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Effect of Sugarcane Bagasse Bio-Compost and Manure on Carbon Fraction and N, P, K Content in Entisols and Their Relationship with Shallot Yields

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Abstract

Bagasse, one of the largest agricultural wastes with suboptimal utilization, could improve Entisols in the tropics by enhancing soil fertility and crop productivity. This study aimed to determine the changes in humic substances and nutrient levels in Entisols and their effects on shallot yield. The study was designed using a completely randomized design, consisting of four treatments of organic matter combinations with NPK fertilizer, four single organic matter treatments, one standard NPK fertilizer dose, and one control. Each was replicated three times. The results showed that using bagasse improved soil conditions by increasing C content and nutrient levels in the soil, enhancing nutrient absorption by plants, and consequently boosting crop yields. The biochar + bagasse compost (2:4) (bio-compost) + NPK resulted in high soil organic C, humic acid, fulvic acid, nutrient availability, and plant nutrient levels, which were comparable to the manure treatment, and significantly increased shallot yield in Entisols. The findings of this study could support the development of nutrient management strategies utilizing bagasse as a potential soil amendment for Entisols.

Keywords: composting; organic fertilizer; sugarcane biochar; sugarcane compost

INTRODUCTION

Soil fertility degradation threatens agricultural cultivation's sustainability in watersheds on Java (Maroeto et al., 2017). Soil organic matter determines fertility and crop production (Mujiyo et al., 2022). One source of organic matter that can be utilized is bagasse. The total bagasse production can reach 35 to 40% of the weight of sugarcane milled (Ishak and Safira, 2021; Sugiharto and Firdaus, 2021) and is one of the most significant volumes of agricultural waste in the world (Liu et al., 2023). Sugarcane bagasse has valuable contents such as 22.4% C, 5.3% moisture content (Taufiqurrohman and Dewi, 2024), 0.51% N, 0.26 g kg^{-1} P, 1 g kg^{-1} K, and 0.4 g kg^{-1} Si, making it a potential source of organic matter (Xu et al., 2021). However, bagasse is also a significant source of lignocellulose containing cellulose (32 to 45%), hemicellulose (20 to 32%), lignin (17 to 32%) (Arni, 2018) so that further processing must be carried out, such as composting (Alabi et al., 2022) or utilized as biochar (Miranda et al., 2021) so that it can be used as organic material.

Bagasse can potentially be an organic material that improves Entisols, especially in the tropics. Entisols are characterized by low fertility, less stable structure, and low water binding capacity (Mohamed et al., 2020). In addition, this soil has low nutrient content and cation exchange capacity (Wahyuni et al., 2023), so it is necessary to

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improve it by applying organic materials. Manure is one type of organic matter that is often used in soil improvement because it can increase pH, soil organic C, total N (Du et al., 2020), available P, and available K and plays a role in increasing crop yields (Wang et al., 2020). On the other hand, various studies on using bagasse as compost and biochar have also shown positive effects in soil improvement efforts. Several previous studies have reported that the combination of bagasse compost and bacterial consortium (Liu et al., 2023), bagasse biochar, and rice husk (Rahman et al., 2022) gave results that the addition of bagasse-based organic matter can increase soil organic C, nutrient availability, reduce content and specific gravity, and improve soil aggregate stability. Applying a combination of biochar-compost of bagasse can also reduce P fixation in the soil, thus increasing plant P availability (Betyar et al., 2023)

Based on these data, bagasse-based organic matter is essential in improving soil properties to support crop cultivation. Increasing soil organic C after bagasse application improves overall Entisol soil fertility and condition. Increased organic C can potentially increase the production of humic substances during the humification process, which plays a role in nutrient and carbon balance in the soil (T. Yang et al., 2021). Such nutrient balance and improved soil conditions after organic matter application can potentially increase ascorbic acid content and significantly affect mineral accumulation, particularly Ca and Mg in shallot bulbs (Ncayiyana et al., 2018). However, there is still little information on integrated studies on the impact of the combined application of compost and bagasse biochar on the production of humic substances, their effect on nutrient levels in Entisols, and their effect on crop production. This study aims to determine changes in humic substances and nutrient levels in Entisols treated with compost and bagasse biochar and its impact on shallot yield.

MATERIALS AND METHOD

Location and soil characteristics

The pot experiment was conducted in the Greenhouse of the Faculty of Agriculture, Universitas Sebelas Maret, from June to November 2024. The soil used for the experiment was taken from a composite of topsoil Entisols at a depth of 0 to 20 cm geographically located at 110°45’23.2” E and 7°32’04.6” S (Ali et al., 2020; Syamsiyah et al., 2024). This soil has very low organic C and P contents and moderate levels of N and K (Table 1). In general, it has a low fertility level.

Experimental design

The research was conducted in two planting periods designed using a completely randomized design (CRD) consisting of four treatments of combinations of organic materials with NPK fertilizer and four single organic materials, namely manure (K1A0), manure + NPK (K1A1), sugarcane bagasse biochar (K2A0), sugarcane bagasse biochar + NPK (K2A1), sugarcane bagasse compost (K3A0), sugarcane bagasse compost + NPK (K3A1), biochar + bagasse compost (2:4) (bio-compost) (K4A0), biochar + bagasse compost (2:4) (bio-compost) + NPK (K4A1), as well as one standard NPK fertilizer dose treatment (K0A1), and one as control (K0A0) with the doses listed in Table 2. The composting process of bagasse is carried out for two months by mixing the shredded bagasse with EM4 solution and molasses. Compost temperature and humidity are monitored routinely

Table 1. Entisols characteristics at the research site

Parameter	Value	Unit	Rating*
Total N	0.27	%	Medium
Available P	3.38	ppm	Very low
Exchangeable K	0.40	(me 100 g^{-1})	Medium
Organic C	0.56	%	Very low
pH	6.21	-	Somewhat acidic (5.5–6.5)
Texture			Sandy loam
Silt	13.26	%	
Clay	15.01	%	
Sand	71.73	%	

Note: * = Based on assessment from the Testing Center for Soil and Fertilizer Standard Instruments (2023)

Table 2. Treatments in the study

Code	Treatments	Organic material (kg ha^{-1})		NPK fertilizer rate (kg ha^{-1})
		Compost	Biochar	
K0A0	Control	0	0	0
K0A1	Standard NPK	0	0	525
K1A0	Manure	10,000	0	0
K1A1	Manure + NPK	10,000	0	525
K2A0	Sugarcane bagasse biochar	0	10,000	0
K2A1	Sugarcane bagasse biochar + NPK	0	10,000	525
K3A0	Sugarcane bagasse compost	10,000	0	0
K3A1	Sugarcane bagasse compost + NPK	10,000	0	525
K4A0	Biochar + bagasse compost (2:4) (bio-compost)	6,667	3,333	0
K4A1	Biochar + bagasse compost (2:4) (bio-compost) + NPK	6,667	3,333	525

Table 3. Results of organic matter analysis

Parameter	Bagasse compost	Bagasse biochar	Manure
Total N (%)	1.92	0.91	1.82
P_2O_5 (%)	2.05	0.96	2.62
K_2O (%)	2.49	1.59	1.38
pH	7.5	7.7	7.6
Organic C (%)	31.62	17.84	21.43
C/N (%)	16.46	19.60	11.90

during the first two weeks. It decreases in intensity in the following days while making biochar, which is carried out through pyrolysis (Maulana et al., 2025).

Compost, biochar, and bio-compost used in this study were made from sugarcane bagasse waste. Cow manure was also added to compare with the characteristics in Table 3. The 5 kg of soil media was put into the experimental pots and given inputs in organic materials (compost, biochar, bio-compost) one week before planting. The prepared planting media was used for two planting periods. The dosage of bagasse waste and manure added during the incubation period was 10 tons ha^{-1} (Ndulue et al., 2021; Thakur et al., 2023) and was only added during the first planting period. The NPK fertilizer dose was 525 kg ha^{-1} (Sumarna et al., 2024) converted to 7.87 g pot^{-1} and applied three times: at 0, 14, and 28 days after planting.

Sampling and parameter observation

Soil samples from each treatment were analyzed to measure various parameters, such as organic C (Walkley and Black), humic acid and fulvic acid were extracted using a solution of sodium hydroxide and sodium pyrophosphate (Syamsiyah et al., 2023a), total N (Kjehldahl method), available P (Olsen method), base saturations (1 M NH_4OAc extract, pH 7.0) (Testing Center for Soil and Fertilizer Standard Instruments, 2023).

Statistical analysis

The research data were analyzed using Analysis of Variance (ANOVA) with a confidence level of 95%. If the ANOVA results show significant differences, Duncan's Multiple Range Test (DMRT) will be performed to determine differences between treatment means. A Pearson correlation test will also examine the relationship between variables.

RESULTS AND DISCUSSION

Soil organic C, humic acid, and fulvic acid

Soil organic C is a significant component of organic matter, accounting for up to 58% of the total content (Blanco-Canqui et al., 2013; Supriyadi et al., 2020). Managing organic C through appropriate practices is crucial for improving soil ecosystem functions (Syamsiyah et al., 2023a; Suntoro et al., 2024). Soil organic C levels were significantly affected by organic matter application ($p < 0.01$). Soil organic matter is a factor that can increase soil fertility index

(Mujiyo et al., 2022). The analysis showed that the bagasse bio-compost treatment produced the highest organic C content, followed by the bagasse biochar treatment, both with NPK and as a single organic material, with significantly different results than the control and manure treatments (Figure 1). Organic C continued to increase until the second planting. The K4A1 treatment showed an increase of about 1.10 times or 10%, while the K2A0 showed an increase of 1.13 times or 13% higher than the first planting.

On the other hand, the K1A1 treatment also showed an increase of up to 1.12 times or 12% higher than the first planting but with a lower C content than the bagasse treatment. This is because bagasse has a high C content, allowing it to contribute more soil organic C than other organic materials (Setiawati et al., 2022). In line with Benbi et al. (2017), bagasse can contribute more soil organic C up to 4.16 tons ha^{-1} and have the highest C contribution compared to crop residues or manure. The addition of organic matter in the form of biochar also plays a significant role in increasing soil organic C content because it is stable in the environment, so it has the potential to be an adequate C storage (Zhu et al., 2017; Han et al., 2020). The difference in C content in each organic material also affects the production of humic substances during the decomposition process.

Humic substances are bioactive complexes formed from the decomposition of plant and animal tissues (Jarukas et al., 2021). Humic substances can affect soil's physical, chemical,

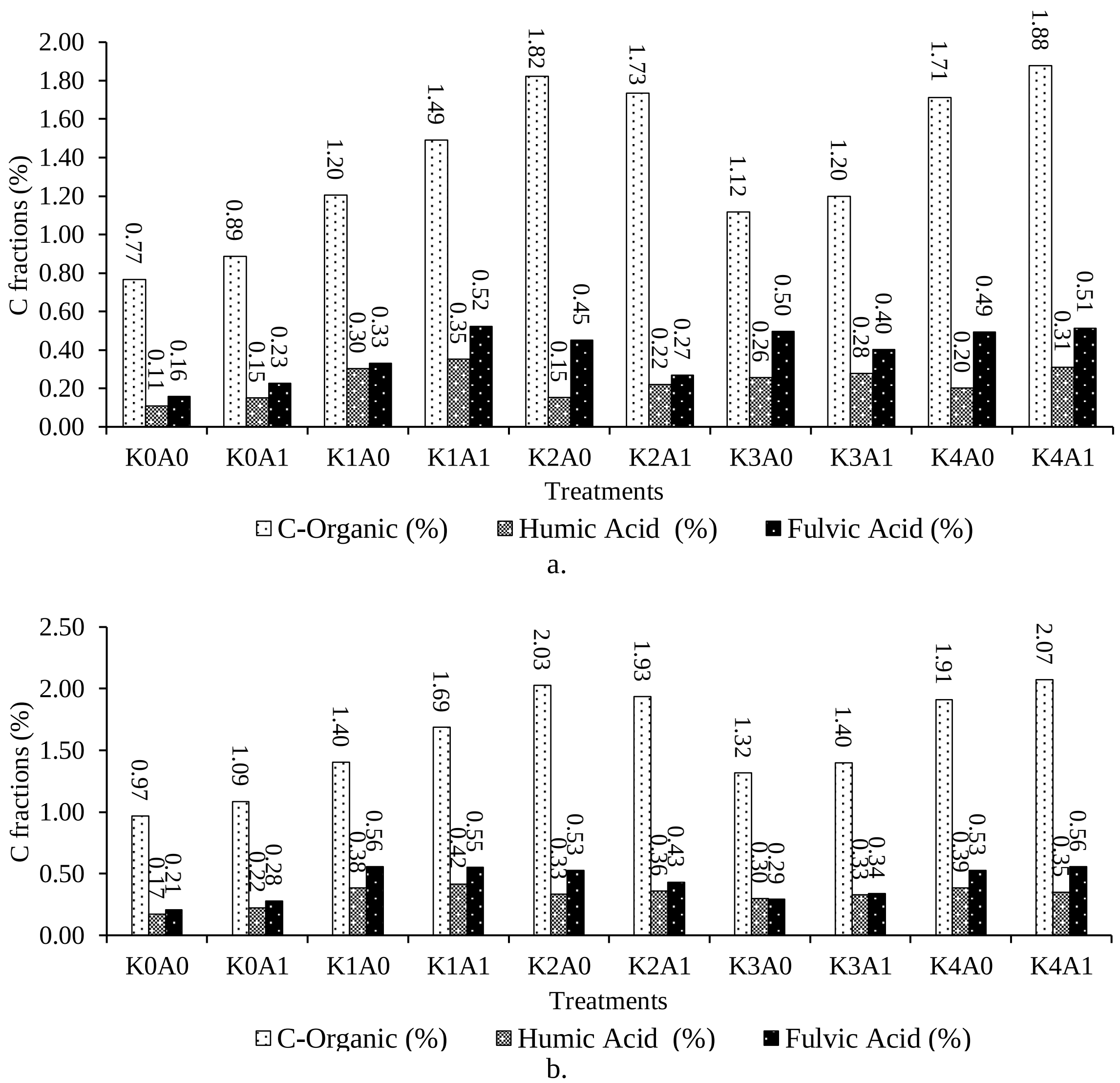

Figure 1. Carbon fraction (Organic C, humic acid, fulvic acid) of the 1st (a) and 2nd (b) plantings

and biological properties by controlling ion movement and transport (Nardi et al., 2002; Muscolo et al., 2020), improving water retention soil structural stability (Ampong et al., 2022), microbial activity (Nardi et al., 2021), and plant physiology (da Silva et al., 2021). These substances are divided into fulvic acid (soluble under all pH conditions), humic acid (soluble in alkali), and humin (insoluble) (Zavarzina et al., 2021), with main functional groups such as carboxylic, phenolic, carbonyl, and hydroxyl (T. Yang et al., 2021). The addition of organic matter had a significant effect on the increase in C-humic acid and C-fulvic acid both in the first planting and the second planting ($p < 0.01$), with increasing results with increasing planting time (Figure 1). These results align with the research of Feng et al. (2024) that the long-term application of organic matter significantly increases soil organic matter content and affects the structure of the microbial community, which impacts the composition of humic and fulvic acid.

Manure produced the highest levels of humic and fulvic acid at both planting times, with results that were not significantly different from the K1A1 treatment but significantly different from the control, NPK, and biochar treatments (Figure 1). Humic and fulvic acid levels in the manure treatment increased 3.18 and 3.25 times in the first planting and 2.23 and 2.61 in the second planting compared to the control treatment, in the K1A1 treatment showed an increase in humic and fulvic acid of 2.81 and 3.18 times in the first planting and 2.05 and 2.67 in the second planting compared to the control. In comparison, in the biochar treatment, there was a lower increase of 2 and 1.68 times in the first planting and 2.11 and 2.04 in the second planting compared to the control treatment. This is related to the higher stability of organic C in bagasse, especially in the form of biochar.

In line with Li et al. (2024), different forms of organic materials give different responses to the characteristics of organic C and soil humus, where organic materials that have higher organic C stability, such as biochar, have a more prolonged impact compared to crop residues or manure because they are more resistant to the breakdown of soil microorganisms (Zhu et al., 2017; Han et al., 2020), in addition, the addition of organic materials accompanied by NPK fertilizer can produce higher humic and fulvic acid content than the control, as well as a single application of organic materials or NPK. This is because the addition of inorganic fertilizers such as NPK can support the activity of microorganisms to increase the rate of decomposition and indirectly have an impact on improving the production of humic and fulvic acid (Boguta et al., 2021).

Soil N, P, and K nutrient content

Total N and available P increased at all planting times by applying various organic materials alone or in combination with NPK fertilizer (Table 4). The analysis showed that the treatments significantly affected total N

Table 4. Effect of treatment on soil nutrient content

Code	Treatments	Total N (%)		Available P (ppm P)		Exchangeable K (me 100 g^{-1})	
		1st planting	2nd planting	1st planting	2nd planting	1st planting	2nd planting
K0A0	Control	0.11^{a}	0.21^{a}	2.43^{a}	3.28^{a}	0.17^{a}	0.23^{a}
K0A1	Standard NPK	0.18^{b}	0.45^{c}	6.27^{bc}	7.76^{cd}	0.35^{c}	0.36^{b}
K1A0	Manure	0.24^{c}	0.53^{de}	3.61^{a}	4.85^{b}	0.23^{b}	0.41^{b}
K1A1	Manure + NPK	0.29^{c}	0.63^{ef}	6.43^{bc}	8.88^{d}	0.38^{c}	0.52^{c}
K2A0	Sugarcane bagasse biochar	0.18^{b}	0.29^{b}	2.73^{a}	3.79^{b}	0.18^{a}	0.38^{b}
K2A1	Sugarcane bagasse biochar + NPK	0.26^{c}	0.36^{b}	5.53^{b}	7.19^{c}	0.35^{c}	0.52^{c}
K3A0	Sugarcane bagasse compost	0.26^{c}	0.56^{def}	3.22^{a}	4.90^{b}	0.24^{b}	0.37^{b}
K3A1	Sugarcane bagasse compost + NPK	0.29^{c}	0.67^{f}	5.77^{b}	7.16^{c}	0.42^{d}	0.67^{d}
K4A0	Biochar + bagasse compost (2:4) (bio-compost)	0.26^{c}	0.52^{d}	3.37^{a}	4.59^{b}	0.22^{b}	0.39^{b}
K4A1	Biochar + bagasse compost (2:4) (bio-compost) + NPK	0.34^{d}	0.61^{def}	7.67^{c}	8.88^{d}	0.48^{e}	0.55^{c}

Notes: Different lowercase letters in rows and columns indicate significant differences at 5% DMRT

($p < 0.01$). This effect was due to the relatively low C/N ratio of organic matter in this study, which accelerated the decomposition of organic residues and increased the release of available N (Hoyle and Fairbanks, 2013). The K1A1 treatment produced the highest total N at all planting times, with results that were not significantly different from the manure treatment but significantly different from the control and single NPK application. These results are in line with Rocha et al. (2015). Adding bagasse to mineral soil can be an effective way to increase nutrient availability and can be used as a potential source of N for plants. Similar results were expressed by Tangsir et al. (2017). Applying bagasse to mineral soils can improve soil quality, increase nutrient availability, and reduce N losses from leaching.

The treatment given also had a very significant effect on soil available P ($p < 0.01$) (Table 4). The highest soil available P was found in the K4A1 treatment at all planting times, with results that were not significantly different from several treatments, such as the single NPK treatment and manure + NPK. This is because P has poor solubility properties and is easily fixed with several metal elements in the soil, causing the unavailability of P in the soil (Asril et al., 2023). However, adding organic matter with NPK fertilizer resulted in higher P content than the control or the single application of organic matter or NPK. These results align with Syamsiyah et al. (2023b), who reported that combining organic and inorganic fertilizers increases available P, with organic fertilizers serving as a potential source after mineralization and inorganic fertilizers providing readily available P. The analysis also showed that the concentration of exchangeable base cations, such as K, increased with organic material application. The treatment of organic matter given had a very significant effect on soil exchangeable K, with the highest results obtained in the K1A1 treatment ($p < 0.01$) at all planting times (Table 4). In line with Xu et al. (2022), the application of bagasse in high amounts increases the K content in the soil layer and can reduce the loss of K elements through the leaching process (Oktaviani et al., 2018; Iqbal et al., 2019).

Relationship between humic substance and Soil N, P, and K

Proper selection of organic matter is a major factor in optimizing soil fertility and crop productivity. Organic matter from crop residues contains about 45% C and 0.5 to 10% N. The C/N ratio indicates the proportion of N and other nutrients to C in organic matter. The C/N ratio can reflect the degree of biodegradability of organic matter, which can indicate the amount and rate of nutrient release that may be expected due to decomposition (Hoyle and Fairbanks, 2013).

This study used different forms of organic matter with a relatively low C/N ratio (Table 3). The relatively low C/N ratio of the added organic matter can accelerate the decomposition process (Li et al., 2022), thus increasing the availability of nutrients in the soil and available to plants. The organic matter with a high C/N ratio has high organic C stability, so it is more resistant to decomposition, impacting the production of humic substances and low nutrient release (Li et al., 2024). Humic substances can function as ion exchange systems and metal complexes (chelating), which play an essential role in nutrient availability in the soil (F. Yang et al., 2021; Mindari et al., 2025). This can be seen from the positive correlation between N, P, and K nutrient levels with humic and fulvic acids in the first and second planting (Table 5).

Humic substances play a role in dissolving and assisting the movement of nutrients plants and microorganisms need. The redox properties of humic substances can support N transformation by regulating the activity of microorganisms involved in the N cycle (Jin et al., 2024). In addition, humic substances can also mobilize P in the soil and increase P release (F. Yang et al., 2021). This can be seen from the significant positive correlation between humic substances and total N and P availability in the soil. The analysis also showed a significant correlation between the K concentration of humic and fulvic acid. Humic substances have a strong capacity to hold exchangeable cations such as K^+, making them more available for plant uptake while reducing the risk of leaching (Ampong et al., 2022).

Yield of shallot plants

Shallot plant yield can be observed through bulb weight and diameter (Table 6). The analysis shows that the treatments significantly affected the bulbs' weight and diameter ($p < 0.01$). The K3A1 and K4A1 treatments produced the highest bulb weight and diameter compared to other

Table 5. Relationship between humic substance and Soil N, P, and K

	Total N 1st planting	Available P 1st planting	Exchangeable K 1st planting	Humic acid 1st planting	Fulvic acid 1st planting	Total N 2nd planting	Available P 2nd planting	Exchangeable K 2nd planting	Humic acid 2nd planting	Fulvic acid 2nd planting
Total N 1st planting	1									
Available P 1st planting	0.568**	1								
Exchangeable K 1st planting	0.673**	0.886**	1							
Humic acid 1st planting	0.738**	0.398*	0.473**	1						
Fulvic acid 1st planting	0.596**	0.157	0.216	0.433*	1					
Total N 2nd planting	0.779**	0.487**	0.620**	0.625**	0.623**	1				
Available P 2nd planting	0.613**	0.964**	0.909**	0.478**	0.215	0.557**	1			
Exchangeable K 2nd planting	0.705**	0.776**	0.842**	0.664**	0.431*	0.642**	0.820**	1		
Humic acid 2nd planting	0.620**	0.096	0.116	0.740**	0.547**	0.424*	0.148	0.478**	1	
Fulvic acid 2nd planting	0.505**	0.179	0.166	0.479**	0.549**	0.345	0.218	0.421*	0.738**	1

Note: *Correlation is significant at the 0.05 level; **Correlation is significant at the 0.01 level treatments. This finding is in line with Díaz-pérez et al. (2021), who suggested that the use of organic matter can increase tuber yield by improving soil properties and increasing the availability of nutrients such as N, P, and K (Karimah et al., 2024) and reducing nutrient leaching from the root zone which ultimately increases tuber weight and tuber diameter (Fatirahma and Kastono, 2020; Khan et al., 2024).

Increased N is crucial in boosting shallot plant yield, as N supports root growth and enhances nutrient absorption, resulting in better plant growth and larger bulbs (Ryan et al., 2024). This finding aligns with Gessesew et al. (2015), who reported that larger shallot bulbs are achieved by applying wide plant spacing in combination with high N levels. Phosphate also plays an essential role in enhancing the activity of various enzymes involved in growth and carbohydrate metabolism. This role includes starch formation and breakdown, translocation of photosynthetic products, N metabolism, and protein synthesis

Table 6. Effect of treatments on the yield of shallot plants

Code	Treatments	Tuber weight (g)		Tuber diameter (cm)	
		1st planting	2nd planting	1st planting	2nd planting
K0A0	Control	4.67a	5.14a	1.03a	1.51a
K0A1	Standard NPK	12.00bc	12.69bc	1.66bcd	2.35cde
K1A0	Manure	15.33bcd	16.02bcd	1.32abc	2.01abc
K1A1	Manure + NPK	18.67d	20.01d	1.82cd	2.61de
K2A0	Sugarcane bagasse biochar	10.00ab	10.45ab	1.14ab	1.59ab
K2A1	Sugarcane bagasse biochar + NPK	16.67cd	16.68bcd	1.51abcd	2.08bcd
K3A0	Sugarcane bagasse compost	15.33bcd	16.02bcd	1.60bcd	2.29cde
K3A1	Sugarcane bagasse compost + NPK	18.67d	19.36cd	1.93d	2.51cde
K4A0	Biochar + bagasse compost (2:4) (bio-compost)	12.00bc	12.69bc	1.36abc	2.05abcd
K4A1	Biochar + bagasse compost (2:4) (bio-compost) + NPK	19.33d	21.38d	1.99d	2.70e

Notes: Different lowercase letters in rows and columns indicate significant differences at 5% DMRT

Table 7. Effect of treatment on plant tissue N, P, K nutrient content

Code	Treatments	N (%)		P (%)		K (%)	
		1st planting	2nd planting	1st planting	2nd planting	1st planting	2nd planting
K0A0	Control	1.89a	2.53a	0.16a	0.23a	2.79a	3.01a
K0A1	Standard NPK	3.53bcd	4.37c	0.27abc	0.36bc	3.86abc	4.35bc
K1A0	Manure	2.45abc	3.22abc	0.23ab	0.33abc	3.46ab	3.96abc
K1A1	Manure + NPK	3.71cd	4.23bc	0.36cd	0.47d	4.08bc	4.59bc
K2A0	Sugarcane bagasse biochar	2.33ab	3.17abc	0.23ab	0.33abc	3.30ab	3.92abc
K2A1	Sugarcane bagasse biochar + NPK	3.13abcd	3.47abc	0.29bc	0.35bc	3.85abc	3.75ab
K3A0	Sugarcane bagasse compost	2.55abc	3.08abc	0.25abc	0.31ab	3.61ab	3.63ab
K3A1	Sugarcane bagasse compost + NPK	3.50bcd	4.29bc	0.31bc	0.49d	4.13bc	4.48bc
K4A0	Biochar + bagasse compost (2:4) (bio-compost)	2.42ab	2.97ab	0.23ab	0.30ab	3.60ab	3.79abc
K4A1	Biochar + bagasse compost (2:4) (bio-compost) + NPK	3.86d	4.38c	0.42d	0.43cd	4.89c	4.90c

Notes: Different lowercase letters in rows and columns indicate significant differences at 5% DMRT

(Yanti et al., 2024). In addition, K plays an essential role in increasing the yield of shallot plants because of its role as an activator of carbohydrate-forming enzymes and the process of translocation of photosynthetic products that can trigger an increase in the size and number of shallot bulbs (Tarjiyo, 2023; Yamika et al., 2024). This result can be seen from the positive correlation between the increase in the size and number of shallot bulbs and an increase in the N, P, and K concentration of plant tissue at the first and second plantings (Table 7).

CONCLUSIONS

Applying bagasse-based organic matter improves Entisols by increasing soil organic C, humic acid, and fulvic acid content and nutrient availability, increasing nutrient uptake and shallot yield. The biochar + bagasse compost (2:4) (bio-compost) + NPK (K4A1) showed the highest improvement, comparable to the manure treatment. These findings highlight the potential of bagasse as a soil improver. Future research should focus on its long-term effects on soil health, microbial activity, and nutrient cycling. It should also optimize application rates and combinations with other additives for sustainable soil fertility management.

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