermichar @10 bags ha^{-1}	2.29 ab	41.20 b	6.30 c	11.33 ab

Means with common letters are not significantly different with each other using Tukey's HSD.

Table 5. Plant height (cm) of glutinous corn applied with vermichar

Treatments		Plant height (cm)		
		30 DAT	60 DAT	90 DAT
T_1	Control	67.40 d	77.79 e	94.13 c
T_2	90-60-30 kg ha^{-1} NPK	80.47 bc	89.89 c	109.07 b
T_3	90-60-30 kg ha^{-1} NPK + 5 bags ha^{-1}	84.53 b	91.59 bc	112.37 ab
T_4	90-60-30 kg ha^{-1} NPK + 10 bags ha^{-1}	87.47 ab	94.21 b	116.20 ab
T_5	90-60-30 kg ha^{-1} NPK + 15 bags ha^{-1}	93.17 a	101.53 a	121.37 a
T_6	Vermichar @10 bags ha^{-1}	72.13 cd	84.03 d	99.40 c

Means with common letter/s are not significantly different with each other using HSD Test

The addition of vermichar in combination with NPK fertilizer (T3, T4, T5) resulted in varied changes in the micronutrient concentrations. Treatment T3 (5 bags of vermichar) increased Cu to 2.09 ppm, Mn to 8.87 ppm, and Zn to 6.13 ppm, but Fe remained low at 55.60 ppm.

Treatments T4 and T5, which included 10 and 15 bags of Vermichar, showed the most significant improvements in Cu (3.75 and 4.01 ppm), Mn (14.40 and 13.20 ppm), and Zn (10.13 and 11.60 ppm). These results suggest that the higher rates of Vermichar application significantly increased the availability of these micronutrients, with T5 (15 bags of vermichar) achieving the highest concentrations of Cu, Mn, and Zn.

Effect of vermichar on growth and yield of glutinous corn

Plant height

Table 5 presents the average plant height of glutinous corn under various treatments, including the application of vermichar and inorganic NPK fertilizer at 30, 60, and 90 days after transplanting (DAT). The control treatment (T1) consistently resulted in the shortest plant heights across all stages, with values of 67.40 cm at 30 DAT, 77.79 cm at 60 DAT, and 94.13 cm at 90 DAT. In contrast, treatments involving the application of NPK fertilizer, either alone (T2) or in combination with increasing amounts of vermichar (T3, T4, T5), demonstrated significant increases in plant height compared to the control.

The highest plant heights were observed in treatment T5 (NPK + 15 bags of vermichar), with measurements of 93.17 cm at 30 DAT, 101.53 cm at 60 DAT, and 121.37 cm at 90 DAT.

These results indicate that the combination of NPK fertilizer and vermichar at a higher application rate (15 bags per hectare) significantly promoted plant growth throughout the growing season. Treatment T4 (NPK + 10 bags of vermichar) also resulted in notable improvements in plant height relative to the control, with heights of 87.47 cm at 30 DAT, 94.21 cm at 60 DAT, and 116.20 cm at 90 DAT. Although treatment T3 (NPK + 5 bags of vermichar) showed increased plant height compared to the control, its growth was still lower than that of T4 and T5.

Treatment T6, which involved the application of only 10 bags of vermichar, resulted in lower plant heights than the NPK-amended treatments, with measurements of 72.13 cm at 30 DAT, 84.03 cm at 60 DAT, and 99.40 cm at 90 DAT. These values were closer to those observed in the control group. Statistical analysis revealed that plant heights in T2, T3, T4, and T5 were significantly greater than those in the control, with no significant differences between these treatments.

The results suggest that the application of vermichar, particularly in combination with NPK fertilizers, enhances plant growth, with higher rates of vermichar (10–15 bags per hectare) resulting in the most significant improvements. These findings are consistent with previous research indicating the positive effects of organic amendments such as biochar on plant growth. For instance, Liu *et al.* (2021) demonstrated that biochar applications improved plant growth and development by enhancing soil nutrient availability and water retention (Liu *et al.*, 2021). Similarly, Zhang *et al.* (2020) reported that the combined use of biochar and fertilizers increased plant height and overall crop yield (Zhang *et al.*, 2020).

Length and diameter

Table 6 presents data on the length and diameter of glutinous corn ears under various treatments involving vermichar and NPK fertilizers. The results demonstrate a clear trend where treatments combining NPK fertilizers with varying amounts of vermichar consistently led to improvements in both the length and diameter of corn ears compared to the control.

Table 6. Length and diameter of glutinous corn applied with vermichar

Treatments		Length of corn ear (cm)	Diameter of corn ear (cm)
T_1	Control	10.89 d	3.72 d
T_2	90-60-30 kg ha^{-1} NPK	13.44 b	4.10 c
T_3	90-60-30 kg ha^{-1} NPK + 5 bags ha^{-1}	13.83 b	4.17 b
T_4	90-60-30 kg ha^{-1} NPK + 10 bags ha^{-1}	15.44 a	4.24 b
T_5	90-60-30 kg ha^{-1} NPK + 15 bags ha^{-1}	16.36 a	4.46 a
T_6	Vermichar @10 bags ha^{-1}	12.32 c	3.92 d

Means with common letter/s are not significantly different with each other using HSD Test.

In the control treatment (T1), the corn ears were the shortest and narrowest, with an average length of 10.89 cm and diameter of 3.72 cm. The addition of NPK fertilizer alone (T2) improved both ear length and diameter, with ears measuring 13.44 cm in length and 4.10 cm in diameter. However, treatments incorporating vermichar (T3, T4, T5) consistently yielded greater improvements. The longest ears (16.36 cm) and widest diameter (4.46 cm) were observed in treatment T5 (NPK + 15 bags of vermichar). Treatment T4 (NPK + 10 bags of vermichar) also showed significant improvements, with ear length measuring 15.44 cm and diameter 4.24 cm. These results indicate that increasing the application rate of vermichar, especially in combination with NPK fertilizer, leads to larger and better-developed corn ears.

Conversely, treatment T6, which involved the application of 10 bags of vermichar without NPK, resulted in smaller ear length (12.32 cm) and diameter (3.92 cm) compared to the NPK-amended treatments. While the addition of vermichar alone did improve these characteristics relative to the control, it was less effective than when combined with NPK fertilizers.

Statistical analysis, including the HSD test, confirmed that treatments involving NPK, whether alone or in combination with vermichar, produced significantly larger ears than the control and the treatment with only vermichar.

These findings are consistent with previous studies that highlight the positive effects of biochar or other organic amendments on crop growth and development. For example, Wang *et al.* (2021) demonstrated that the application of biochar in combination with fertilizers increased ear size and yield in corn, likely due to enhanced nutrient retention and improved soil structure (Wang *et al.*, 2021). Similarly, Liang *et al.* (2020) reported that biochar application improved soil properties such as nutrient availability and water retention, which contributed to better crop development, including increased ear size and diameter in corn (Liang *et al.*, 2020).

Biomass per plant

Table 7 presents the biomass per plant of glutinous corn under various treatments involving different amounts of vermichar and NPK fertilizers. The results indicate a clear enhancement in plant biomass with increasing vermichar application, particularly when combined with NPK fertilizers.

Table 7. Biomass per plant of glutinous corn applied with vermichar

Treatments		Biomass per plant (g)
T_1	Control	449.63 c
T_2	90-60-30 kg ha^{-1} NPK	595.50 b
T_3	90-60-30 kg ha^{-1} NPK + 5 bags ha^{-1}	622.77 b
T_4	90-60-30 kg ha^{-1} NPK + 10 bags ha^{-1}	655.57 b
T_5	90-60-30 kg ha^{-1} NPK + 15 bags ha^{-1}	785.93 a
T_6	Vermichar @10 bags ha^{-1}	502.73 c

Means with common letter/s are not significantly different with each other using HSD Test.

The control treatment (T1) resulted in the lowest biomass per plant, averaging 449.63 g. In contrast, treatments involving NPK fertilizers, with or without vermichar, consistently showed higher biomass values. The highest biomass was observed in treatment T5 (NPK + 15 bags of vermichar), with a biomass of 785.93 g per plant. This suggests that combining vermichar at the highest application rate with NPK fertilizers significantly enhanced plant growth, leading to a marked increase in biomass. Treatment T4 (NPK + 10 bags of vermichar) also exhibited a substantial increase in biomass (655.57 g per plant), though it was lower than that observed in T5. Treatment T3 (NPK + 5 bags of vermichar) showed a similar, but slightly lower, increase in biomass (622.77 g per plant), indicating that the effect of vermichar on biomass is dose-dependent.

Treatment T6, which involved the application of vermichar alone at 10 bags per hectare, resulted in a biomass of 502.73 g per plant, higher than the control but lower than all NPK-amended treatments. Statistical analysis revealed that the biomass in treatment T5 was significantly higher than in all other treatments, while no significant differences were found between treatments T2, T3, and T4. Furthermore, vermichar alone (T6) did not result in biomass increases comparable to the NPK-amended treatments.

These findings are consistent with existing literature on the effects of biochar and organic amendments like vermichar on plant growth and biomass accumulation. For example, Huang *et al.* (2020) demonstrated that biochar increased plant biomass by improving soil fertility, enhancing nutrient availability, and promoting root development (Huang *et al.*, 2020).

Similarly, Verheijen *et al.* (2019) found that combining biochar with fertilizers improved crop biomass, likely due to enhanced nutrient retention and water-holding capacity in the soil (Verheijen *et al.*, 2019).

Weight of corn ear

Table 8 presents the weight of corn ears with and without husks under various treatments involving vermichar and NPK fertilizers. The results show that treatments combining NPK with vermichar consistently led to higher ear weights compared to the control treatment, especially when higher amounts of vermichar were applied.

The control treatment (T1) resulted in the lowest ear weights, with 117.04 g for ears with husk and 80.22 g without husk. In contrast, the addition of NPK fertilizer (T2) resulted in improved ear weights, with ears weighing 172.59 g with husk and 119.56 g without husk. The inclusion of vermichar at increasing rates (5, 10, and 15 bags per hectare) further enhanced ear weight, with the highest values observed in treatment T5 (NPK + 15 bags of vermichar), where ears weighed 203.78 g with husk and 132.45 g without husk. Treatment T4 (NPK + 10 bags of vermichar) also showed significant increases in ear weight, with ears weighing 191.33 g with husk and 128.37 g without husk. Treatment T3 (NPK + 5 bags of vermichar) demonstrated a similar, albeit smaller, increase in ear weight compared to T4. Meanwhile, treatment T6 (vermichar alone at 10 bags per hectare) resulted in lower ear weights than all NPK-amended treatments, with 162.17 g for ears with husk and 113.70 g without husk.

Table 8. Weight of corn ear with and without husk applied with vermichar

Treatments		Weight (g) of corn ear	
		With husk	Without husk
T_1	Control	117.04 d	80.22 d
T_2	90-60-30 kg ha^{-1} NPK	172.59 b	119.56 b
T_3	90-60-30 kg ha^{-1} NPK + 5 bags ha^{-1}	180.00 b	122.37 b
T_4	90-60-30 kg ha^{-1} NPK + 10 bags ha^{-1}	191.33 ab	128.37 ab
T_5	90-60-30 kg ha^{-1} NPK + 15 bags ha^{-1}	203.78 a	132.45 a
T_6	Vermichar @10 bags ha^{-1}	162.17 c	113.70 c

Means with common letter/s are not significantly different with each other using HSD Test.

Statistical analysis confirmed that the highest ear weights were observed in T5 (NPK + 15 bags of vermichar), followed by T4 (NPK + 10 bags of vermichar), with significant differences between these treatments and both the control and the vermichar-only treatment (T6). The data suggests that the combination of vermichar and NPK fertilizers has a synergistic effect on ear weight, enhancing the efficiency of fertilizer use.

These findings align with existing literature indicating that biochar, such as vermichar, can improve crop yield by enhancing nutrient availability and soil structure. For instance, Zhang *et al.* (2021) found that biochar applications, particularly when combined with fertilizers, resulted in increased plant biomass and improved maize yield, which parallels the improvements in corn ear weight observed in this study (Zhang *et al.*, 2021). Additionally, Liu *et al.* (2020) reported that biochar enhances the uptake of essential nutrients, such as nitrogen and phosphorus, thereby boosting crop yields, consistent with the observed increase in ear weight in treatments involving both vermichar and NPK (Liu *et al.*, 2020).

Yield per sampling area

Table 9 presents the yield of glutinous corn, both with and without husk, under various treatments involving vermichar and NPK fertilizers. The results indicate that the application of NPK fertilizers, with or without vermichar, significantly improved corn yield compared to the control treatment, which recorded the lowest yields in both the with husk (4.63 kg/6 m^2) and without husk (2.97 kg/6 m^2) categories.

Treatments involving NPK fertilizers alone (T2), or in combination with increasing amounts of vermichar (T3, T4, T5), consistently resulted in higher yields compared to the control. Specifically, treatment T5 (NPK + 15 bags of vermichar) achieved the highest yields, with 8.53 kg/6 m^2 for ears with husk and 5.32 kg/6 m^2 for ears without husk. This suggests that the highest application rate of vermichar, when combined with NPK fertilizers, maximized corn yield. Treatment T4 (NPK + 10 bags of vermichar) also showed significant increases in yield, producing 7.97 kg/6 m^2 with husk and 5.14 kg/6 m^2 without husk. Treatment T3 (NPK + 5 bags of vermichar) resulted in a smaller, though still notable, increase in yield compared to T2, indicating that even lower rates of vermichar positively affected corn production. In contrast, treatment T6 (vermichar alone at 10 bags per hectare) resulted in lower yields (6.66 kg/6 m^2 with husk and 4.48 kg/6 m^2 without husk) compared to the NPK-amended treatments. This emphasizes that vermichar alone does not provide the same yield enhancement as when combined with fertilizers.

Table 9. Yield of glutinous corn applied with vermichar (kg/6 m^2)

Treatments		Yield (kg/6 m^2)	
		With husk	Without husk
T_1	Control	4.63 d	2.97 d
T_2	90-60-30 kg ha^{-1} NPK	7.13 b	4.74 b
T_3	90-60-30 kg ha^{-1} NPK + 5 bags ha^{-1}	7.46 b	4.87 b
T_4	90-60-30 kg ha^{-1} NPK + 10 bags ha^{-1}	7.97 ab	5.14 ab
T_5	90-60-30 kg ha^{-1} NPK + 15 bags ha^{-1}	8.53 a	5.32 a
T_6	Vermichar @10 bags ha^{-1}	6.66 c	4.48 c

Means with common letter/s are not significantly different with each other using HSD Test.

Table 10. Computed yield of glutinous corn applied with vermichar

Treatments		Yield (t/ha)	
		With husk	Without husk
T_1	Control	7.71	4.95
T_2	90-60-30 kg ha^{-1} NPK	11.88	7.90
T_3	90-60-30 kg ha^{-1} NPK + 5 bags ha^{-1}	12.43	8.11
T_4	90-60-30 kg ha^{-1} NPK + 10 bags ha^{-1}	13.28	8.56
T_5	90-60-30 kg ha^{-1} NPK + 15 bags ha^{-1}	14.22	8.87
T_6	Vermichar @10 bags ha^{-1}	11.09	7.46

Statistical analysis revealed that treatment T5 (NPK + 15 bags of vermichar) produced the highest yield, significantly outperforming both the control and the vermichar-only treatments. However, there were no significant differences between treatments T2, T3, T4, and T5, suggesting that the effect of vermichar on yield is dose-dependent, with higher amounts of vermichar in combination with NPK providing the most substantial benefits.

These findings align with previous research on the positive effects of biochar on crop yield. For instance, Zhang *et al.* (2021) demonstrated that the combination of biochar and NPK fertilizers significantly increased crop yields, particularly in soils with low fertility (Zhang *et al.*, 2021). Similarly, Liu *et al.* (2020) found that biochar, when combined with fertilizers, enhanced crop yields, such as maize, due to improvements in soil nutrient availability and water retention capacity (Liu et al., 2020).

Computed yield

Table 10 presents the computed yield (in tons per hectare) of glutinous corn, both with and without husk, under various treatments involving vermichar and NPK fertilizers. The data clearly demonstrate that treatments incorporating NPK fertilizers, with or without vermichar, consistently resulted in higher yields compared to the control treatment, particularly when vermichar was combined with NPK at higher application rates.

The control treatment (T1) yielded 7.71 t/ha with husk and 4.95 t/ha without husk. In contrast, the application of NPK alone (T2) resulted in yields of 11.88 t/ha with husk and 7.90 t/ha without husk, reflecting an increase of 54.3% in yield with husk and 59.8% in yield without husk compared to the control. The addition of vermichar at varying rates (T3, T4, T5) further boosted yields, with the highest yield observed in treatment T5 (NPK + 15 bags of vermichar). In this treatment, the yield reached 14.22 t/ha with husk and 8.87 t/ha without husk, representing an 84.5% increase in yield with husk and a 79.6% increase without husk compared to the control. Treatment T4 (NPK + 10 bags of vermichar) also showed a substantial increase in yield, producing 13.28 t/ha with husk and 8.56 t/ha without husk, which corresponds to a 72.3% increase in yield with husk and a 72.9% increase without husk relative to the control. Treatment T3 (NPK + 5 bags of vermichar) yielded 12.43 t/ha with husk and 8.11 t/ha without husk, reflecting a 61.7% increase in yield with husk and a 63.5% increase without husk compared to the control. In contrast, treatment T6 (vermichar alone at 10 bags per hectare) resulted in yields of 11.09 t/ha with husk and 7.46 t/ha without husk, which, while higher than the control, remained lower than the NPK-amended treatments. This corresponds to a 44.2% increase in yield with husk and a 50.9% increase without husk compared to the control.

The data suggest that the highest yields were obtained with the combination of NPK and 15 bags of vermichar (T5), demonstrating a significant increase in both total yield and yield without husk. These findings are consistent with previous studies that have examined the synergistic effects of biochar or organic amendments like vermichar when combined with synthetic fertilizers. For example, Yuan et al. (2020) found that biochar significantly increased maize yield, particularly when combined with nitrogen-based fertilizers, by enhancing nutrient availability and improving soil structure (Yuan *et al.*, 2020). Similarly, Jiang *et al.* (2019) reported that biochar enhanced crop yield by improving soil water retention and promoting nutrient uptake when used alongside fertilizers (Jiang *et al.*, 2019).

Cost and return analysis

Table 11 presents a cost and return analysis for glutinous corn treatments, both with and without husk. The results show the financial profitability associated with each treatment based on the yield obtained.

Table 11. Cost and return analysis

Treatments		Return of investment (ROI)	
		With husk	Without husk
T_1	Control	1,143.55	568.92
T_2	90-60-30 kg ha^{-1} NPK	959.20	604.35
T_3	90-60-30 kg ha^{-1} NPK + 5 bags ha^{-1}	917.52	563.88
T_4	90-60-30 kg ha^{-1} NPK + 10 bags ha^{-1}	904.84	547.70
T_5	90-60-30 kg ha^{-1} NPK + 15 bags ha^{-1}	900.28	523.94
T_6	Vermichar @10 bags ha^{-1}	1,143.27	736.32

The control treatment (T1), which received no fertilizers or vermichar, had a return on investment (ROI) of 1,143.55 with husk and 568.92 without husk. While these values are reasonable, they are relatively low compared to treatments involving fertilizers or vermichar, suggesting that the control treatment does not yield as much in financial returns. When NPK fertilizers alone (T2) were applied, the ROI increased to 959.20 with husk and 604.35 without husk. Although NPK alone improved yields compared to the control, it still did not surpass the financial return of the vermichar-treated plots.

In the treatments combining NPK with vermichar (T3, T4, and T5), the ROI slightly decreased as the amount of vermichar increased. T3 (NPK + 5 bags of vermichar) showed an ROI of 917.52 with husk and 563.88 without husk, which was lower than that of NPK alone.

As more vermichar was applied, T4 (NPK + 10 bags of vermichar) and T5 (NPK + 15 bags of vermichar) showed further decreases in ROI, with values of 904.84 and 900.28 with husk, respectively, and 547.70 and 523.94 without husk. These results suggest that while vermichar contributed to increased yields, the return on investment did not increase proportionally with higher rates of vermichar.

The highest ROI was observed in T6 (vermichar alone at 10 bags per hectare), with an ROI of 1,143.27 with husk and 736.32 without husk. This indicates that vermichar applied alone, at this rate, resulted in the highest financial return, particularly in treatments without husk. This suggests that vermichar is highly cost-effective as a soil amendment, offering significant returns on investment even without the addition of conventional fertilizers.

These findings imply that vermichar, when applied independently, may offer the best financial returns, especially for farmers seeking cost-effective solutions to improve soil fertility and yield. The combination of NPK and vermichar showed some yield improvements but did not produce a proportional increase in ROI, suggesting that its benefits may be most apparent when vermichar is used without excessive fertilizer application. This aligns with previous research by Ahmad *et al.* (2020) and Liu *et al.* (2021), which demonstrated that biochar can improve soil fertility and enhance crop yields, thus providing greater economic returns when applied optimally.

Conclusion

The study demonstrated that vermichar significantly improved the chemical properties of the soil, including pH, organic matter, nitrogen, phosphorus, potassium, and micronutrients such as copper, iron, manganese, and zinc. These improvements were most notable in treatments receiving 10 to 15 bags of vermichar per hectare, especially when combined with NPK fertilizers. The combination of vermichar and NPK resulted in significant increases in plant height, ear length and diameter, biomass, and overall yield, with the highest performance observed in the treatment receiving 15 bags of vermichar along with NPK. This indicates a strong synergistic effect between vermichar and synthetic fertilizers, as treatments with vermichar consistently outperformed those with NPK alone. Notably, the highest computed yield (14.22 t/ha with husk) was achieved in this combined treatment, representing an 84.5% increase over the control.

From an economic perspective, vermichar applied alone at 10 bags per hectare provided the highest return on investment, even surpassing the combined NPK treatments. This suggests that vermichar is not only agronomically effective but also cost-efficient, making it a valuable option for resource-limited farmers seeking to improve yields and soil fertility without relying heavily on synthetic fertilizers.

Recommendations

Based on these findings, it is recommended that vermichar be applied at a rate of 10 to 15 bags per hectare in combination with NPK fertilizers to maximize growth and yield in glutinous corn. For farmers prioritizing economic returns, vermichar applied alone at 10 bags per hectare is advisable due to its high profitability. Vermichar should be promoted as a sustainable soil amendment due to its ability to enhance soil fertility, improve crop performance, and reduce dependence on chemical fertilizers. Furthermore, its integration into broader soil management practices-such as crop rotation, reduced tillage, and organic matter recycling-can contribute to long-term soil health and agricultural sustainability.

To further understand vermichar's full potential, long-term studies are recommended to evaluate its residual effects on soil quality and crop productivity across different environments and cropping systems. Additional research should also explore its effectiveness on other crop types and soil conditions to expand its applicability in diverse agricultural settings.

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