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To cite this article: Jauhari Syamsiyah *et al* 2026 *IOP Conf. Ser.: Earth Environ. Sci.* **1632** 012049

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Residual effects of biochar, compost, and biochar–compost combined with NPK fertilizer on yield of shallots (*Allium cepa* L.) in inceptisols during the third planting season

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Abstract. Soil fertility depletion and declining agricultural productivity, largely due to land degradation, remain critical challenges for tropical soils. Organic amendments are commonly applied to restore degraded soils; however, their effects are relatively slow and often persist beyond a single planting season. Biochar and compost, alone or in combination, can improve soil fertility and crop performance, yet their residual effects across multiple planting seasons require further evaluation. This study examined the residual influence of biochar, compost, and their combination on the growth and yield of shallots (*Allium cepa* L.) in the third planting season under Inceptisol conditions. A completely randomized factorial design was employed with two factors, consisting of the type of residual material from the first planting season (no organic fertilizer, bagasse compost, bagasse biochar, or bagasse biocompost applied at 10 t/ha) and NPK fertilizer applied at three dosage levels (0%, 50%, and 100%). Results indicated that the combination of biocompost with 100% NPK significantly increased plant height and fresh tuber yield compared to the control. Moreover, the treatment combining biochar with 50% NPK (B2A2) also increased dry tuber weight, which was not significantly different from the best-performing treatment. These findings suggest that integrating organic amendments can enhance fertilizer efficiency, sustain crop productivity, and promote environmentally friendly agricultural practices in tropical soils.

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1. Introduction

Indonesia is one of the world's largest producers of agro-industrial waste, with bagasse as being a major b-product of the sugar industry(1). Annually, sugar mills generate approximately 587,082 tons of bagasse (2,3), of which about 97.4% is utilized as boiler fuel, while the remaining fraction remains underutilized and may pose environmental risks if improperly managed (4). Despite these limitations, sugarcane bagasse has considerable potential as a source of organic material for soil amendment (5). However, the high content of lignin and structural carbohydrates, such as cellulose and hemicellulose (6)limit its direct application in agriculture, necessitating appropriate pretreatment prior to soil incorporation (7)

Composting and pyrolysis have been widely reported as effective pretreatment methods to enhance the agronomic value of sugarcane bagasse by accelerating the degradation of lignin and cellulose compounds and increasing material stability (8,9)These processes transform bagasse into compost and biochar with improved nutrient availability and persistence in soil. Organic amendments such as compost and biochar are known to gradually release essential nutrients, including nitrogen, phosphorus, and calcium (10,11)thereby extending nutrient availability and generating residual effects in subsequent growing seasons (12)In addition, their application contributes to the improvement of soil chemical properties, such as pH, soil organic carbon, and cation exchange capacity (13,14).

Various studies have been conducted on compost and biochar residues, including the use of pine-based compost and biochar to increase peanut yields in the second growing season (15)and enhanced carbon mineralization associated with compost and biogas residues from cow manure (16)However, most studies have focused on short-term or second-season effects and on organic amendments derived from materials other than sugarcane bagasse, leaving limited information on their long-term residual effects up to the third growing season. Shallot (*Allium cepa* L.) is an economically important horticultural crop in Indonesia and is highly responsive to soil nutrient availability due to its shallow root system and short growth cycle. Shallot (*Allium cepa* L.) is an economically important crop in Indonesia and is highly responsive to soil nutrient availability due to its shallow root system and short growth cycle. Its cultivation commonly depends on intensive NPK fertilization, which may reduce nutrient use efficiency and soil quality when applied excessively, highlighting the need for integrated nutrient management(17). Therefore, this study evaluated the residual effects of biochar, compost, and their combination, applied with three levels of NPK fertilizer, on shallot yield in Inceptisols during the third growing season, providing new insight into the long-term potential of sugarcane bagasse-based organic amendments to support reduced mineral fertilizer inputs.

2. Method

This study employed a completely randomized factorial design with two factors and three replications. The first factor was organic amendment, consisting of B1: no organic material, B2: compost, B3: biochar, and B4: biocompost prepared from a mixture of biochar and compost at a ratio of 1:4 (w/w). The second factor was NPK fertilizer level, comprising A1: 0% of the recommended dose, A2: 50% of the recommended dose, and A3: 100% of the recommended dose. Compost, biochar, and biocompost were applied at a rate of 10 t/ha at the beginning of the study during the first growing season, approximately four months prior to the third growing season evaluated in this study. The recommended dose of NPK fertilizer (15–15–15) was 525 kg/ha, while ZA fertilizer (ammonium sulfate) was applied as a supplementary fertilizer at a fixed rate

of 185 kg/ha. NPK fertilizer was applied at 0, 14, and 36 days after planting (DAP), whereas ZA fertilizer was applied at 30 DAP using ring placement.

Table 1. Treatment of Organic Matter and NPK fertilizers

Sugarcane bagasse residue (B)	Level Inorganic fertilizer dose (A)		
	Control	NPK 50%	NPK 100%
Control	B_1A_1	B_1A_2	B_1A_3
Compost	B_2A_1	B_2A_2	B_2A_3
Biochar	B_3A_1	B_3A_2	B_3A_3
Bio-Compost	B_4A_1	B_4A_2	B_4A_3

The growing medium consisted of Inceptisol soil (5 kg per pot) that had been used in the previous growing seasons.The soil had low fertility, with a pH of 6.37, organic carbon content of 1.52%, total nitrogen of 0.18%, available phosphorus of 8.73 mg/kg, exchangeable potassium of 0.61 mg/kg, and a cation exchange capacity (CEC) of 15.23 cmol/kg. Bima Brebes shallot (*Allium cepa* L.) bulbs were cut one-third from the tip and planted at one bulb per pot. Crop maintenance included watering, weeding, and pest and disease control. Plant height, number of leaves, fresh bulb weight, and dry bulb weight were recorded at harvest. Data were analyzed using analysis of variance (ANOVA), followed by Duncan's Multiple Range Test (DMRT) at a 95% confidence level. All statistical analyses were performed using SPSS software.

3. Results and Discussion

3.1 Plant Height

The height of shallot plant showed variation, although statistically there was no significant difference between treatments (Figure 1). The interaction between biochar and compost with NPK fertilizer had a significant effect on the height of shallot plants (*Allium cepa* L.). The biocompost + 100% NPK treatment (B4A3) yielded the best results with a 60.84% increase in plant height compared to the control (B1A1). This significant interaction indicates that the effectiveness of mineral fertilizer was strongly influenced by the presence of organic amendments under the inherent soil conditions of Inceptisols. Inceptisols are generally characterized by low organic matter content, limited nutrient retention capacity, and moderate cation exchange capacity, which can restrict nutrient availability for plant growth(18). The application of biocompost likely improved soil organic carbon and cation exchange capacity, thereby enhancing nutrient retention and reducing nutrient losses from applied NPK fertilizer. This synergistic effect contributed to improved nutrient uptake and vegetative growth of shallots, particularly under the highest NPK level.

These findings are in line with the research by Zhihui et al. (19)who reported that the combination of organic fertilizer with nitrogen and phosphorus can improve root development and nutrient absorption, thereby supporting vegetative plant growth. Similarly, Sadegh-Zadeh (20)and Manolikaki & Diamadopoulos (21)reported that biochar and compost residues can enhance shallots growth by increasing the availability of major nutrients such as N, P, and K. Sugarcane bagasse has the potential to be a source of nitrogen (22)which plays an important role

in the formation of amino acids, proteins, and chlorophyll that support photosynthesis and plant growth(23).

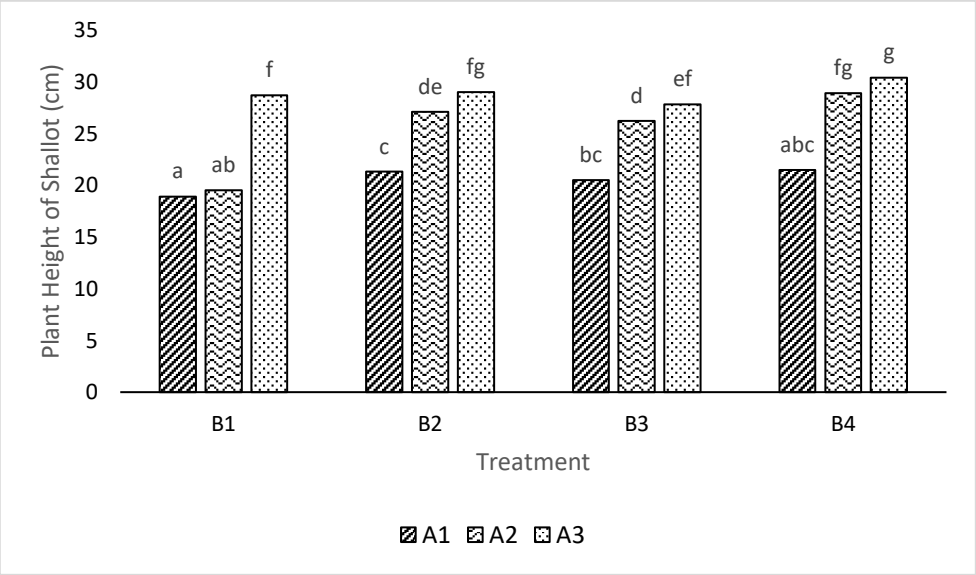


Figure 1. Plant height of Shallot at various treatments

3.2 Number of Leaves

The results of the analysis of variance show that the level of NPK dosage has a significant effect on the number of shallot leaves ($P<0.05$), while the application of sugarcane bagasse residue in various forms and the interaction between the two have no significant effect ($P>0.05$). The organic amendments did not significantly affect leaf number because their residual nutrients were released too slowly and in insufficient amounts to meet the rapid nutrient demand during early leaf initiation. In contrast, leaf number in shallots is primarily determined by immediately available nitrogen and phosphorus supplied by mineral NPK fertilizer. The application of inorganic fertilizer increased the number of leaves by 5% at the 50% NPK level (A2) and 6.5% at the 100% NPK level (A3) compared to without NPK (A1). The increase in the number of leaves is related to the ability of the roots to absorb and translocate nutrients to all parts of the plant(24). Nitrogen plays a role in the composition of amino acids and proteins, while phosphorus plays a role in cell division and energy transfer, so the availability of both is very important in the formation of vegetative organs such as leaves (25)so that the addition of NPK fertilizer can significantly increase the number of leaves (26).

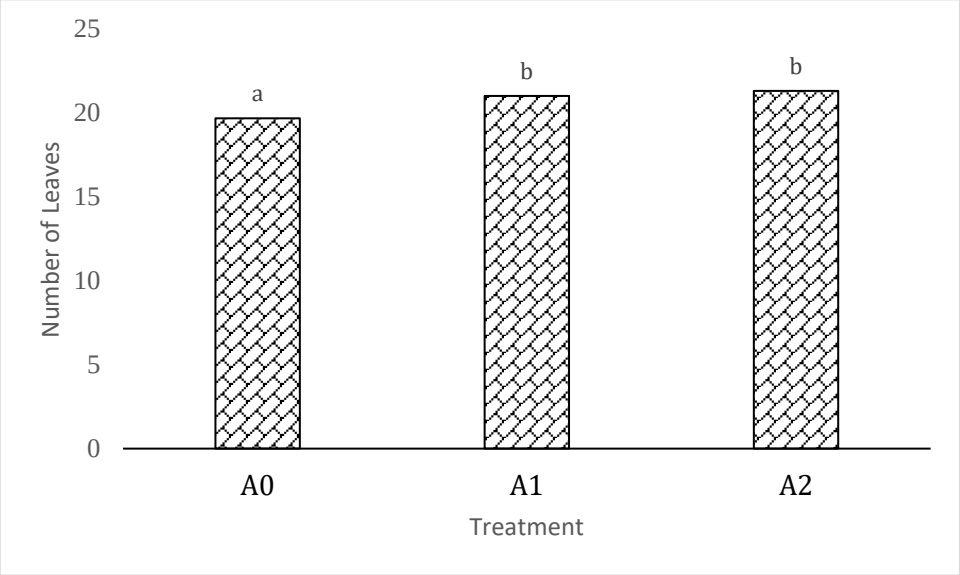


Figure 2. Leaf number of Shallot at various treatments

3.3 Fresh Weight of Bulbs

The weight of fresh shallot bulbs is significantly influenced by the interaction of sugarcane bagasse residue in various forms and levels of NPK compound fertilizer ($P<0.05$).

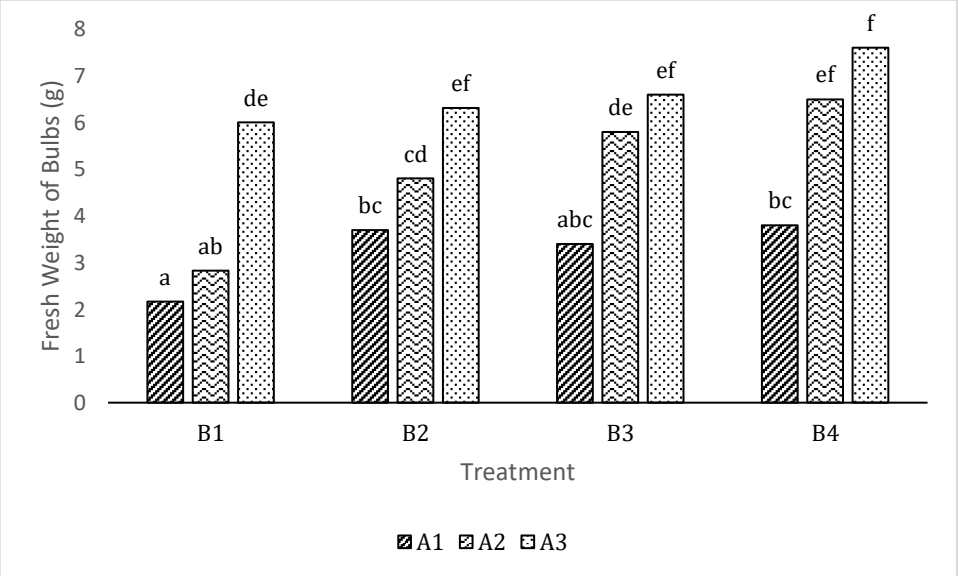


Figure 3. Fresh Weight of Bulbs at various treatments

The DMRT test results show that the combination of biocompost + 100% NPK (B4A3) produced the highest fresh bulb weight with an increase of approximately 251% compared to the control (B1A1). These findings are in line with Fadillah et al. (27) who reported that the combination of organic matter and NPK synergistically increased the weight of shallot bulbs. In addition, Sadegh-Zadeh(20)and Ngindi et al (28)confirmed that the application of biochar and compost can increase yields by improving the availability of macro nutrients, particularly N, P, and K.

3.4 Dry Weight of Bulbs

Analysis of variance shows that the interaction between bagasse residue and NPK fertilizer dosage has a significant effect ($p<0.05$) on the dry weight of shallots.

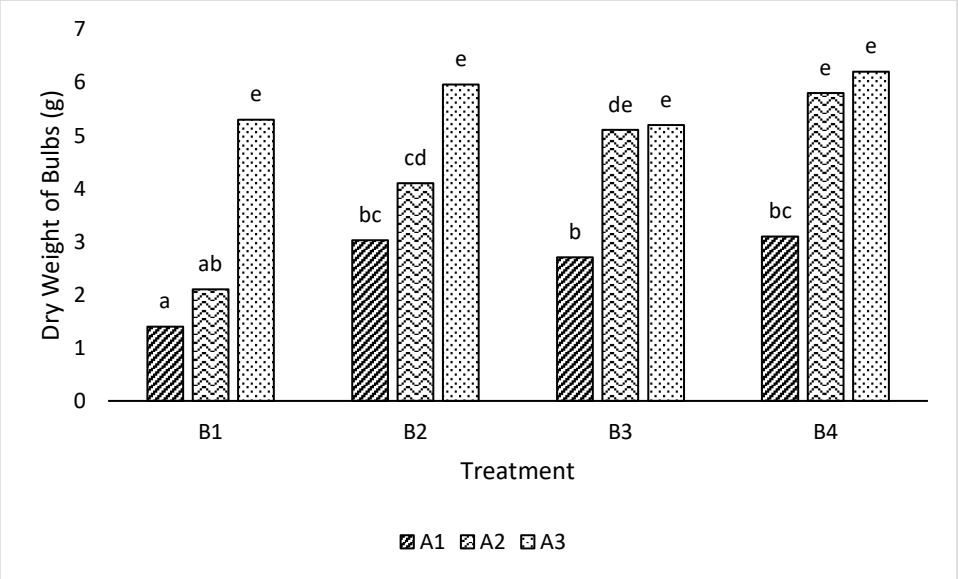


Figure 4. Dry Weight of Bulbs at various treatments

Further DMRT tests confirmed that the biocompost + 100% NPK treatment (B4A3) produced the highest dry tuber weight with a 342% increase compared to the control (B1A1). Meanwhile, the biochar + 50% NPK treatment (B2A2) also showed an increase that was not significantly different from the best treatment. This is consistent with findings reported by Wijaya et al.(17) who demonstrated that the combined application of biochar, compost, and NPK fertilizer can increase soil organic carbon, total nitrogen, and cation exchange capacity (CEC), thereby enhancing the uptake of nitrogen, phosphorus, and potassium by shallot plants. This increase in nutrient availability ultimately results in the highest fresh and dry bulb weight. The pores and surface area of biochar increase the soil's capacity to adsorb nutrients and provide a habitat for microbes, thereby accelerating the decomposition of organic matter(29,30)and providing nutrients for plants such as phosphorus and potassium, which act as enzyme activators, carbohydrate formation, and photosynthesis translocation processes (30)that can increase the dry weight of shallots (31).

4. Conclusion

The integration of sugarcane bagasse-based biocompost with NPK fertilizer improved shallot growth and bulb yield, whereas inorganic fertilizer alone mainly enhanced vegetative growth. This study contributes new evidence on the residual effectiveness of bagasse-based organic amendments persisting up to the third growing season, an aspect that remains limited in current literature. However, the results were obtained from a single soil type and one cropping cycle. Therefore, further long-term and multi-location studies are required to confirm the sustainability and broader applicability of sugarcane bagasse residue utilization in shallot production systems.

Acknowledge

The authors would like to thank the Department of Soil Science, Faculty of Agriculture, Sebelas Maret University, and the Institute for Research and Community Service (LPPM) UNS for their support and facilities provided. This research was funded by the Fundamental Research Program B (PFB-UNS) with contract number 369/UN27.22/PT.01.03/2025.

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