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Residue of biochar-organic fertilizer after one year of use on corn (*Zea mays* L.) plants in Alfisol

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ABSTRACT

Introduction: Nutrient-poor soil can lead to reduced crop yields. Biochar-organic fertilizer has demonstrated positive effects over several growing seasons. However, the efficacy of biochar-organic fertilizers varies based on the raw materials used and the duration of their application in the soil. This study aims to assess the residues of biochar, manure, and compost one year after their application on maize plants in Alfisol. **Methods:** A 300 kg/ha dosage was employed for a single treatment of biochar, manure, and compost. Additionally, biochar was combined with manure or compost at a dose of 150 kg/ha each. The experiment utilized a randomized block design with nine treatments and three replications, including a control group. The treatments comprised biochar made from coconut shell and husk, compost, manure, shell+compost biochar mixture, shell+manure biochar mixture, husk+compost biochar mixture, and husk+manure biochar mixture. Corn variety Pertiwi 3 was harvested upon reaching physiological maturity. **Results:** Combining husk biochar with chicken manure exhibited the most favorable response regarding plant height, leaf area, and weight. Furthermore, combining cob biochar and chicken manure yielded optimal cob length, weight without seeds, and seed weight. **Conclusion:** After one year, applying shell biochar mixed with manure demonstrated the most significant residual effect on corn plants.

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INTRODUCTION

Global warming has extensive impacts not only on environmental issues but also on crop production. The decrease in food production attributed to climate change can disrupt food security, particularly if not counterbalanced with efforts to reduce CO_2 emissions. Corn, as a staple food crop, needs increased production to align with the escalating levels of greenhouse gases. Corn is the most widely cultivated agricultural commodity, surpassing palm oil, rice, and sugar cane. According to Simanjuntak (2022), Indonesia relies on imports of corn, soybeans, and wheat, posing a risk to food security. There is a crucial need to enhance domestic food production, particularly corn. It involves more than just using superior hybrid seeds, intensification, or extensification; it necessitates careful attention to soil fertility and productivity. Kaharuddin *et al.* (2020) emphasized that applying 12 tonnes/ha of filter cake to Alfisol resulted in the highest glutinous corn production.

The availability of food production and the sustainability of fertile and productive land are integral components of the agricultural system—however, dry land challenges soil fertility, such as in Alfisols. Generally, Alfisols are deficient in both macro and micro-nutrients but are abundant in Ca and Mg (Salbiah, 2012). Wijanarko *et al.* (2007) noted that clay buildup from upper horizons in Alfisols makes the soil dense, hindering root penetration. The organic matter is low, and aeration water and nutrient retention are inadequate. This condition is attributed to the agro-climate in tropical regions, where rapid decomposition and mineralization of organic material occur, resulting in low soil fertility. Chemical properties of Alfisols, as reported by Wijanarko *et al.* (2007), include acid-neutral pH, very low to medium available P, low to high K-dd, low organic C, medium to very high Ca, medium to high Mg, medium to very high CEC, high Fe, and high Zn.

Organic materials, such as rice husks, corn cobs, and organic waste, are abundant and serve as raw materials for biochar production. The use of biochar has gained widespread acceptance due to its positive outcomes. The highest sweet corn yields have been achieved with a combination of corn stem biochar (40 tonnes/ha) and compost (10 tonnes/ha) (Safitri *et al.*, 2018). Additionally, bamboo waste biochar at a rate of 10 tonnes/ha produces 7.83 tonnes/ha of dry-shelled corn (Lelu *et al.*, 2018), while the application of 40 tonnes/ha of cocoa husk biochar to Ultisol results in the highest corn crop production (3.95 tonnes/ha) (Shalsabila *et al.*, 2017). Research on biochar residues also demonstrates a lasting positive effect; as Mapegau *et al.* (2022) state, husk biochar remains in the soil for a more extended period than chicken manure, maintaining a residual impact on subsequent corn crops. Combining biochar residue and goat manure fertilizer has enhanced corn yields (Raharjo & Delang, 2020).

The simultaneous application of 40 tons of biochar/ha and 10 tons of compost/ha on Alfisol results in a decrease in soil bulk weight by 26.5%, along with an increase in soil porosity (9.2%) and available water pores (61.9%) (Safitri *et al.*, 2018). Similarly, the combination of 8 tonnes/ha of biochar and 30 tonnes/ha of compost increases the availability of P, C-organics, and soil pH in Ultisol (Herhandini *et al.*, 2021). Herman and Resigia (2018) reported that the tithonia biochar-compost mixture enhances the availability of nutrients in Ultisol. Bahri *et al.* (2020) further asserted that applying biochar along with manure increases hybrid corn yields in Ultisol. According to Herlambang *et al.* (2019), soil treated with coconut shell biochar yields better corn compared to soil without biochar, receiving only organic fertilizer from cow dung and sugar cane bagasse. The positive impact of biochar application was also noted by Zhu *et al.* (2014), who found that straw biochar, applied at a rate of 24 tons/ha to Ultisol and Oxsisol, can increase available P by 4.9% to 142.9% and reduce aluminum concentration by 47.4% to 61.5%.

Several studies have been conducted on Ultisol involving biochar and organic fertilizer (Sujana & Pura, 2015; Herman *et al.*, 2018; Bahri *et al.*, 2020; Herhandini *et al.*, 2021). These studies have consistently demonstrated that biochar and organic fertilizers can address fertility issues effectively. However, their application to Alfisol still requires further development, considering that fertilizer usage is specific to soil and plant types. Biochar can be derived from various sources, such as agricultural biomass, plantations, and livestock, each of which can influence the characteristics of the resulting biochar. Iskandar and Rofiatin (2017) highlighted that the composition of chemical compounds like cellulose, hemicellulose, and lignin in biomass varies, impacting the produced biochar. The characteristics of biochar differ based on the raw material (Widowati *et al.*, 2017), and they exert diverse effects on the soil (Kolambani & Widowati, 2022). Lahori *et al.* (2017) explained that biochar application contributes to sustainable improvement in soil quality.

Since biochar decomposes over an extended period, its combination with manure is recommended (Martiningsih, 2020). Research results from Widowati *et al.* (2020) indicate that each soil amendment material exhibits distinct effectiveness in influencing the physical properties of the soil. Further studies are needed, particularly regarding the impact on plants after one year, to explore variations in the types of organic fertilizer and biochar applied separately or in combination. This research aims to evaluate the subsequent impact of biochar-organic fertilizer application on corn plants in Alfisol.

METHODS

Tools and materials

The equipment utilized in this study were meters, calipers, a Leaf Area Meter type LI-3100C, analytical scales, and a Drying Oven. The materials employed include coconut shell biochar, rice husk biochar, compost, chicken manure, urea, SP36, and KCl. Dried rice husks were obtained from rice mills producing rice, while dried corn cobs were sourced from PT. Bisi International Kediri. Biochar from coconut shells and rice husks was made at a temperature of 350°C at Sain Technopark, Tribhuwana Tunggadewi University. Before being applied to the soil, corncob biochar underwent grinding for a smoother texture, while rice husk biochar could be used directly.

The compost used was municipal organic waste (vegetable leftovers from the market), processed into compost, and obtained from the Integrated Waste Processing Site (TPST) in Mulyo Agung Village, Dau District, Malang Regency. The obtained compost was ready for soil application without any additional ingredients. The chicken manure utilized came from the Japfa Comfeed chicken farm and was also prepared for soil application. Pertiwi 3 variety corn seeds were used in this research.

Place of execution

The research was conducted in Bawang Hamlet, Lowokwaru District, Malang City, utilizing soil samples collected from the top surface to a depth of 30 cm. The soil samples originated from Kalipare District, Malang Regency, obtained in polybags from previous research.

Method used

This research continued the initial study on corn plants during the first planting period, which utilized Alfisol soil samples from Kalipare District, Malang Regency. The planting medium consisted of polybags filled with 10 kg of Alfisol soil.

The application of shell biochar, husk biochar, manure, and compost into polybags, according to the designated treatments, was conducted in the first study using a Randomized Block Design (RBD) with nine treatments as follows:

Control, Compost, Manure (Manure), Shell biochar, Husk biochar, Shell biochar + Compost, Shell biochar + Manure, Biochar husk + Compost, Biochar husk + Manure

The dosage was 300 grams per polybag for a single application of ingredients, while the dosage was 150 grams for mixed ingredients. The application of the designated treatment doses was carried out before the first corn planting in April 2016. Subsequent research on the second corn planting in May 2017 did not involve the addition of biochar or organic fertilizer. For the second corn planting, polybags were replaced from the previous research, and hard clods of soil were crushed before being placed into polybags to ensure the undisturbed development of plant roots.

Three corn seeds were simultaneously planted in each polybag without prior sowing, and one plant was retained after 7 days of planting. Once the seeds developed into plants, they were watered and weeded. Urea, SP36, and KCl fertilizers were added according to the recommended dose. Observations of growth variables were conducted every two weeks until they reached the maximum vegetative phase (2-8 weeks). Destructive observations of plants were performed at the end of the vegetative period, examining the growth of 3 plant samples and 5 plant samples at harvest.

Corn growth and yield variables included height, stem diameter, number of leaves, leaf area, dry weight of leaves and stems, total dry weight of plants above ground, cob length, cob diameter, weight of corn with husks removed, weight of cobs without seeds, weight of 100 corn kernels, and dry shelled weight. Measurements of the dry weight of leaves stems, and total plants were taken precisely when the plants were 8 weeks after planting (marked by the appearance of male flowers, indicating the end of the vegetative phase). Dry weight measurements were carried out in an oven at 80°C for 2 days. Harvesting occurred approximately 103 days after planting when the generative period concluded, as indicated by dried-out leaves and hardening of the corn kernels attached to the cob (moisture content at harvest is 12-14%). Before harvesting, the corn plant leaves were pruned, and the corn husks were peeled open. Maintenance involved watering as needed (70-80% of field capacity) and applying chemical fertilizer twice as recommended, with 1/3 of the dose 7 days after planting and 2/3 of the dose 4 weeks after planting.

Experimental design

The method used in this research was a Randomized Block Design (RBD), which included 9 treatments, namely 1. Without biochar or organic fertilizer (control), 2. Compost, 3. Chicken manure (pukan), 4. Shell biochar, 5 husk biochar, 6. shell biochar+compost, 7. shell biochar+manure, 8. husk biochar+compost, 9. husk biochar+manure. Each experiment was repeated three times, and each treatment was provided with 8 polybags placed in the field. Each polybag was filled with 10 kg of soil sample so that two hundred and sixteen (216) experimental units were placed randomly in each replication at an 80 x 25 cm distance on the polybag.

Data analysis

The research data obtained was carried out using Analysis of Variance (ANOVA). If there was a real effect, the Smallest Real Difference (SRD) test was continued at a real level of 5%.

RESULTS AND DISCUSSION

Corn plant growth

Husk biochar residue mixed with chicken manure proved the most effective for the plant height parameters throughout the observation period (Table 1). The combination of these two materials exhibited a superior effect on increasing plant height, even when applied within a year. The study results confirm that the joint use of these substances is more advantageous than applying them separately (Table 1). In the second planting season, the benefits of the residue from these two ingredients were more effective, synergistic, and profitable in enhancing the height of corn plants. The effectiveness of these benefits in increasing plant height becomes more pronounced when both ingredients are used together at the same dosage. Biochar aids active roots in absorbing nutrients generated from the decomposition and mineralization of organic fertilizer. Jova *et al.* (2021) noted that once the roots begin to grow and come into contact with the biochar, they receive the benefits of the biochar as a soil amendment. Biochar is crucial in stimulating root growth for enhanced nutrient absorption, leading to better plant growth.

Enhancing plant growth is closely linked to the benefits of biochar in elevating the CEC of the soil, allowing the nutrients released by manure to be retained by the soil for increased plant height in the second planting season. Following biochar application, abiotic oxidation occurs on the outer surface of the particles, forming carboxylate groups and leading to an increase in CEC (Cheng *et al.*, 2006). Specifically, during vegetative growth, nitrogen is more crucial than phosphorus or potassium, as indicated by Sa'adah and Islami (2019) and Yuniarti *et al.* (2019).

Table 1. Biochar-organic fertilizer residue on corn plant height in the second growing season in Alfisol

Treatment	Height at Age (MST)							
	2		4		6		8	
Control	9.17 ± 0.36	a	19.33 ± 0.98	a	44.56±1.50	a	67.11 ± 2.53	a
Compost	10.83 ± 0.49	bc	26.33 ± 0.47	bc	53.78 ± 0.42	b	110.89±9.21	de
Manure (Manure)	11.39 ± 0.31	c	32.00±2.60	de	59.44±3.63	cde	114.89 ± 1.77	e
Shell biochar	11.00±0.59	bc	29.56±3.22	cd	54.00±2.94	b	92.56±1.50	b
Husk biochar	11.00±0.14	bc	25.56±2.11	b	56.11 ± 0.95	bcd	88.44±7.29	b
Shell biochar + Compost	10.44 ± 0.28	b	26.67±2.16	bc	55.56 ± 0.16	bc	100.56±9.75	c
Shell biochar + Manure	11.11 ± 0.51	bc	32.56 ± 0.42	e	60.33±3.07	de	108.67±6.22	de
Biochar husk + Compost	10.67 ± 0.24	bc	26.44 ± 2.04	bc	53.89±2.20	b	105.67±4.50	cd
Biochar husk + Manure	11.50 ± 0.24	c	34.22 ± 0.57	e	61.00 ± 0.27	e	128.56 ± 2.68	f
BNT 5%	0.85		3.75		4.64		7.48	

Note: Columns with numbers followed by the same letter mean there is no significant difference in Smallest Real Difference (SRD) 5%

Not only does the positive impact of the synergy between biochar+manure or biochar+compost manifest in plant height, but it is also evident in leaf area (Table 2). The best leaf area, aligned with the optimal plant height, is observed in the rice husk biochar + manure residue. According to Sudjana (2014), biochar applied to agricultural soil can act as a bio-activator, providing nitrogen elements that enhance nitrogen uptake in leaves and increase plant biomass. The broader a plant's leaves increase nutrient absorption and availability (Herman & Salamah, 2020). Warnock *et al.* (2007) mentioned that nutrients are available to plants because biochar absorbs nutrients and water in the soil, reducing nutrient loss due to washing. In the long term, biochar plays a role in increasing and optimizing plant growth and production.

Table 2. Biochar and organic fertilizer residues on leaf area, dry weight of leaves, stems, and total corn plants for the second growing season in Alfisol

Treatment	Observation 8 MST							
	Leaf Area (cm2)		BK Dry Leaves (g)		BK Batang (g)		BK Total Plant (g)	
Control	1969.93±61.45	a	14.38±1.50	a	21.08±1.27	a	35.47±1.92	a
Compost	3459.40±91.14	d	25.93±2.06	bc	35.83±1.20	cd	61.77±3.25	c
Manure (Manure)	3484.94±40.47	d	26.48±3.02	bc	39.52±0.65	d	66.00±3.19	d
Shell biochar	2856.36±40.11	bc	26.32±0.76	bc	29.02±2.16	b	55.33±1.53	bc
Husk biochar	2776.19±71.65	b	26,27±4.63	bc	25.73±1.35	b	52.00±5.95	b
Shell biochar + Compost	3272.76±50.65	cd	23.92±2.65	b	34.42±2.10	c	58.33±2.63	bc
Shell biochar + Manure	3493.55±27.55	d	30.98±1.20	cd	44.88±2.68	e	75.87±2.00	e
Biochar husk + Compost	3313.96±63.11	d	30.70±0.96	cd	36.38±2.17	cd	67.08±1.99	d
Biochar husk + Manure	3927.55±87.89	e	32.45±0.67	d	44.60±2.91	e	77.05±3.38	e
BNT 5%	430.70		5.13		4.37		7.00	

Note: Columns with numbers followed by the same letter mean there is no significant difference in BNT 5%

Dry weight is an indicator of whether growth is good or not. Growth will improve if the dry weight increases (Sitompul & Guritno, 1995). Biomass dry weight increased with biochar application (Widowati *et al.*, 2014). N absorption enough will produce wider leaves to increase plant biomass(Sudartiningsih *et al.*, 2002). Biochar, whose function is to increase nutrient uptake, will affect plant weight. Nutrients that are easily absorbed will stimulate the development of cells, tissues, and plant organs so that the weight of the plant will increase, the leaves will get wider, and the stem will get bigger and longer. These factors will influence the formation of plant weight. The best leaf weight was shown by the husk + manure biochar residue treatment (Table 2). The best stem weight and overall plant weight were shown by cob biochar residue + manure. However, the husk+husk biochar residue was more consistent than shell biochar (Table 2). According to Alviana and Susila (2009), dry fruit weight is more accurate for evaluating plant growth. The vegetative phase of a plant is important because it can affect biomass. The biomass produced is the final result of the plant's vegetative period.

Biomass is the result of photosynthesis, as seen from the weight of dry matter of plant parts at a certain phase. The overall dry weight of the plant above the ground was observed when female flowers appeared, and vegetative growth was maximal. The highest total weight was from giving biochar (shell/husk) with added manure. Biochar production is greater from husk + manure biochar residue than from the application of biochar alone or manure alone. Manure is a source of nitrogen and phosphorus, which plants use to increase biomass production. Phares *et al.* (2017) stated that available P, CEC, and soil organics increase with biochar + poultry manure combustion.

Yield components and crop yield

The findings of this research align with those stated by Manggas *et al.* (2021), indicating that combining biochar+compost or biochar+manure can enhance plant yields. In this study, the nitrogen, phosphorus, and potassium levels from chicken manure were higher than those from compost, contributing more effectively to the growth and corn yield (Widowati *et al.*, 2017; Widowati *et al.*, 2024). The nitrogen, phosphorus, and potassium content in manure were 4.05%, 11.62%, and 0.29%, respectively; on the other hand, compost contained 2.6%, 3.87%, and 0.04%, respectively.

While the combination of husk+manure biochar resulted in the best plant growth (plant height, leaf area, and weight), it does not necessarily guarantee the best yield and components. The most favorable cob length was achieved through the combination treatment of shell biochar + manure (Table 3). The diameter and size of the cobs are closely related to the yield of a particular variety (Robi'in, 2009).

Biochar enhances soil organic matter and improves available water retention capacity (Widowati *et al.*, 2020). The residual combinations of biochar+manure or biochar+compost and the control or single treatments demonstrated the best yield components and overall crop yields (Tables 3 and 4). Changes in soil properties in response to various organic fertilizers and biochar types were observed. Generally, the enhancement in soil chemical properties was more pronounced when biochar and manure were combined in the three soil types (Widowati *et al.*, 2020).

Table 3. Biochar and organic fertilizer residues in yield components and corn yields in the second planting season in Alfisol

Treatment	Yield Components and Crop Yield					
	Cob Length (cm)		Cob Diameter (cm)		BK Without Kelobot (g)	
Control	11.17±0.36	a	4.26±0.04	a	134.11±24.63	a
Compost	15,17±0.95	bcd	5.13±0.02	bcd	265.78±19.42	bcde
Manure (Manure)	16,11±1.23	cd	5.19±0.02	cd	302.11±37.56	de
Shell biochar	12.50±1.09	a	4.79±0.19	bc	196.33±37.60	ab
Husk biochar	13.67±0.27	b	4.83±0.13	bcd	227.67±25.30	bc
Shell biochar + Compost	15.39±1.23	bcd	5.16±0.05	cd	273.33±27.72	cde
Shell biochar + Manure	16.50±0.47	d	5.30±0.02	d	322.67±26.13	e
Biochar husk + Compost	14,11±1.29	bc	4.86±0.11	bcd	238.78±48.95	bcd
Biochar husk + Manure	13.72±1.01	b	4.56±0.21	ab	210.89±47.92	bc
BNT 5%	2.12		0.47		73.35	

Note: Columns and numbers followed by the same letter indicate no significant difference at BNT 5%

The improved physico-chemical properties of soil through biochar application positively impact plants. Megi (2011) noted that the cob's diameter and length increase with high-phosphorus chicken manure fertilization. The observations indicated the highest dry weight of cobs in the cob biochar+manure treatment.

Table 4. Biochar and organic fertilizer residues on yield components and crop yields

Treatment	Yield Components and Crop Yield					
	Cob Weight Seedless (g)		Weight of 100 Seeds (g)		BK *Pipilan* (g)	
Control	12.67±1.66	a	25.56±0.16	a	67.44±12.33	a
Compost	23.67±3.07	bcde	29.00±0.72	ab	147.56±18.23	bcde
Manure (Manure)	26.33±3.21	de	30.09±1.86	a	158.56±19.29	de
Shell biochar	18.22±3.50	ab	27.11±2.47	a	120.78±10.24	bc
Husk biochar	19.56±2.53	bc	26.89±2.32	a	120.22±11.03	bc
Shell biochar + Compost	25.33±3.68	cde	29.78±2.57	ab	151.22±16.66	cde
Shell biochar + Manure	29.67±2.84	e	32.44±0.42	b	175.78±13.76	e
Biochar husk + Compost	21.11±4.53	bcd	27.22±3.54	a	127.89±25.77	bcd
Biochar husk + Manure	20.33±2.18	bcd	26,22±1.75	a	112.56±25.81	b
BNT 5%	6.59		4.28		37.74	

Note: Columns and numbers followed by the same letter indicate no significant difference at BNT 5%

The shell biochar+chicken manure mixture performed better than the other treatment (Table 3). Shell biochar, derived from wood-based materials, contains a higher carbon content than other materials like husks (Yuan *et al.*, 2019). Table 4 further demonstrates that the shell biochar+manure combination treatment produced the highest weight of seedless cobs among all treatments. According to Somputan (2014), the increased weight of corn cobs is influenced by the photosynthesis process and the translocation of photosynthates to seeds/cobs. Additionally, as highlighted by Seriminawati *et al.* (2005), robust nutrient absorption supports plant growth, leading to increased photosynthate yield for the development of plant organs. Table 4 reveals that the cob biochar residue plus manure yielded the highest weight of 100 corn kernels. The plant results underscore that the combination of biochar and organic fertilizer outperforms either component alone.

Pangaribuan *et al.* (2012) reported that chicken manure contains higher levels of N, P, and K nutrients than other livestock manures due to the combination of solid and liquid manure from poultry. Plants can effectively utilize the nutrients released from manure with the assistance of biochar, which retains these nutrients and prevents leaching. Syafruddin *et al.* (2007) state that nitrogen is continuously required throughout the plant's growth, starting from the growing point, stem, leaves, male flowers, and eventually transferring to the seeds.

The combination treatment of cob biochar+manure produced the best-shelled corn among all treatments (Table 4). Kimetu *et al.* (2008) stated that applying biochar in degraded soil can enhance yields. Dariah and Nurida (2015) demonstrated a significant effect on wet cobs and dry-shelled corn when applying 2.5 tonnes/ha of biochar without specifying the treatment duration.

CONCLUSION

The shell biochar treatment supplemented with manure at a dose of 150 grams per polybag yielded the most favorable follow-up effects on cob length and diameter, the weight of 100 seeds, dry weight without husks, dry weight of cobs without seeds, and dry weight of shells after one year.

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