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Corn root characteristic affected by several Compost-enriched Biochar (BioKom) application in Inceptisol

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Abstract. Inceptisols are relative low-fertility, slightly acidic soils with limited nitrogen (N), phosphorus (P), and potassium (K) content. Biochar is a pyrolyzed organic material with a high surface area and cation exchange capacity (CEC), but low in essential nutrients, which must be supplemented by compost. This study examined the effects of five types of biochar embedded with composted biomass (BioKom) on corn root characteristics. A field pot trial using 20 t ha^{-1} of young coconut waste, rice husk, cassava peel, sugarcane bagasse, and pulai wood biochars was conducted, with each mixed with 20 t ha^{-1} of compost. A randomized complete block design (no-factor) and a 5% HSD test were used for variance analysis and replicated three times. Parameters measured were root depth, root weight, shoot weight, shoot-to-root ratio, and shoot root depth. Results showed no differences in all parameters, except specific root depth. While most parameters showed no significant differences, specific root depth was improved by treatments. Pulai wood with the highest fixed carbon content among others showed significant differences in specific root depth therefore showed highest efficiency in root growth and resource acquisition. This study suggests that BioKom can enhance root growth and improve corn yield in nutrient-poor Inceptisols.

1. Introduction

Inceptisol, which is distributed in various tropical regions, including Indonesia, has relatively low mineral properties and low productivity. This soil structure is less able to provide optimal nutrients for plants, including corn. The limitations of Inceptisol tend to be slightly acid with a moderate content of organic carbon but poor availability of essential nutrients such as nitrogen, potassium**,** and phosphorus, lead to a low efficiency of plant nutrient uptake, which has the potential to inhibit the growth of corn. Therefore, enough space should be given to increase soil productivity and health.

Amendments such as compost-enriched biochar is recommended for the improvement of physical, chemical, and biological properties of Inceptisol soils. It can improve water retention, cation exchange capacity, nutrient availability in soils, while composting enriches soil organic matter and promotes activities of microorganisms for soil health.Biochar, a carbon -rich solid material obtained by the pyrolysis of organic matter can enhance soil health and optimize agricultural yields. This is of primary importance when it comes to soils where biochar should retain the water, improve nutrient availability and encourage colonization by beneficial micro-organisms; all promoting both root growth below ground and health above [1],[2]. Despite its promising benefits, the biochar itself has no nutrient content, thus addition compost in providing some nutrients may create interesting mutual benefits for soil health. Therefore, the specific effects of biochar enriched with compost (BioKom) on root morphology and development [3], particularly in corn grown on Inceptisols, remain underexplored.

The interaction between compost-enriched biochar application and corn root development must, therefore, be recognized in arriving at an optimization of agricultural methodologies in Inceptisols. The root represents the first interface between plants and soil; through its structure and function, the uptake of nutrients and water is assured. Biomass and roots form a mutual bond with the soil. Plant roots often penetrate the porous structure of biochar, leading to decomposition between the organic matters and thus maintaining soil moisture. Biochar can also increase its pH values (acidity), and the ability of cation exchange affects the efficiency of the biomass. However, a healthy root system helps water and nutrients move quickly. Most plants that grow in dry areas have thick roots that spread close to the soil surface or extend into the ground. Improving root growth using biochar can increase the vigor and productivity of maize crops, especially in challenging soil environments [2], [4]. When biochar is combined with compost-rich in organic matter and microbial life, beneficial microbes will call it home and help break down organic matter. It speeds up the nutrient cycling, making those essential nutrients available to the plant, such as nitrogen, phosphorus, and potassium. This work, therefore, seeks to add to the knowledge gap in the study of the response of corn root pattern to composted biochar on inceptisol soils for sustainable agriculture and food security.

2. Materials and methods

The materials used in this research were biomass waste such as young coconut waste, cassava peels, rice husk, sugarcane bagasse, and pulai wood were obtained from local area. These biomass waste were used for making biochar. The procedure for making Biochar using the Kon-tiki model follows the guidelines established by the Ithaka Instrument waste combustion technology model [5]. For compost production, selected materials included rain tree (*Albizia saman*) leaves, and cow manure was fermented for two weeks using decomposer effective microorganism 4 (EM4). Additionally, various equipment's were employed, including an infrared thermometer gun, a muffler reactor furnace with a temperature ranges up to 2150°C, an analytical balance and other necessary tools for both laboratory analyses and fieldwork. Seeds of corn variety using Bonanza types obtained from local market. NPK fertilizer was used as basic fertilizer. Proximate analysis was used to characterize the biochar. Soil and compost samples were analysed at soil and water testing lab, Faculty of agriculture, Universitas Syiah Kuala.

The experimental design employed was a non-factorial randomized complete block design (RCBD) with six treatments (including control) and three replicates, resulting in 18 experimental units. Analysis of Variance (ANOVA) at a 5% and 1% significance level was conducted to determine whether treatments had significant effects on the measured parameters. If significant effects were found, the Honest Significant Difference (HSD) test was performed at the 5% or 1% significance level. The observed parameters were corn root depth, root weight, shoot weight, shoot-to-root ratio (S/R) and specific root depth (SRD). Specific root depth (SRD) is the ratio between the total root depth of corn plants and the root weight. A higher SRD value indicates a smaller root diameter [11]. The S/R ratio is a variable for drought tolerance in the plant [14]. A lower S/R ratio would indicate that the treatment are working well because it is not as much stress on these roots to provide all this water and nutrients. In contrast, a high S/R ratio is indicative of nutrient-limitation that roots are costly adopting strategies to forage

Root depth was the distance from the soil surface to deepest that corn roots could reach. The root depth indicates how it uses resources lower down than the surface of the soil. The ability to access water and nutrients in deeper soil layers is an advantage where soils are naturally dry or nutrient -poor; longer roots equate to greater capacity for capture. Weight of corn root is calculated as the total dry weight of the plant roots after undergoing a drying process to remove their moisture content.

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3. Results and discussion

3.1. Characteristic of biochar, soil and compost

The testing results for soil and compost (table 1) shows significant differences in fertility characteristics. The soil has a highly acidic pH of 4.26, while the compost's pH is more favourable at 6.30, promoting better plant growth. Organic carbon content is notably low in the soil at 0.80%, contrasting with the compost's rich organic matter level of 16.77%. The available phosphorus in the soil, P-avail, stands at 1.45 mg kg^{-1}, which is relatively low and indicates nutrient limitation. While in total, P-P-Total stands at 0.01% compared to 0.10% in compost. In addition, the calcium exchange in the soil, Ca-exch, has been measured at 6.22 cmol(+) kg^{-1}, showing that at least some forms of nutrients in this category can be found in this soil. There is a low percentage of nitrogen in the soils, measured at 0.16% in comparison with the compost at 1.45%. This compost also exhibits a total potassium concentration of 1.26% (K-Total), showing nutritional superiority. Moisture content, given as 26.07%, is provided only for compost and may contribute to microbial activities and nutrient availability. In summary, these results will evidence the fact that the compost has much more fertility potential, and therefore, the application of compost may bring about an immense improvement in the quality of the soil.

The Inceptisol used in this study is predominantly influenced by Al and Fe, as evidenced by its low pH. The addition of organic materials such as biochar and compost, along with pH adjustment, can improve soil conditions [2],[3],[6]. Organic anions can bind Al and Fe ions in the soil and form insoluble complex compounds, leading to a decrease in the concentration of Al and Fe. Consequently, the reduction in Al and Fe concentration reduces the hydrogen ions responsible for soil acidity, resulting in an increase in pH [7]. Compost offers numerous advantages compared to soil, including improved pH, organic content, and nitrogen levels, as well as enhanced water holding capacity. The addition of compost to soil that is deficient in these parameters can improve soil quality, enhance fertility, and support more effective plant growth [8]. The moisture content of compost is 26.07% hence compost can hold moisture, and this is advantageous in that soil can stay for long and resistant to drought. Soil had low electrical conductivity (0.05 mS/cm), meaning salt concentration was low, which is good for plants. The water holding capacity registered in the soil was 8.09% and this trace for soil water retention, but upon the addition of compost is expected to increase.

Table 1. Results of soil and compost testing.

No.	Parameter	Soil	Compost
1.	pH	4.26	6.30
2.	C-organic (%)	0.80	16.77
3.	P-avail ($mg.kg^{-1}$)	1.45	-
4.	Ca-exch ($cmol+.\ kg^{-1}$)	6.22	-
5.	N-Total (%)	0.16	1.45
6.	P-Total (%)	0.01	0.10
7.	K-Total (%)	-	1.26
8.	pH H_2O	4.26	-
9.	Moisture (%)	-	26.07

The following table 2 presents the results of the proximate analysis conducted on various types of biochar, including young coconut biochar, rice husk biochar, cassava peel biochar, sugarcane bagasse biochar, and Pulai wood biochar.

Table 2. Proximate analysis results for different types of biochar.

No.	Parameter	Young coconut waste	Rice husk	Cassava peels	Sugarcane bagasse	Pulai wood
1.	pH	9.22	7.29	9.22	8.74	7.6
2.	Moisture (%)	5.91	5.00	12.40	12.00	10.24
3.	Volatile matter (%)	83.46	85.26	83.00	86.40	94.77
4.	Ash content (%)	16.61	14.74	15.20	10.02	4.12
5.	Fixed carbon (%)	66.43	70.53	68.20	76.01	90.62

The analysis of various agricultural waste—young coconut waste, rice husk, cassava peels, sugarcane bagasse, and pulai wood—shows potential for use as soil amendments in corn cultivation. The alkaline pH of young coconut waste and cassava peels (9.22) could help neutralize acidic soils, while the moderate pH of rice husk, sugarcane bagasse, and pulai wood supports balanced soil chemistry. High volatile matter, particularly in pulai wood (94.77%), suggests good organic content, which can improve soil structure. Ash content, highest in young coconut waste (16.61%), provides minerals, and pulai wood's high fixed carbon (90.62%) makes it ideal for enhancing soil carbon storage, water retention, and nutrient availability. These characteristics indicate that these materials could improve soil health and maize growth when used as biochar or organic amendments.

3.2. Parameters observed

3.2.1. Dry weight, shoot weight and root depth of the corn. The average dry root weight, shoot weight and root depth of the corn roots is presented in table 3.

Table 3. Average root weight, shoot weight and root depth affected by treatment applied.

No.	BioKom Treatment	Root weight (g)	Shoot weight (g)	Root depth (cm)
1.	Control (B0)	5.1	16.9	74.5
2.	Young coconut (B1)	4.7	15.9	81.0
3.	Rice husk (B2)	4.9	19.3	83.3
4.	Cassava peel (B3)	6.7	33.8	79.0
5.	Sugarcane bagasse (B4)	8.3	50.4	109.7
6.	Pulai wood (B5)	5.4	21.5	130.0

The variance analysis (table 3) indicated that treatment has no significant effect on all parameters observed. Treatment affected sugarcane bagasse (B4) achieved the best outcomes in terms of plant growth, with the highest root weight of 8.3 g, the highest shoot weight of 50.4 g, and the deepest root depth of 130 cm. This suggests that Treatment B4 is highly effective in supporting the growth of both major plant components, namely roots and shoots, leading to overall optimal plant growth. Conversely, Treatment control (BO) exhibited the lowest results with a root weight of 5.1 g and a shoot weight of 16.9 g, indicating that this treatment is less effective in stimulating plant growth, resulting in limited root and shoot weight.

Treatments control and young coconut waste (BO and B1) yielded lower results, indicating that these treatments have a less positive impact on plant growth. Therefore, to maximize plant growth, treatments that provide a good balance between root weight and shoot weight, such as B4, should be seriously considered.

The biochar derived from pulai wood (B5) has led to a remarkable increase in root depth, measuring up to 130 cm. This indicates notable enhancements in the soil's structural integrity and its ability to retain water. With deeper roots, maize plants can tap into water and nutrients from deeper soil layers, improving their resistance to drought conditions.. This indicates that Treatment B5 is highly effective in promoting deeper root growth, allowing the plant to explore deeper soil layers for water and nutrients. This may suggest that this treatment creates conditions that support optimal root growth [9]. Conversely, Treatment BO exhibited the shortest root depth at 74.5 cm. This suggests that this treatment may be less effective in stimulating root growth compared to other treatments, resulting in potential limitations for the plant in accessing available soil resources [10].

Treatment B4, with a root depth of 109.7 cm, demonstrated good results, although not as extensive as B5. This treatment provided better results compared to Treatment BO and several other treatments, indicating that B4 is also quite effective in stimulating root growth, even though it is not as optimal as B5[9]. Treatments B2 and B1 have relatively similar root depths of 83.3 cm and 81.0 cm, respectively. Both show better results compared to BO, but not as significant as B4 and B5. On the other hand, Treatment B3, with a root depth of 79.0 cm, also shows better results than BO but falls short compared to B4 and B5.

Overall, the data indicate that the root depth of plants can be significantly influenced by the treatments applied. Treatments that significantly enhance root depth, such as B5, can improve the plant's ability to survive and grow better in potentially less optimal conditions. Conversely, treatments that are less effective in stimulating root growth, such as BO, can limit the plant's potential to access necessary resources [9],[10]. The findings suggest that optimizing treatment conditions to promote deeper and more extensive root systems can be crucial for improving plant performance and resilience.

3.2.2. Specific root depth (SRD) and soil root ratio (S/R). The average Specific root depth (SRD) is the ratio between the total root depth of corn plants and the dry root weight is presented in table 4. The variance analysis indicated that SRD was influeced by treatment applied but no S/R. SRD of pulai wood is significantl;y different compared to other treatments. Treatment with higher SRD value indicates a smaller root diameter [11]. This metric helps in understanding the efficiency of root systems in terms of their ability to explore soil and acquire nutrients relative to their weight. A higher SRD often suggests a more efficient root system in terms of space exploration, which can be crucial for plant growth, particularly in nutrient-poor or compacted soils.

Table 4. Specific root depth (SRD) and shoot to root ratio (S/R).

No.	Treatment	SRD (cm g^{-1})	S/R ratio (g g^{-1})
1.	Control (B0)	14.7^{a}	3.55
2.	Young coconut (B1)	17.9^{a}	3.12
3.	Rice husk (B2)	16.9^{a}	3.97
4.	Cassava peel (B3)	11.7^{a}	4.99
5.	Sugarcane bagasse (B4)	13.3^{a}	6.05
6.	Pulai wood (B5)	25.2^{ab}	3.41
	$HSD_{0,05}$	10.21	

Specific Root Depth (SRD) is a crucial parameter for assessing root growth characteristics, particularly in plants that need to adapt to drought and nutrient-poor conditions (adaptive). A higher SRD value indicates that the plant has longer roots, which enhances its ability to access more water and nutrients. This trait is especially important for plants growing in challenging environments where efficient resource acquisition is vital for survival and growth [12],[13].

The S/R ratio is a variable for drought tolerance in the plant [14]. A lower S/R ratio would indicate that the treatment are working well because it is not as much stress on these roots to provide all this water and nutrients. In contrast, a high S/R ratio is indicative of nutrient-limitation that roots are costly adopting strategies to forage. The S/R ratio gives us an idea of the resource use efficiency and how that plant is able to adapt itself on varying soil conditions by balancing its shoot/root growth [15].

Treatment B5 not only provided the highest Specific Root Depth (SRD) but also an appropriate S/R ratio. It is suggesting high efficiency in root growth and a good balance between root and shoot development. Conversely, Treatment BO, with low SRD values and an disproportionate S/R ratio, indicates that this treatment is less effective in supporting optimal root growth. The findings suggest that biokom application can influence root growth efficiency, with several treatments (B1, B2, and B5) showing higher SRD values, indicating improved root capacity for exploring and absorbing nutrients. In contrast, Treatments B3 and B4 did not exhibit an increase in SRD compared to the control. These findings underscore the importance of selecting the appropriate biochar to maximize root growth efficiency and plant yield potential on Inceptisol soils.

Table 4 shows that treatment B5 exhibits the highest Shoot-to-Root (S/R) ratio at 25.2 g g^{-1}. This high ratio indicates that treatment B5 is highly efficient in supporting root growth relative to the above-ground weight of the plant. In other words, plants under this treatment have a larger root weight compared to their shoot weight, which may suggest that these plants possess a more developed root system relative to their above-ground parts [14]. Conversely, treatment BO has the lowest S/R ratio at 3.5 g g^{-1}. This low ratio indicates that the root weight is relatively small compared to the above-ground weight, suggesting an imbalance in growth, where the shoot weight is significantly larger compared to the root weight. This could imply that Treatment BO is less effective in enhancing root growth relative to the shoot growth [15].

Treatment B5 is the most effective in terms of the Shoot-to-Root (S/R) ratio, demonstrating the highest efficiency in supporting root growth relative to the shoot weight. Treatment BO shows the lowest results, indicating that this treatment is less optimal in enhancing root growth compared to the shoot weight. Treatments B1, B2, and B4 exhibit a better balance in terms of the S/R ratio, but there is still room for improvement compared to B5. This research illustrates that root expansion of corn might be substantially modulated by biochar addition.

4. Conclusions

Application of compost-enriched biochar (BioKom) had diverse outcomes on Inceptisol soils in terms of root morphology and growth. The application of sugarcane bagasse biochar, and pulai wood biochar showed several penetral penetrations on root depth, root dry weights and in overall plant growth. Among the treatments, treatment of pulai wood biochar stood out for its higher SRD. The results also suggested that the effectiveness of BioKom can profoundly improve root growth, and thereby optimize corn productivity in low nutrient Inceptisols.

Application of biochar enriched with compost (BioKom) demonstrated varying effects on the root morphology and growth of corn in Inceptisol. Among the treatments, sugarcane bagasse biochar and pulai wood biochar yielded the most significant improvements in root depth, root dry weight, and overall plant growth. Treatment of pulai wood biochar, in particular, exhibited the highest efficiency in root growth and resource acquisition, as indicated by its superior specific root depth (SRD) and shoot-to-root ratio (S/R). These findings suggest that BioKom can substantially enhance root development and optimize corn productivity in nutrient-poor soils like Inceptisols.

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