Effects of biochar and bagasse compost on N, P, and K availability in tropical Inceptisols under the third planting season

Jauhari Syamsiyah[1*], *Triyani* Dewi[2], *Lidya Zaela* Wijaya[3], *Firdha Rahayu* Lukmaningrum[4], *Bardhian Cahyo Aji* Gumilang[1], and *Ristiya Adi* Wiratama[1]

[1]Department of Soil Science, Faculty of Agriculture, Sebelas Maret University, Surakarta, Indonesia
[2]Horticulture Research Center, National Research and Innovation Agency, Soekarno Science and Technology Park, Jalan Raya Jakarta-Bogor KM 46, Cibinong, Bogor 16915, West Java, Indonesia
[3]Doctoral Program in Agricultural Science, Faculty of Agriculture, Sebelas Maret University, Surakarta, Indonesia
[4]Graduate Program of Soil Science, Faculty of Agriculture, Sebelas Maret University, Surakarta, Indonesia

Abstract. Climate change accelerates soil nutrient depletion, leading to reduced soil productivity in tropical regions, thus requiring efforts to enhance soil fertility. Bagasse compost and biochar amandments improve nutrient availability in tropical Inceptisols and plant nutrient uptake. This study aims to examine the impact of biochar, compost, and their combination on soil nutrient availability and the uptake of shallot (Allium cepa L.) in the third planting season. The design used was a completely randomized factorial design with two factors consisting of types of residual materials applied at the beginning of the planting season, namely SB 0: no fertilizer, SB 1: sugarcane bagasse compost, SB 2: sugarcane bagasse biochar, and SB 3: sugarcane bagasse bio-compost, each at 10 tons/ha, and NPK fertilizer with varying dose levels: CF 0: NPK 0%, CF 1: NPK 50%, CF 2: NPK 100% (525 kg/ha). The results showed that the combination of sugarcane bagasse biochar + compost (2:4) (bio-compost) + NPK 50% (SB3CF1) significantly increased soil N, P, and K availability and plant tissue in the third planting season. These findings support the use of bagasse as a potential organic amendment to improve nutrient availability in Inceptisol soils and play a role in reducing global warming.

1 Introduction

Climate change has an impact on the decline in soil nutrient levels, especially in tropical regions with high rainfall. High rainfall intensity accelerates nutrient leaching and exacerbates soil degradation, which ultimately reduces soil productivity and agricultural yields [1] as in the case of Inceptisols, which are vulnerable to these conditions Inceptisol soils have development potential due to their widespread distribution in tropical regions, covering approximately 70.52 million ha or 37.5% of agricultural land in Indonesia.

* Corresponding author: ninukts@staff.uns.ac.id

However, several constraints such as low organic carbon content, cation exchange capacity (CEC), N, P, K availability and acidic to slightly acidic pH (pH 4.5-5.5) must be addressed to optimize their use as agricultural land [2]. However, various agricultural practices, including soil cultivation and fertilizer application, also contribute to increasing carbon dioxide (CO_2) concentrations, which is one of the primary gases causing global warming and climate change. Inorganic fertilizers application stimulated CO_2 emissions by increasing rhizosphere activity, but at the same time it also has the potential to increase CO_2 absorption by leaves through photosynthesis [3].

The use of organic amendments such as compost and biochar is a strategy to increase the productivity of Inceptisols, with bagasse as a potential biomass source for the production of both types of amendments. Compost and biochar can improve soil chemical properties such as pH, total organic carbon, and cation exchange capacity and slowly release nitrogen, phosphorus, and calcium nutrients into the soil thereby potentially providing nutrients in the long term [4]. The gradual and sustained release of nutrients makes compost and biochar effective in reducing the need for inorganic fertilizers.

The results of the study show that there is a positive effect of compost and biochar residues made from sugarcane bagasse on nutrient availability, plant tissue, and shallot growth in the second season in Entisol soil [5] as well as biochar and compost residues from straw on corn plants [6]. However, the effect of compost and sugarcane bagasse biochar on nutrient availability and N, P, and K concentrations in shallot plant tissue in Inceptisols in the third season is still limited. This study aims to evaluate the effect of compost and biochar made from sugarcane bagasse on nutrient availability and N, P, and K concentrations of shallot plant tissue in Inceptisols

2 Method

This research is quantitative experimental research using completely randomized design (CRD) factorial with two factors (Table 1). The first factor consisted of no organic residue (SB0), compost (SB1), biochar (SB2), and bio-compost (biochar with compost) with a ratio of 2:4 (w/w), while the second factor was (CF0): NPK 0%; (CF1): NPK 50%, and (CF2): NPK 100% (recommended). The recommended dose of NPK fertilizer was 525 kg ha^{-1}, applied at 0, 14, and 36 weeks after planting, while 185 kg/ha of ZA fertilizer was applied at 30 weeks after planting as additional fertilizer using the ring placement method.

Table 1. Treatment of Organic Residues and NPK Fertilizer

Sugarcane bagasse (SB) organic residue	**Inorganic fertilizer dosage level (CF)**			**Description**
	Control	**NPK 50%**	**NPK 100%**	
Control	SB0CF0	SB0CF1	SB0CF2	
Compost	SB1CF0	SB1CF1	SB1CF2	
Biochar	SB2CF0	SB2CF1	SB2CF3	
Bio-compost	SB3CF0	SB3CF1	SB3CF2	Comparison of biochar and compost 1:4 (w:w)

The planting medium uses 5 kg of dried, refined, and 2 mm sieved Inceptisols per pot. Compost, biochar, and bagasse bio-compost are applied only in the first season by mixing them into the planting medium. Bima Brebes shallot seeds were planted by inserting one bulb, with the tip cut by 1/3, into the planting hole. Maintenance included weeding, pest and disease control, watering, and pruning. Soil and tissue samples were taken at 60–70 days of age. The data were analyzed using ANOVA, followed by the DMRT test at a 95% level.

3 Results and Discussion

3.1 Soil N, P, K Content

Total nitrogen (N), available phosphorus (P), and exchangeable potassium (K) were significantly affected by the interaction between organic matter residue and NPK fertilizer ($P < 0.05$). The treatment of sugarcane bagasse biochar + compost (2:4) (bio-compost) + 50% NPK (SB3CF1) yielded the best results with a 23% increase in total N compared to the control (SB0CF0) (Table 2). This result was equivalent to the treatment of sugarcane bagasse biochar + compost (2:4) (bio-compost) + 100% NPK (SB3CF2) even though the NPK dose used was higher. This finding indicates that increasing the NPK dose from 50% to 100% did not provide a significant additional effect on total N at the SB3 application level. These results are in line with the studies by Bushron et al.[4] that organic fertilizers often show low effectiveness in initial applications due to slow N release and N immobilization, but this process contributes to an increase in soil N reserves in the long term. Overall, long-term application of organic fertilizers can achieve N utilization efficiency equivalent to 40–70% of mineral fertilizers. Bagasse compost can effectively increase and become a potential source of nitrogen for plants in mineral soils. In addition, the addition of NPK fertilizer containing N also increases the availability of N in the soil. The addition of sugarcane bagasse biochar can reduce N loss due to leaching, because the oxide surface of biochar is able to absorb NH_4^+ and NO_3^-, thereby preventing nitrogen loss [7].

The treatment of sugarcane bagasse biochar + compost (2:4) (bio-compost) + NPK 50% (SB3CF1) also provided the best available P results with an increase of 128% compared to the control (SB0CF0), which was not significantly different from the treatment of sugarcane bagasse biochar + compost (2:4) (bio-compost) + NPK 100% (SB3CF2) (Table 2). These findings indicate that increasing the NPK dose from 50% to 100% did not significantly increase available P at the SB3 application rate. This is in line with Wijaya et al.[5] who found that sugarcane bagasse compost promoted P availability by mineralization processes in soil. The addition of biochar together with compost in the long term can increase P availability by reducing P binding by soil metal elements [8]. Fresh biochar has a relatively low CEC, so it does not directly increase soil CEC. The CEC and anion exchange capacity (AEC) values of biochar increase over time in line with the formation of new functional groups on its surface, so that its long-term application can increase the capacity of biochar to adsorb and retain anions such as P in the soil [9].

The analysis results show that the highest exchangeable K concentration was obtained in the sugarcane bagasse biochar + compost (2:4) (bio-compost) treatment with 50% NPK (SB3CF1) ($p < 0.01$), with an increase of 34% compared to the control (SB0CF0). This value was not significantly different from the treatment with a higher NPK dose, namely sugarcane bagasse biochar + compost (2:4) (bio-compost) + 100% NPK (SB3CF2) (Table 2). This indicates that increasing the NPK dose from 50% to 100% did not significantly increase exchangeable K at the SB3 application rate. Similar results were obtained by Iqbal et al.,[10] that sugarcane bagasse compost can increase soil K availability due to the relatively high K content in sugarcane bagasse compost, which can be made available through mineralization processes in the soil. The addition of biochar also contributes to an increase in exchangeable K through its extensive pore structure and the presence of negatively charged functional groups that effectively bind and retain cations, including K^+ [11]. A significant reduction in K loss through leaching can also be attributed to the high cation exchange capacity (CEC) of bagasse (70.12 cmolc kg^{-1}), which increases the soil's ability to absorb K.

Table 2. Effect of treatments on soil nutrient content

Treatments		Total N (%)	Available P (ppm P)	Exchangeable K (me100 g^{-1})
Sugarcane bagasse (SB) organic residue	**NPK Fertilizer Dosage**			
Control (SB0)	Without NPK (CF0)	$0,30^{a}$	3.72^{a}	0.58^{a}
	50% NPK (CF1)	$0,30^{a}$	4.61^{ab}	0.60^{a}
	100% NPK (CF2)	$0,35^{def}$	7.72^{ef}	0.72^{d}
Sugarcane bagasse compost (SB1)	Without NPK (CF0)	$0,33^{bcd}$	6.04^{cd}	0.62^{ab}
	50% NPK (CF1)	$0,33^{bcd}$	7.43^{de}	0.74^{de}
	100% NPK (CF2)	$0,37^{fg}$	8.6^{ef}	$0.74d^{e}$
Sugarcane bagasse biochar (SB2)	Without NPK (CF0)	$0,32^{ab}$	4.97^{bc}	0.62^{ab}
	50% NPK (CF1)	$0,34^{cde}$	6.46^{cd}	0.71^{d}
	100% NPK (CF2)	$0,36^{efg}$	8.42^{ef}	0.70^{cd}
Sugacane bagasse biochar + compost (2:4) (SB3)	Without NPK (CF0)	$0,32^{abc}$	5.09^{bc}	0.67^{bc}
	50% NPK (CF1)	$0,37^{fg}$	8.49^{ef}	0.78^{ef}
	100% NPK (CF2)	$0,37^{g}$	9.23^{f}	0.81^{f}

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

3.2 N, P, K on Shallot Plant Tissue

The analysis results show that the N, P, K content of plant tissue is significantly influenced by the interaction between organic matter residue and NPK fertilizer ($P < 0.05$). The treatment of sugarcane bagasse biochar + compost (2:4) (bio-compost) + 50% NPK (SB3CF1) produced the best nitrogen content in plant tissue with an increase of 125% compared to the control (SB0CF0). This concentration was not significantly different from the treatment of sugarcane bagasse biochar + compost (2:4) (bio-compost) + 100% NPK (SB3CF2), despite using a higher dose of NPK. These findings indicate that at the SB3 application rate, increasing the NPK dose from 50% to 100% did not have a significant additional effect on N content in plant tissue. In line with Toselli et al. [12] long-term compost application has been shown to increase total soil N, microbial N, and exchangeable N, each with higher values than mineral fertilizer application. The decomposition process of compost in the soil can produce proteins, amino acids, and ammonium (NH_4^+) and nitrate (NO_3^-) ions that can be directly absorbed by plants. In addition, the addition of NPK fertilizer acts as a source of mineral nitrogen that can optimize plant N uptake. Syamsiyah et al. [13] states that the combination of organic and inorganic fertilizers can increase the total N content of the soil, thereby improving the efficiency of nitrogen utilization by plants. Furthermore, [7] stated that biochar treatment increased NH_4^+ and NO_3^- availability in late growing season than no biochar treatment, indicating that biochar stabilized N release in soil, make it more efficient for plant uptake.

The DMRT test results show that the treatment of sugarcane bagasse biochar + compost (2:4) (bio-compost) + NPK 50% (SB3CF1) increased by 100% compared to the control (SB0CF0). This value was not significantly different from the treatment of sugarcane bagasse biochar + compost (2:4) (bio-compost) + 100% NPK (SB3CF2) even though the NPK dose

used was higher. Thus, at the SB3 application rate, increasing the NPK dose from 50% to 100% did not result in a significant additional increase in P content in plant tissues. This is because the addition of sugarcane bagasse compost as organic matter and P substrate in the long term can increase P availability to plants through mineralization processes in the soil. In addition, the application of biochar together with compost can also increase P availability through its retention capacity for nutrients, thereby increasing the efficiency of P uptake by plants. Research by Ali et al. [14], stated that biochar increase soil pH in second growing season than no biochar treatment, optimal soil pH increase P uptake by minimizing P fixation by Al and Fe in low pH.

The analysis results also showed that the highest plant tissue K levels were found in the sugarcane bagasse biochar + compost (2:4) (bio-compost) + NPK 50% (SB3CF1) treatment, with an increase of 128% compared to the control (SB0CF0). This concentration did not show a significant difference compared to the treatment of sugarcane bagasse biochar + compost (2:4) (bio-compost) + NPK 100% (SB3CF2), even though the NPK dose given was higher. This shows that at the SB3 application level, increasing the NPK dose from 50% to 100% does not significantly affect the increase in K levels in plant tissues. This is because the potassium content of bagasse compost is quite high, so that its long-term application can increase K availability and K uptake by plants. The use of bagasse as an organic material can increase nutrient retention due to its high sorption capacity, which is influenced by its large surface area and high porosity [15] resulting in more optimal soil K availability for plants.

Table 3. Effect of treatments on plant tissue N, P, K nutrient content

Treatments		N (%)	P (%)	K (%)
Sugarcane bagasse (SB) organic residue	**NPK Fertilizer Dosage**			
Control (SB0)	Without NPK (CF0)	1.51^{a}	0.20^{a}	1.40^{a}
	50% NPK (CF1)	2.18^{b}	0.30^{b}	1.94^{b}
	100% NPK (CF2)	3.05^{e}	0.36^{cde}	2.86^{cde}
Sugarcane bagasse compost (SB1)	Without NPK (CF0)	2.60^{cd}	0.33^{bc}	2.61^{c}
	50% NPK (CF1)	2.91^{de}	0.35^{cd}	2.85^{cde}
	100% NPK (CF2)	3.51^{fg}	0.40^{ef}	3.22^{ef}
Sugarcane bagasse biochar (SB2)	Without NPK (CF0)	2.39^{bc}	0.24^{a}	1.97^{b}
	50% NPK (CF1)	2.83^{cd}	0.33^{bc}	2.73^{cd}
	100% NPK (CF2)	3.19^{ef}	0.38^{def}	3.07^{def}
Sugacane bagasse biochar + compost (2:4) (SB2)	Without NPK (CF0)	2.60^{cd}	0.31^{b}	2.51^{c}
	50% NPK (CF1)	3.40^{fg}	0.40^{ef}	3.19^{ef}
	100% NPK (CF2)	3.61^{g}	0.41^{f}	3.47^{f}

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

4 Conclusion

The use of sugarcane bagasse as compost, biochar, or a combination of both continues to improve soil fertility in the third growing season. The application of sugarcane bagasse biochar + compost (2:4) (bio-compost) combined with 50% NPK (SB3CF1) resulted in nutrient availability (N, P, and K) and plant tissue nutrient content comparable to the highest fertilizer dose. These improvements are driven by the ability of sugarcane bagasse compost and biochar to enhance nutrient retention and promote long-term mineralization, leading to more efficient nutrient use and reduced dependence on synthetic fertilizers. Since the production and application of synthetic fertilizers contribute to CO_2 emissions, the adoption of these bagasse-based amendments not only improves soil health but also helps mitigate climate change by lowering the carbon footprint of fertilization.

Acknowledgement

The authors would like to express their sincere gratitude to the Department of Soil Science, Faculty of Agriculture, Sebelas Maret University. The authors also gratefully acknowledge the research support provided through the Regular Fundamental Research (PFR) Grant under contract number 1186.1/UN27.22/PT.01.03/2025, funded by the Ministry of Higher Education, Science, and Technology.

Refences

1. S. Solaymani, Impacts of climate change on food security and agriculture sector in Malaysia. Environment, Development and Sustainability. **20**, 4 (2018). https://doi.org/10.1007/s10668-017-9954-4
2. M. La Habi, B. Prasetya, S. Prijono, and Z. Kusuma, The effect of sago pith waste granule compost and inorganic fertilizer on soil physical characteristics and corn (Zea mays L.) production in Inceptisol. IOSR Journal of Environmental Science, Toxicology and Food Technology. **8**, 2 (2014). https://doi.org/10.9790/2402-08223240
3. R. D. Kartikawati dan Nursyamsi, P. Pengairan, D. Penghambat Nitrifikasi, R. Kartikawati, B. Penelitian Lingkungan Pertanian, J. Raya Jakenan-Jaken, D. Nursyamsi, B. Penelitian Pertanian Lahan Rawa Jl Kebun Karet, and L. Utara, Effect of Irrigation, Fertilization, and Nitrification Inhibitor on Greenhouse Gases Emission at Rice Field of Mineral Soils. Ecolab. **vol 7**, 2 (2013)
4. R. Bushron, A. A. Hanuf, A. T. Yulianto, M. W. Lutfi, D. M. Yunita, R. Suntari, and S. Soemarno, Soil nutrient improvement with organic amendments: a basis for lemon orchard management. SAINS TANAH - Journal of Soil Science and Agroclimatology. **22**, 2 (2025). https://doi.org/10.20961/stjssa.v22i2.99868
5. L. Z. Wijaya, J. Syamsiyah, S. Suntoro, S. Minardi, and R. Rahayu, Effect of Sugarcane Bagasse Bio-Compost and Manure on Carbon Fraction and N, P, K Content in Entisols and Their Relationship with Shallot Yields. AgriHealth: Journal of Agri-Food, Nutrition and Public Health. **6**, 1 (2025). https://doi.org/10.20961/agrihealth.v6i1.99420
6. W. Herman and E. Resigia, Efek Residu Biochar Sekam dan Kompos Jerami Padi sebagai Bahan Pembenah Tanah pada Musim Tanam Kedua terhadap Pertumbuhan Padi di Ultisol. LUMBUNG. **20**, 2 (2021). https://doi.org/10.32530/lumbung.v20i2.281
7. S. Gao, M. Medina, L. Gonzalez-Ospina, K. Burce, K. Burce, and A. Melbourne, Boosting soil health and crop nutrients with locally sourced biochar and compost in

Sacramento urban agriculture. Frontiers in Sustainable Food Systems. **9**, 1546426 (2025). https://doi.org/10.3389/fsufs.2025.1546426

8. M. Asril, W. Lestari, Basuki, M. F. Sanjaya, R. Firgiyanto, B. Manguntungi, M. K. Swandi, M. Paulina, and W. R. Kunusa, Mikroorganisme Pelarut Fosfat pada Pertanian Berkelanjutan. Yayasan Kita Menulis. Medan. (2023)
9. Z. Zhang, X. Huang, S. Qin, M. Azeem, H. Wang, and S. Yang, Effects of different application ratios of biochar-organic compound fertilizers and chemical fertilizers on soil nutrition content and yield of maize. SAINS TANAH - Journal of Soil Science and Agroclimatology. **22**, 2 (2025). https://doi.org/10.20961/stjssa.v22i2.102140
10. A. Iqbal, L. He, A. Khan, S. Wei, K. Akhtar, I. Ali, S. Ullah, F. Munsif, Q. Zhao, and L. Jiang, Organic manure coupled with inorganic fertilizer: An approach for the sustainable production of rice by improving soil properties and nitrogen use efficiency. Agronomy. **9**, 10 (2019). https://doi.org/10.3390/agronomy9100651
11. C. Raul, V. S. Bharti, G. Krishna, Y. D. Jaffer, and S. Lenka, Sugarcane bagasse biochar : Suitable amendment for inland aquaculture soils. Aquaculture Reaearch. (2020). https://doi.org/10.1111/are.14922
12. M. Toselli, E. Baldi, L. Cavani, M. Mazzon, M. Quartieri, G. Sorrenti, and C. Marzadori, Soil-plant nitrogen pools in nectarine orchard in response to long-term compost application. Science of the Total Environment. **671**, (2019). https://doi.org/10.1016/j.scitotenv.2019.03.241
13. J. Syamsiyah, A. Herawati, H. Widijanto, B. A. Nugraha, and D. P. Ariyanto, Nitrogen mineralization from rice straw and cow manure with various moisture conditions in organic paddy fields. Soil Environment. **42**, 1 (2023). https://doi.org/10.25252/SE/2023/243010
14. M. Ali, O. H. Ahmed, M. B. Jalloh, W. C. Primus, A. A. Musah, and J. F. Ng, Co-Composted Chicken Litter Biochar Increases Soil Nutrient Availability and Yield of Oryza sativa L. Land. **12**, 1 (2023). https://doi.org/10.3390/land12010233
15. N. Xu, J. H. Bhadha, A. Rabbany, S. Swanson, J. M. Mccray, Y. Li, S. L. Strauss, and R. Mylavarapu, Sugarcane bagasse amendment mitigates nutrient leaching from a mineral soil under tropical conditions. Pedosphere. **32**, 6 (2022). https://doi.org/10.1016/j.pedsph.2022.06.020