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PEMANFAATAN LIMBAH TEMPURUNG KELAPA DAN KOTORAN TERNAK UNTUK MENINGKATKAN KUALITAS TANAH DAN PRODUKSI BAWANG MERAH DALAM MENDUKUNG PERTANIAN BERKELANJUTAN

UTILIZATION OF COCONUT SHELL WASTE AND LIVESTOCK MANURE TO IMPROVE SOIL QUALITY AND SHALLOT PRODUCTION IN SUPPORT OF SUSTAINABLE AGRICULTURE

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ABSTRAK

Pengaruh biochar tempurung kelapa dan pupuk kandang kambing terhadap karakteristik kimia tanah Ultisol belum diteliti secara menyeluruh. Penelitian ini bertujuan untuk mengetahui pengaruh biochar dan pupuk kandang kambing terhadap beberapa sifat tanah yaitu pH tanah, kejenuhan basa, kapasitas tukar kation (KTK), dan ketersediaan N, P, dan K serta dampaknya terhadap hasil bawang merah dalam mendukung pertanian berkelanjutan. Percobaan ini menggunakan rancangan acak kelompok faktorial dengan tiga kali ulangan. Biochar tempurung kelapa, sebagai faktor pertama, terdiri dari empat taraf (0, 15, 25, dan 35 t ha^{-1}), dan pupuk kandang kambing, sebagai faktor kedua, terdiri dari tiga taraf (10, 15, dan 20 t ha^{-1}). Hasil penelitian menunjukkan bahwa pemberian biochar tempurung kelapa sebanyak 15 t ha^{-1} yang dikombinasikan dengan pupuk kandang kambing sebanyak 20 t ha^{-1} secara nyata meningkatkan pH tanah, KTK, kejenuhan basa, ketersediaan hara, dan hasil bawang merah. Pupuk kandang kambing berfungsi sebagai sumber nutrisi langsung, sementara biochar tempurung kelapa berfungsi sebagai reservoir nutrisi yang secara bertahap melepaskan nutrisi ke dalam larutan tanah untuk diserap tanaman. Disimpulkan bahwa kombinasi 15 t ha^{-1} biochar tempurung kelapa dan 20 t ha^{-1} pupuk kandang kambing merupakan amandemen tanah yang paling efektif untuk meningkatkan kesuburan tanah Ultisol dan mendukung produksi bawang merah berkelanjutan.

KEYWORDS:

Coconut shell biochar, goat manure, shallot, sustainable agriculture

ABSTRACT

This study aimed to determine the effects of coconut shell biochar and goat manure on several soil chemical properties, namely soil pH, base saturation, cation exchange capacity (CEC), and the availability of N, P, and K, and their impact on shallot yields in supporting sustainable agriculture. This experiment used a factorial randomized block design with three replications. Coconut shell biochar, as the first factor, consisted of four levels (0, 15, 25, and 35 t ha^{-1}*), and goat manure, as the second factor, consisted of three levels (10, 15, and 20 t* ha^{-1}*). The results showed that the application of 15 t* ha^{-1} *of coconut shell biochar combined with 20 t* ha^{-1} *of goat manure significantly increased soil pH, CEC, base saturation, nutrient availability, and shallot yields. Goat manure served as a direct nutrient source, while coconut shell biochar served as a nutrient reservoir that gradually released nutrients into the soil solution for plant absorption. The combination of 15 t* ha^{-1} *of coconut shell biochar and 20 t* ha^{-1} *of goat manure was most effective in improving soil chemical properties and increasing the fertility of ultisol soil and supporting sustainable shallot production.*

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1. INTRODUCTION

Utilizing agricultural waste into value-added products is an important strategy for realizing a sustainable agricultural system (Oyedeji *et al.*, 2024). Coconut shells are abundant in tropical regions. Coconut shells are often burned openly, discarded, or used only as household fuel. However, if managed with the right technology, coconut shells can be processed into biochar, which offers various benefits for the agricultural sector and the environment. Agricultural and livestock waste, if not managed correctly, can lead to pollution of the environment and degradation of soil. These materials, including coconut shells and livestock manure, can be converted into valuable organic soil amendments that enhance soil fertility and support sustainable agriculture (Lehmann & Joseph, 2015; Dittakit *et al*., 2023).

Coconut shells are categorized as dry organic waste with a high carbon content and are rich in essential elements such as potassium, magnesium, and calcium (Ahmad *et al.*, 2022), while goat manure is a wet organic waste containing high concentrations of nitrogen, phosphorus, and potassium, thus improving soil structure and biological activity (Rana and Roy, 2024). In North Sumatra Province, where coconut cultivation is widely practiced, substantial quantities of coconut shell waste are generated annually. This biomass has considerable potential as a lignocellulosic feedstock for biochar production because of its high carbon content (Pusat Data dan Sistem Informasi Pertanian, 2020; Wibowo *et al*., 2019).

The shrinkage of coconut shells when converted into biochar is influenced by several factors, including temperature, combustion duration, and processing method (Coomes & Miltner, 2017). Generally, coconut shells shrink significantly when converted into biochar. This shrinkage is caused by a reduction in water and organic matter content during the combustion process, resulting in a solid carbon residue. The resulting carbon residue typically weighs about 20-30 percent less than the original coconut shell, or even more than the weight of the remaining coconut shell after the combustion process in the form of biochar (Prayzogo *et al*., 2012, Paetsch *et al*., 2017).

Similarly, goat farming waste in the form of manure can be composted into organic fertilizer. The integration of these two wastes is in line with the principles of circular agriculture, converting residues into resources that enhance soil productivity (Rahmat *et al*., 2018). Coconut shell biochar exhibits high stability, along with a porous and large surface area, which allows it to retain water and nutrients efficiently. Biochar enhanced cation exchange capacity, soil pH, and base saturation, which in turn minimizes nutrient leaching (Xu *et al*., 2013; Lehmann & Joseph, 2015; Widowati *et al*., 2020). Meanwhile, goat manure provides a direct supply of macronutrients (N, P, K) and organic matter that stimulate microbial activity and improve nutrient cycling (Mbatha *et al*., 2021). The combination of biochar and goat manure is expected to create synergistic effects: biochar retains nutrients released from manure decomposition, while manure accelerates biochar surface activation and colonization by soil microbes.

Previous research indicate that a biochar dose of between 10–30 t ha^{-1} is optimal for improving the properties of Ultisols without causing nutritional imbalance (Nurida *et al*., 2013; Lehmann & Joseph, 2015; Gámiz *et al*., 2016; Lopez & Garcia, 2018, Panjukang *et al*., 2023). Based on this research, an approach was taken to increase local shallot production by using organic materials (Panjaitan *et al*., 2023) combined with biochar. Goat manure is an appropriate choice because it offers richer nutrients than non-goat manure. It should be noted that goat manure has a lower water content than cow manure but a higher water content than chicken manure, as shown by Hoover *et al*., 2019; Mbatha *et al*., 2021.

Given that Ultisol soils dominate marginal lands in North Sumatra, improving soil fertility is crucial for sustainable shallot cultivation (Nurida *et al*., 2013; Herlambang *et al*., 2023). Therefore, this study aimed to evaluate the effects of coconut shell biochar and goat manure on soil chemical characteristics and shallot yields, and to identify the most effective combination to improve soil quality and support sustainable agriculture.

2. MATERIAL AND METHOD

This research was conducted at the experimental garden of the Faculty of Agriculture, Methodist University of Indonesia on Jalan Harmonika Baru Pasar II, Tanjung Sari, Medan, North Sumatra Province, at an altitude of approximately 32 m above sea level from February to May 2022.

The materials used in this experiment included shallot bulbs of the Bima Brebes variety, composted goat manure, coconut shell biochar produced through controlled open-pit pyrolysis, Ultisol soil, and a botanical pesticide derived from neem leaves. The equipment used consisted of a burning barrel for biochar production, polybags measuring 15 × 40 cm, measuring devices, and standard laboratory tools for soil analysis.

The study was designed with a two-factor randomized block design. The first factor was coconut shell biochar (B), which consisted of four levels: B0 = 0 g plant^{-1} (without biochar); B1 = 46 g plant^{-1} (≈ 15 t ha^{-1}); B2 = 77 g plant^{-1} (≈ 25 t ha^{-1}); B3 = 108 g plant^{-1} (≈ 35 t ha^{-1}); The second factor was goat manure (K) which consisted of three levels : K1 = 31 g plant^{-1} (≈ 10 t ha^{-1}); K2 = 46 g plant^{-1} (≈ 15 t ha^{-1}); K3 = 61 g plant^{-1} (≈ 20 t ha^{-1}). Thus, 12 treatment combinations were obtained which were repeated three times.

The determination of the application dose of Biochar and manure refers to the results of previous studies which stated that the combination of Biochar doses of 10-30 ha^{-1} combined with organic fertilizer of 10–20 t ha^{-1} is effective in improving soil chemical properties without causing an increase in alkalinity (Nurida *et al*., 2013; Widowati *et al*., 2020).

The research began with the preparation of the planting medium, consisting of sifted Ultisol soil, which was then mixed with Biochar and goat manure according to the treatment. The planting medium was placed in 5-kg polybags and incubated for two weeks to stabilize the soil pH. Afterward, the shallot bulbs were planted, and the plants were cared for according to shallot maintenance standards throughout the research period. The parameters observed were soil chemistry and plant growth and production. Soil chemical parameters consisted of soil pH (H_2O), base saturation, cation exchange capacity (CEC), and the availability of nitrogen (N), phosphorus (P), and potassium (K). Yield parameters consisted of fresh bulb weight and dry bulb weight per plant and per plot. Soil and plant analysis followed standard procedures from the Indonesian Soil Research Center (1983). Data were analyzed using ANOVA at a 5% significance level, followed by Duncan's Multiple Range Test (DMRT) if a significant effect was found.

3. RESULT AND DISCUSSION

3.1 Soil Characteristics

The chemical characteristics of the Ultisol soil before treatment are shown in Table 1, while the properties of coconut-shell biochar and goat manure are presented in Table 2. The Ultisol used in this study had a sandy-clay texture, low organic-carbon and nutrient contents, and acidic reaction (pH 5.2), indicating low fertility and poor buffering capacity. Therefore, soil amendments such as biochar and organic manure were applied to improve soil quality and nutrient retention.

Naturally, the soil's fertility was notably low, primarily due to deficiencies in both macro and micronutrients. Consequently, the study necessitated the incorporation of land amendments and organic materials, such as biochar and composted livestock manure, to enhance soil quality and fertility.

Table 1. Chemical properties of ultisol used in this research

No.	Properties	Value	Category*
1	pH (H2O)	5.2	Acid
2	Total N (%)	0.02	Very low
3	N available (%)	0.01	Very low
4	Organic-C (%)	0.04	Very low
5	Total P (ppm)	18.91	Very low
6	P available (ppm)	5.59	Very low
7	Total K (%)	0.02	Very low
8	K available (me 100 g^{-1})	0.25	Very low
8	Total Ca (me 100 g^{-1})	0.31	Very low
9	Total Na (me 100 g^{-1})	0.14	Very low
10	Total Mg (me 100 g^{-1})	0.23	Very low
11	CEC (me 100 g^{-1})	7.67	Low
12	Base saturation (%)	12	Very low
13	Al-dd (me100 g^{-1})	0.37	Very low
14	Fe (ppm)	1.62	Very low

Description: * Criteria evaluation based on Soil Research Center (1983).

Table 2. Chemical properties coconut shell biochar and goat manure

No	Analysis	Coconut shell biochar	Goat manure
1	pH (H2O)	10.06	9.04
2	C organic (%)	56.87	27.89
3	Total N (%)	0.26	2.04
4	C/N Ratio	-	13.67
5	Total P (%)	0.37	1.67
6	Total K (me 100 g^{-1})	0.85	2.01
7	Water content (%)	7.36	9.5

Table 3. Soil analysis results after addition coconut shell biochar and goat manure

Treatment Factors	Soil acidity (pH)	Base Saturation (%)	Cation Exchange Capacity (me 100 g^{-1})
Biochar (B)			
0 $t.ha^{-1}$	6.40	24.19a	6.69a
15 $t.ha^{-1}$	6.38	28.10b	5.71a
25 $t.ha^{-1}$	6.39	22.11c	9.50b
35 $t.ha^{-1}$	6.38	24.94d	8.77b
Goat manure (K)			
10 $t.ha^{-1}$	6.40	24.23	8.49
15 $t.ha^{-1}$	6.39	25.85	7.14
20 $t.ha^{-1}$	6.37	24.44	7.37
B x K interaction	(-)	(-)	(-)

Note: The numbers in the columns and treatment factors are the same followed by the same letter show no different real at DMRT level error 5%; (+) /(-): interaction biochar and fertilizer dosage real/not real.

The inclusion of soil amendments resulted in notable improvements in base saturation, CEC, and soil pH (H2O). As indicated in Table 3, the soil pH increased from its initial value of 5.2 to a range of 6.37 to 6.40. The application of biochar and goat manure increased soil base saturation from an initial value of 12% to approximately 22–28% after treatment. Meanwhile, the cation exchange capacity (CEC) showed variations among treatments, indicating differences in the soil's ability to retain exchangeable cations.

3.2 Soil pH.

Application of biochar and goat manure slightly increased the soil pH from 5.2 to around 6.3–6.4, shifting the reaction toward neutral. Although statistically non-significant, this rise suggests that the alkaline nature of biochar and organic anions released during manure decomposition contributed OH^- ions that neutralized soil acidity (Gámiz *et al*., 2016; Hoover *et al*., 2019). Similar findings were reported by Widowati *et al*., (2020) showing that organic amendments can progressively buffer soil acidity in Ultisol soils.

3.3 Base Saturation

Biochar application significantly affected soil base saturation (Table 3). The highest value (28.10 %) was recorded at 15 t ha^{-1} biochar, representing a 16 % increase compared with the control. This improvement results from the alkaline mineral content of biochar particularly Ca, Mg, and K that replaces exchangeable Al^{3+} and H^+ ions on the soil colloids. Goat manure addition also improved base saturation, although not significantly different among doses, suggesting that the manure primarily contributed nutrients rather than altering soil charge balance. Overall, base saturation rose from 12 % initially to 22–28 % after treatment, confirming the liming effect of both materials Widowati *et al*., (2020) noted that the duration of biochar application to the soil could impact base saturation, with values at 120 days being higher than those at 60 days post-application. This suggests that base saturation is affected not only by biochar application rate but also the time of interaction between biochar and soil.

3.4 Cation Exchange Capacity (CEC)

CEC values clearly increased with the addition of biochar up to 25 t ha^{-1} (Table 3). This improvement relates to the large surface area of biochar and the presence of negatively charged groups, such as $^-$COOH and $^-$OH, which can bind nutrient cations like Ca^{2+}, Mg^{2+}, K^+, and NH_4^+. However, raising the biochar rate to 35 t ha^{-1} did not result in further increases in CEC. This suggests that too much biochar may lessen the role of active organic matter in the soil. Similar findings were reported by Lehmann & Joseph (2015) and Méndez *et al*., (2012). They noted that applying biochar at moderate rates tends to improve nutrient retention while maintaining good soil aeration.

3.5 Soil N, P, and K Availability

The availability of soil N, P, and K after applying coconut shell biochar and goat manure is shown in Table 4.

Table 4 . Effect of applying coconut shell biochar and goat manure on soil N, P, K availability

Treatment Factors	N availability (%)	P availability (ppm)	K availability (me /100 g)
Biochar (B)			
0 t.ha $^{-1}$	0.20 a	11,12 ab	0.94 b
15 t.ha $^{-1}$	0.36 b	11.65 b	0.97 b
25 t.ha $^{-1}$	0.20 a	10.26 a	0.71 a
35 t.ha $^{-1}$	0.21 a	11.56 b	0.83 ab
Goat manure (K)			
10 t.ha $^{-1}$	0.21 a	11.31	0.91
15 t.ha $^{-1}$	0.32 b	11.22	0.83
20 t.ha $^{-1}$	0.21 a	10.91	0.83
B x K interaction	(-)	(-)	(-)

Description: Numbers followed by the same letters in the same column indicate no significant difference at the 5% level in the DMRT test.

Both biochar and goat manure applications improved the availability of N, P, and K compared to the untreated control (Table 4). The 15 t ha^{-1} biochar treatment produced the highest N (0.36 %), P (11.65 ppm), and K (0.97 me 100 g^{-1}). Adding goat manure at 15 t ha^{-1} also led to a notable improvement in N (0.32 %), showing its value as a nutrient source. The combined treatment (B1K3 = 15 t ha^{-1} biochar + 20 t ha^{-1} manure) provided balanced nutrient availability and achieved the highest shallot yield. These results show that biochar's porous structure helps retain nutrients released during manure breakdown, reducing leaching losses and improving fertilizer use efficiency (Awasthi *et al*., 2016; Borchard *et al*., 2019).

The substantial increase in soil P after the biochar application comes from its high P content. However, the low initial level of soil K meant that adding biochar and goat manure did not significantly raise the soil's K availability, since K is prone to leaching and transport during harvesting (Lehmann, J., & Joseph, 2015; Kurniawati *et al*., 2023; Panjukang *et al*., 2023).

The improved nutrient availability in biochar-amended soil may relate to the large surface area of biochar, which offers more places for adsorption. The binding of organic matter or minerals with adsorbed nutrients to biochar may further help retain nutrients. These effects of biochar can limit nutrient leaching from the soil, resulting in better fertilizer use efficiency. This observation supports earlier findings that showed increased nitrogen retention from adding biochar.

The decomposition of organic matter produces various compounds such as proteins and amino acids, which are then converted by soil microorganisms into ammonium (NH_4^+) and nitrate (NO_3^-). Both forms are sources of nitrogen available to plants in the soil. Therefore, the increase in total N levels in this study is thought to be related to the mineralization of organic matter added to the soil. During the decomposition process, organic compounds gradually break down, releasing nitrogen, which can then be utilized by plants.

3.6 Shallot Production

Analysis of variance data showed a significant interaction effect between coconut shell biochar and goat manure on the fresh and dry weight of shallot bulbs per plant and per plot, as presented in Table 5.

Table 5. The weight of fresh bulbs per shallot plant was increased by the application of coconut shell biochar and goat manure

Treatment	Fresh Weight of Shallot Bulb per plant (g plant^{-1})	Dry Weight of Shallot Bulb per plant (g plant^{-1})	Dry Weight of Shallot Bulb per plot (g plot^{-1})
B0K1	10.30 bc	6.78 bc	58.10 abcd
B0K2	11.72 bcd	7.74 bcd	78.83 cd
B0K3	10.33 bc	7.59 bcd	52.27 abc
B1K1	12.32 bcd	8.88 cde	78.73 cd
B1K2	15.43 d	11.68 ef	129.07 ef
B1K3	31.58 f	25.41 g	215.93 g
B2K1	10.14 b	7.02 bc	67.50 bcd
B2K2	14.53 cd	10.63 de	94.03 de
B2K3	19.88 e	15.11 f	140.17 f
B3K1	8.85 ab	5.65 ab	51.17 abc
B3K2	8.72 ab	6.09 abc	40.77 ab
B3K3	6.27 a	3.49 a	32.63 a

Note: B0K1; B0K2; B0K3 = biochar plus goat manure @ 0 & 10 t.ha^{-1}; @0 & 15 t.ha^{-1};0 &20 t.ha^{-1}; B1K1; B1K2; B1K3 = biochar plus goat manure @ 15 & 10 t.ha^{-1}; 15 & 15 t.ha^{-1}; 15 & 20 t.ha^{-1}; B2K1; B2K2; B2K3 =biochar plus goat manure @ 25 & 10 t.ha^{-1}; @25 & 15 t.ha^{-1};25 &20 t.ha^{-1}; B3K1; B3K2; B3K3 = biochar plus goat manure @ 35 & 10 t.ha^{-1}; @ 35 & 15 t.ha^{-1}; 35&20 t.ha^{-1}, values followed by different lower case letters are significantly different at p = 0.05 according to Duncan's multiple range test.

The B1K3 treatment combination (Table 5) significantly produced the heaviest fresh weight of shallot bulbs, while the B3K3 treatment produced the lowest fresh weight of shallot bulbs compared to all other treatment combinations. Increasing the dose of coconut shell biochar resulted in a decrease in the fresh weight of shallot plants bulbs.

The application of coconut shell biochar increases water availability for plants. Increased soil water availability also increases the water content in tubers, thereby increasing the fresh weight of plant tubers (Lopez, M.A., & Garcia, 2018; Yoanma *et al*., 2022). This reinforces the role of biochar as a soil amendment, increasing soil pH, cation exchange capacity (CEC), and base saturation. Biochar increases the soil's water-holding capacity, allowing plants to receive adequate moisture. Water availability is directly related to fresh weight of plant bulbs, total water content, and photosynthetic output.

Furthermore, the application of coconut shell biochar significantly affected the dry weight of plant bulbs. The B1K3 treatment produced the heaviest dry weight of plant bulbs, while the B3K3 treatment produced the lowest. The accumulation of nutrients on the surface of biochar colloids increases the soil's ability to retain and provide nutrients to plants. This condition supports the bulb formation process and the accumulation of photosynthates in plant tissues, thus contributing to the increase in dry weight of shallot bulbs.

4. CONSLUSIONS

The application of coconut shell biochar and goat manure significantly improved the chemical properties of Ultisol soil, resulting in increased N, P, K, and pH, increased base saturation, and cation exchange capacity. This ultimately improved Ultisol soil fertility and contributed to better shallot growth and yields. The combination of biochar and goat manure at doses of 15 t ha^{-1} biochar and 20 t ha^{-1} goat manure proved to be the most effective treatment for improving soil chemical properties and shallot production. Further research is recommended with longer biochar application periods on Ultisol soils. This way, the effectiveness of coconut shell biochar and goat manure can be determined under different soil and climate conditions, for sustainable agriculture.

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