Research Article

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Biochar technology to increase cassava crop productivity: A study of sustainable agriculture on degraded land

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Abstract: The aim of this study is to improve soil fertility in cassava, corn, and peanut plants by using biochar technology on degraded land. This research is experimental. This trial used five treatments, No organic amendments, farm yard manure (FYM) 20 Mg ha^{-1} once, FYM 20 Mg ha^{-1} yearly, FYM biochar technology 15 Mg ha^{-1} once, and cassava stem (CS) biochar technology 15 Mg ha^{-1} once. The design used in this study was a randomized group design (RAK) with three repeats. Before the experiment, the characteristics of treatment material, namely, the manure, biochar, and CS waste biochar were studied. It was observed that cassava, corn, and peanut crops increased nutrient C, water availability, N, P, K, and cation exchange capacity (CEC). From the observations, the treatment of using biochar technology on intercropping cassava and corn can increase C by 25.7 g kg^{-1}, K by 177 cmol, CEC by 17.63 cmol , and water availability by16.87%. Meanwhile, the application treatment of biochar FYM technology on cassava and peanut intercropping can increase C by 24.4 g kg^{-1}, N by 1.3 g kg^{-1}, P by 12.2 g kg^{-1}, K by 1.74 cmol, CEC by 17.93 cmol, and water availability by 17.41%. The use of biochar technology (15 Mg ha)$^{-1}$ in intercropping cassava with maize or groundnut within 2 years can improve soil fertility and maintain yields. Intercropping cassava with corn or peanuts within 2 years can increase soil fertility and maintain crop yields. Thus, biochar technology has greater potential for the improvement of degraded land in the relatively short term (2 years) and supports sustainable agriculture.

Keywords: application, biochar technology, cassava crops, sustainable agriculture systems, degraded land

1 Introduction

Cassava is the most important food crop in Indonesia, which is useful as significant sources of food for farmers and can increase income. Data from the Food and Agriculture Organization show that Indonesia ranks fifth as the largest cassava producer in the world. Indonesia is recorded as being able to produce 17.7 million cassavas in 2021 [1]. Cassava has enormous potential for trade between areas with food surplus and food deficit, contributing to poverty alleviation and increasing household food security [2–4]. Cassava is a drought-resistant plant that can grow in hot, dry conditions and infertile soil [5,6]. Cassava has several characteristics that provide comparative advantages in marginal environments, where farmers still need the technology to process plant biomass waste into biochar, generating income from farmers' idle land [7–9]. Cassava plants have drought resistance, adaptability, low input requirements, and high yield potential.

Applying inorganic fertilizers can increase cassava yields, but it is not possible to maintain yield stability over a long period [10–12]. It is feasible to boost soil fertility and nutrient availability with organic matter and less soluble fertilizers, which can lead to increased cassava yield without the need for excessive use of macronutrients [13,14]. Cassava requires lots of minerals, especially potassium, nitrogen, and phosphorus, to produce high yields [11,15]. Using less soluble fertilizers and combining manure

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with NPK fertilizer can improve soil fertility and reduce nutrient leaching, increasing cassava yield [16]. Applying organic amendments is a straightforward approach for increasing soil productivity and stabilizing crop yields in areas of decline with deficient concentrations of soil organic matter [17,18]. Organic amendments, such as manure, compost, and biochar technology, can increase soil carbon and nitrogen contents, increase soil biological activity, and increase crop yields. Manure, compost, and biochar can help improve the organic matter content in the soil, which is essential for soil health and plant growth [19,20]. Cover crops can help reduce decomposition rates by providing a source of organic matter that decomposes slowly [21–23]. Adding organic matter to the soil is limited in wet tropical conditions like Indonesia. Each addition of organic matter to the soil will undergo rapid decomposition, meaning repeated additions are necessary during each growing season to maintain soil health and productivity [24,25]. The quality of degraded soil in Indonesia is characterized by low nutrient and organic content, firm acidity, and low microbial activity [26,27].

For this problem, biochar is believed to improve the ability of soil to retain water, reduce water and nutrient leaching, and enhance plant nutrient availability. It can also improve the physical and chemical characteristics of soils used for agriculture and horticulture [28–30]. Applying biochar can boost agricultural yields on degraded tropical soils, which are easily generated in rural areas using inexpensive methods [31,32]. The production of biochar from cassava waste requires careful consideration of the pyrolysis process to achieve optimal biochar properties [33–35]. It has been proven that biochar can boost soil fertility and short-term agricultural production. Long-term studies on using biochar to improve soil quality and cassava crop yield are still required [29]. There is no clear statement on how often biochar should be applied to cassava plants [36]. A form of charcoal made from organic materials called "biochar" can be added to soil to increase crop yields and soil fertility [37]. By burning organic materials like wood chips, leaf litter, or dead plants in an atmosphere with very little oxygen, a process known as "pyrolysis" produces biochar [38,39]. The productivity of cassava plants will continue to increase, accelerating land degradation. For this reason, this study is an effort to conduct experiments on the application of biochar made from cassava stem (CS) waste and manure in the intercropping system of cassava + corn and cassava + peanuts. The results of this research are expected to be an important source of knowledge about agricultural development efforts, especially the application of biochar on degraded land.

2 Materials and methods

2.1 Experimental study area

The research was conducted at the Wisnuwardhana University Experimental Garden in Jatikerto, Malang, Indonesia, from September 2020 to May 2022. About 25 cm of soil existed at the experiment setting, and its texture was loam the soil's pH was 6.49, its organic matter content was 6.5 g kg^{-1}, its total nitrogen content was 0.8 g kg^{-1}, available phosphate was 11.1 mg kg^{-1}, as well as its exchangeable potassium was 1.56 cmol kg^{-1}. Different rainy and dry seasons have been observed in this experimental garden. The average annual rainfall (1998–2008), based on data from the Karangkates Dam Climatology Station in East Java, Indonesia, was due to the wet season running from mid-November until the middle of March, averaging 1,800 mm. However, the yearly rainfall we enjoyed when we carried out the research experiment was unique, totaling 2,435 mm while spaced out throughout the year. The daily average temperature was 28°C, with a minimum of 25°C at night, and peak of around 32°C in the daytime.

3 Research design and experimental plots

This treatment was set up in a randomized group design (RAK) with three treatments on a 6.25 × 6.0 m plot. The maize, peanut, and maize cultivars used are "*Pioneer 2*" and "*Turangga*," respectively. For the intercropping scheme, the planting space between rows of cassava was 1.25 × 0.30 m for maize and 0.40 × 0.30 m for groundnuts. Cassava is planted without any ridges at a planting period of 1.25 × 1.0 m. With this technique, each plot contains 260 plants distributed over 15 rows of peanuts – 30 plants on 5 rows of maize, 15 rows of corn, and 5 rows of cassava. Bed formation is required for planting cassava, and intercropping maize and groundnuts. A single application of 15 Mg ha^{-1} of biochar is utilized for the first crop. To maintain an equal level of organic C, farm yard manure (FYM) is applied at a rate of 20 Mg ha^{-1} (Table 1). Trial used five treatments, No organic amendments, FYM 20 Mg ha^{-1} once, FYM 20 Mg ha^{-1} yearly, FYM biochar technology 15 Mg ha^{-1} once, Cassava stem biochar technology 15 Mg ha^{-1} once. The design used in this study was a RAK with three repeats. All treatments in the study received the same amount of fertilizers, which were 400 kg ha^{-1} of urea

Table 1: Effect of organic amendments on maize and peanut yield in the cassava-based intercropping system at Jatikerto, Malang, Indonesia

Treatments	Maize yield in cassava + maize system (Mg/ha)		Peanut yield in cassava + peanuts system (Mg/ha)	
	2020–2021	2021–2022	2020–2021	2021–2022
No organic amendments	3.05 ± 0.01^{a}	2.72 ± 0.05^{a}	1.00 ± 0.06	0.70 ± 0.01^{a}
FYM 20 Mg ha^{-1} once	3.61 ± 0.21^{bc}	2.68 ± 0.08^{a}	1.19 ± 0.02	0.91 ± 0.04^{ab}
FYM 20 Mg ha^{-1} yearly	3.48 ± 0.02^{ab}	4.05 ± 0.12^{b}	1.18 ± 0.04	1.31 ± 0.05^{c}
FYM Biochar technology 15 Mg ha^{-1} once	4.05 ± 0.05^{c}	4.12 ± 0.03^{b}	1.07 ± 0.01	1.08 ± 0.01^{bc}
CS biochar technology 15 Mg ha^{-1} once	3.49 ± 0.07^{ab}	3.59 ± 0.01^{b}	1.05 ± 0.03	0.97 ± 0.02^{ab}

^{abcd}Values bearing different superscripts within columns show significant differences at $p < 0.05$, in treatments with organic manure addition once it was made in the first year.

(45% N), 100 kg ha^{-1} of SP36 (36% P_2O_5), and 100 kg ha^{-1} of KCl (50% K_2O). This means that all the plots in the study received the same amount of nitrogen, phosphorus, and potassium fertilizers. Fermenter is applied on both sides of the cassava row at 25 cm from the cassava plant. N is used in three stages: first dose is used after planting, second after 30 days, and the last after crop harvest. All P and K fertilizers were given during the planting time.

Biochar is produced using chicken manure (FYM) from local farmers in Malang, Indonesia's Jatikerto, a hamlet. It is sun-dried to attain a moisture level that is around 15%. A biochar reactor utilizing pyrolysis technology is provided with about 10 kg of sun-dried FYM.

The device is housed within a heating drum made of stainless steel and is 50 cm in height and 40 cm in diameter. Sawdust serves as the ignition fuel for the stove. The material in the drum can burn at a temperature of up to 350°C (240–350°C) over 8–10 h until the biochar is removed.

The traditional approach of autothermal burning is used to generate CS biochar via eliminated stems from previous cassava plants in a pit that measures about 1.5 × 1.5 × 1 m in length. Charcoal is gathered in this system within 48 h, and the temperature noticed here varies between 200 and 370°C. To produce charcoal for usage in the field, the biochar generated through this technique is cooled, dried, and pulverized to pass through a 1.0 mm sieve. Table 2 shows the characteristics of the FYM and biochar used in the present study.

Cassava + maize and Cassava + peanuts are two intercropping systems, and biochar made from FYM, which is applied every year, constitutes one of the five organic treatments, which are biochar made from FYM, CS, FYM applied once at the beginning of the experiment, biochar created from FYM applied annually, and no FYM treatment, which is the control. (1) Cassava + maize were grown under the system (control, no organic treatment, no groundnut crop), (2) cassava with maize with yearly FYM, (3) FYM biochar method combined with cassava and maize, (4) CS biochar method combined with cassava and maize, (5) Cassava with maize without a fertilizer that is organic, (6) Cassava with peanuts with just one application of FYM at the start of the experiment, (7) a combination of cassava and peanuts with yearly treatment of FYM, (8) cassava + peanuts with FYM biochar technology, (9) CS biochar technique combined with cassava and peanuts, and (10) without organic amendment, peanuts.

Before and during the second cassava crop harvest, data regarding yields and characteristics of the soil were collected. Harvesting all crops, except ones in the outer rows, gives the crop. Cassava, maize, and groundnuts each have a harvest spacing of 3.75 × 4.0, 3.75 × 5.4, and 4.8 × 5.4 m, respectively. Different yields of peanuts, cassava, maize, and cassava (with moisture contents differing from 14 to 18%) are employed to express comparable yields. Four soil samples of approximately 0.5 kg (up to a depth of 20 cm) were collected from each plot in a mixed zigzag pattern, and for laboratory testing, 0.5 kg composite

Table 2: Characteristics of the FYM and biochar made from CS

Organic amendments	pH	C (g kg^{-1})	N (g kg^{-1})	P (g kg^{-1})	K (g kg^{-1})	Cation exchange capacity [CEC] (cmol)
FYM	6.4	191.7	13.2	3.8	4.1	—
FYM biochar	7.8	254.4	7.7	8.4	7.8	17.6
CS biochar	8.0	403.1	0.8	2.0	9.3	12.4

samples of each were collected. In a pH meter, the pH of the soil is measured in H O (1:1), total nitrogen is determined utilizing the Kjeldahl method, and soil organic carbon is calculated using the Walkley and Black techniques. Bray II solution was utilized to extract P off the substrate, its concentration was measured using a spectrophotometer.

To determine the available soil moisture content, two undisturbed soil samples were collected from each plot at a depth of approximately 10–15 cm. Gravimetric soil moisture content is calculated by multiplying gravimetric soil water content by soil bulk density. Volumetric soil moisture content is evaluated using pressure plate equipment at matrix potential, m, field capacity (FC) is calculated at −33 kPa, and wilting point (WP) is estimated at −15 MPa. By multiplying the gravimetric soil moisture content, one may get the volumetric soil moisture content by the total weight of the soil. Then, the soil's bulk density is divided by the gravimetric soil water content. By reducing the content at FC to the content at WP, the soil's available water content was identified.

Ethical approval: All applicable international, national, and institutional guidelines applicable to the research were followed.

4 Data analysis

Every year, a statistical examination of plant growth and yield data is carried out for each plant. Plant development and yield data were analyzed statistically for each crop year using the SPSS version 25 application. ANOVA was used to determine treatment differences. LSD at a dose of 5% was investigated for variations between treatments.

5 Results

5.1 Intercrop yields

The aim of this research was to observe the effect of organic amendment of manure application and biochar technology on intercropping cultivation of cassava with corn and cassava with peanuts. Biochar, a charcoal made from organic waste, can increase crop yields and soil fertility when added to soil. However, the optimal application rate and frequency of biochar and other organic fertilizers depend on various elements, including crop type, soil type, and climate conditions [40]. The yield of maize produced with cassava has been enhanced by applying farmyard waste and biochar (Table 1).

In the first year, 3.05 ± 0.01 Mg ha^{-1} of maize was produced, with no organic amendment, it increased to 3.61 ± 0.21 Mg ha^{-1} with FYM treatment used at 20 Mg ha^{-1}, and 4.05 ± 0.05 Mg ha^{-1} using FYM biochar technology at 15 Mg ha^{-1}. Table 3 demonstrates that while the initial soil organic matter content (9.5 g kg^{-1} C) was relatively low, it was shown to increase total N and available potassium significantly, as a result of the soil's ability to store water and the application of organic materials. Table 3 shows that the initial soil organic matter content (9.5 g kg^{-1} C) was shallow, but after the improvements, obtainable K and water holding capacity increased significantly. Maize yield with the FYM treatment decreased from 3.61 Mg ha^{-1} at the start of the trial to 2.68 Mg ha^{-1} after the second year. According to the viewpoint of Enesi et al. [41], the fresh root yield of cassava tubers and starch content is highest between 180 and 330 days in July; income shows seasonal variations and depends on the day of harvest.

Table 3: Soil properties after harvesting the second-year cassava treated with different organic amendments at Jatikerto, Malang, Indonesia

Treatments	C (g kg^{-1})	N (g kg^{-1})	P (g kg^{-1})	K (cmol)	CEC cmol	Available water (%)
Before experiment	9.4^{a}	0.7^{a}	11.0	1.55^{ab}	15.64^{a}	15.56^{a}
Cassava + maize (20 Mg ha^{-1} FYM once)	11.1^{abc}	1.1^{bc}	12.3	1.57^{abc}	14.77^{a}	16.21^{ab}
Cassava + maize (20 Mg ha^{-1} FYM yearly)	19.6^{abcd}	1.3^{c}	11.7	1.75^{bc}	17.67^{bc}	17.23^{b}
Cassava + maize (15 Mg ha^{-1} FYM biochar once)	25.1^{d}	1.3^{c}	12.0	1.64^{abc}	18.31^{c}	17.14^{b}
Cassava + maize (15 Mg ha^{-1} CS biochar once)	25.7^{ab}	1.1^{bc}	11.6	1.61^{abc}	15.16^{ab}	15.66^{ab}
Cassava + maize (without organic amendments)	10.4^{ab}	1.0^{b}	11.5	1.61^{abc}	15.16^{ab}	15.66^{ab}
Cassava + peanuts (20 Mg ha^{-1} FYM once)	21.7^{abcd}	1.3^{b}	10.8	1.55^{ab}	15.26^{abc}	16.75^{b}
Cassava + peanuts (20 Mg ha^{-1} FYM applied yearly)	23.2^{bcd}	1.3^{c}	11.0	1.70^{bc}	16.72^{abc}	16.75^{b}
Cassava + peanuts (15 Mg ha^{-1} FYM biochar once)	24.4^{cd}	1.3^{c}	11.0	1.70^{bc}	17.93^{bc}	17.41^{b}
Cassava + peanuts (15 Mg ha^{-1} CS biochar once)	20.2^{abcd}	1.1^{bc}	11.7	1.76^{c}	17.34^{abc}	17.95^{b}
Cassava + peanuts (without organic amendments)	10.2^{ab}	1.1^{b}	11.7	1.48^{a}	14.86^{ab}	14.36^{a}

^{abcd}Values bearing different superscripts within columns show significant differences at $p < 0.05$, in treatments with organic manure addition once it was made in the first year.

FYM's brief positive effects were not sustained beyond one crop cycle. Therefore, repeated additions of FYM might be needed yearly for sustained production [40]. Wahyuningsih et al.'s research revealed that on light soils with a tillage layer (60–80 cm) and relatively poor soil fertility, to be able to get high cassava yields, planting UK2 cultivars is possible with mild fertilizer doses, which is 112.5 kg N + 108 kg P_2O_5/ha + 120 kg K_2O. This technology package can produce 80.22 t ha^{-1} of fresh tubers, utilization of other kinds is greater. The results in Table 1 demonstrate that the application of CS biochar has no discernible impact on the yield of maize compared to treatments without organic amendment (Table 2). This is due to the low N concentration. Thus, the accessibility of nitrogen from organic matter may be essential for improving maize production. Understanding nutrient absorption and dilution patterns can provide valuable information for farmers and researchers to develop environmentally friendly and economically viable sustainable management practices for cassava. Therefore, it is important to understand the nutrient absorption and dilution patterns during the growth cycle to increase cassava productivity on degraded land and identify sustainable management practices for cassava. This can help provide adequate nutrient supply, especially N, P, and K, at the right time [42].

In the initial year of the study, organic matter application had no significant other impact on the yield of groundnut grown in an intercropping system of cassava + groundnut (Table 1). Peanuts might meet their own N requirements through atmospheric N fixation with the help of the Rhizobium bacteria. Notwithstanding this, the yields of maize and peanuts decreased in the cassava-based agriculture system with only one dose of FYM. Organic compost or farmyard manure produces higher crop yields when combined with fertilizer. Composted cattle manure can be an effective way to improve soil fertility and increase maize yields compared to the sole use of inorganic P fertilizer. Continuous cropping systems requiring high rates of N and P fertilizers without manure can decrease crop yields. A balanced organic fertilizer is essential not only to increase crop yields but also to maintain soil fertility. [43]. It may be believed that within a year of application, organic C from FYM mostly breaks down in humid, tropical climates. However, if FYM is used consistently yearly, higher maize productivity could be maintained [42]. This is not unforeseen, given that organic biochar is more stable than traditional organic manure, such as FYM, and its positive effects will last longer [44].

5.2 Cassava yield

The yield of cassava intercropped with peanuts was significantly increased by the use of FYM and biochar derived from FYM (Figure 1). When cassava intercropped with peanuts was given biochar produced from FYM (21.44 Mg ha^{-1}) or FYM (21.66 Mg ha^{-1}), the yield was significantly higher than that accomplished (18.88 Mg ha^{-1}) without organic

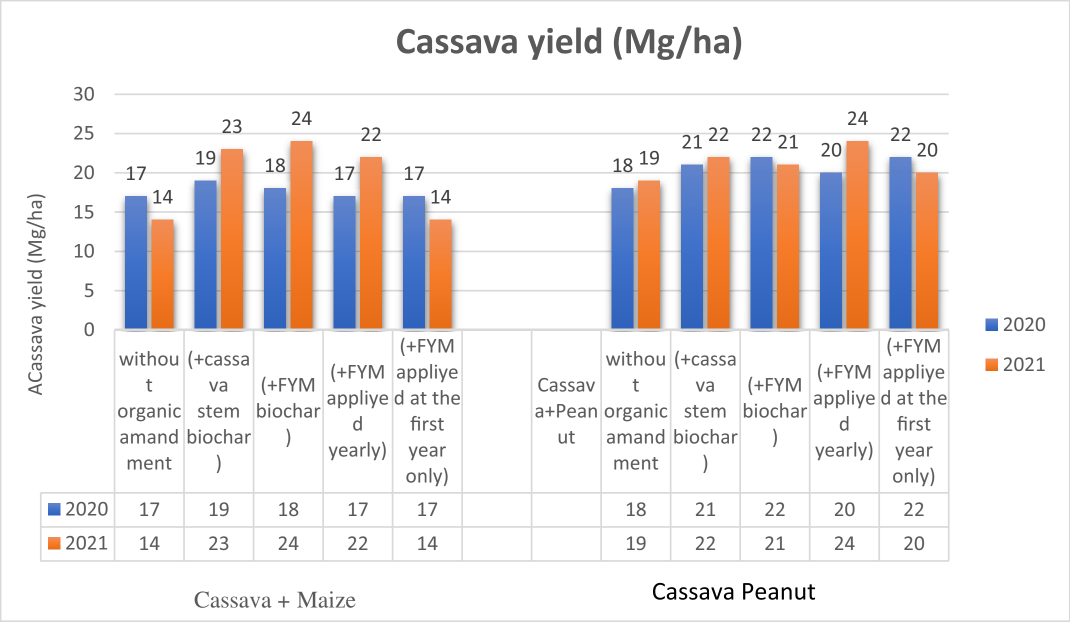

Figure 1: Effect of organic amendment on cassava yield intercropped with maize and peanut system, at Jatikerto, Malang, Indonesia.

additives [45]. However, the latter was statistically about par with biochar created from cassava (20.44 Mg ha^{-1}). Similarly, 14.44 Mg ha^{-1} cassava was grown using cassava and maize without organic fertilizers, which did not change significantly from that with organic additives. Compared to cassava with peanuts, intercropping cassava with maize resulted in a considerably lower yield with the same organic amendments, as shown in Figure 1. This is suitable as cassava produced with peanuts will face less competition for light and plant nutrients and maize [46].

In the first year of the experiment, the quantity of cassava was reduced when cassava and maize were planted together without fertilizer made from organic matter or with FYM applied (Figure 1). But in the second year of the experiment, the opposite was true, application of organic amendments across treatments increased cassava yields [12]. However, the cassava yield reduction in the first year can be avoided if FYM technology and biochar technology are applied annually [47]. In comparing the two cropping systems, it was discovered that the cassava yields changed more across seasons in the cassava + corn intercropping system compared to the cassava + groundnut intercropping system, indicating that the farmer might encounter a decrease in the quality on the site [48]. However, biochar technology could preserve cassava production [49]. The results for cassava intercropped with peanuts were relatively consistent at 19 Mg ha^{-1} (in treatment without organic amendments), the yield increased to 22 Mg ha^{-1} in biochar technology application treatment, and in FYM technology application treatment (applied once) in the second year, the yield increased to 24 Mg ha^{-1}, because it got additional N fixation from intercropping bean roots with cassava tubers [50]. If FYM and biochar technologists are applied in each growing season, the yield of cassava further increases to 24.80 Mg ha^{-1}, an important gain over other forms of treatment [51].

5.3 Soil properties

The results of experimental observations are presented in Table 3, a comparison of untreated soil (control) and soil treated with manure treatment (FYM) and biochar technology indicated an increase in groundwater availability, organic soil C, N, accessible P, CEC, and exchangeable K (Table 3). However, FYM treatment was required every planting season to maintain soil organic C, indicating that FYM's organic C mainly decomposed within a year [52]. However, FYM treatment was required every planting season to maintain soil organic C, indicating that FYM's organic C mainly decomposed within a year, the presence of certain organic C aromatic compounds from the biochar content can explain its ability to retain nutrients and stimulate soil fertility. The physicochemical properties of biochar can vary depending on the pyrolysis temperature and feedstock kind used to produce it [53]. Biochar from plant material shows a higher potential for C absorption than biochar from impurities, due to the higher C/N ratio. The higher carbon to nitrogen ratio (C/N ratio) in a substance indicates a higher carbon content relative to nitrogen.

The high surface charge that is negative due to the oxidation of carboxylate groups and phenolic biochar is the root cause of the higher CEC in soil treated with biochar technology and FYM technology (applied yearly) [12]. In the first year of cassava, CEC of FYM-treated soil is used only once, so either the presence or lack of organic matter had a discernible impact (Table 3).

6 Discussion

From the observations, the application treatment of CS biochar technology on intercropping cassava + maize can increase C by 25.7 g kg^{-1} , K by 177 cmol , CEC by 17.63 cmol , and available water by 16.87%. While in the application treatment of FYM biochar technology on intercropping cassava + peanuts, it can increase C by 24.4 g kg^{-1}, N by 1.3 g kg^{-1}, P by 12.2 g kg^{-1}, K by 1.74 cmol, CEC by 17.93 cmol, and available water 17.41%. According to Nariyanti et al. [54], interchangeable calcium, interchangeable magnesium, cation exchange capacity, total nitrogen, C/N ratio, and nitrogen to cation ratio are the factors that determine soil fertility. Various research on biochar strengthens the function of biochar in enhancing soil characteristics and increasing cassava productivity. Using biochar technology substantially impacts improving soil qualities, such as raising pH and dehydrogenase activity and boosting soil organic carbon content [55]. Biochar technology and organic fertilizer have increased cassava productivity, with dried cassava biomass and fresh tuber yields increasing by 21.7–59.6 and 76.6–112.2%, respectively [56]. Trichoderma and biochar applied together have been found to enhance growth characteristics and boost yields in cassava plants. Trichoderma can enhance plant development and guard against soil-borne illnesses while applying biochar can improve soil's physical and chemical characteristics. Reducing the demand for synthetic fertilizers using Trichoderma and biochar can minimize environmental pollution and increase sustainability [57]. Biochar application can decrease the toxicity of heavy metals and improve soil quality, leading to improved plant growth and reduced environmental pollution [58].

Our results show that intercrop production in cassava-based cultivation techniques in Jatikerto, Malang, Indonesia, utilizes marginal or degraded soil and cannot be maintained by applying inorganic fertilizers alone. Applying organic amendment technology improves soil fertility and bears steady crop yields [12]. Soil enrichment using FYM technology should be performed every planting season [24]. However, processing organic C from FYM technology to biochar, which is more resilient, may increase its stability [59]. CS can be utilized to make charcoal and is a possible component of feed [60]. However, producing biochar using typical natural materials will be more expensive. But since biochar's benefits stay longer, it will considerably assist [48].

7 Conclusion

Cassava and maize yields dropped under the control treatment, respectively, from 17.1 to 13.7 and 3.6 to 2.7 Mg ha^{-1}. Utilizing organic manure, biochar technology, and its adaptations increase cassava yields and soil fertility. The yield of plants will increase for a year with the introduction of FYM technology (20 Mg ha^{-1}) while intercropping cassava and maize. However, the intercropping of peanuts and cassava only lasts for 2 years. Cassava and maize have a greater capacity to sustain crop output for 2 years following biochar (15 Mg ha^{-1}) treatment, which increases their productivity. As a consequence of its power to absorb organic C in the soil, biochar technology possesses more potential for soil carbon sequestration compared to FYM because the biochar treatment's soil organic matter content (20.3–25.8 kg C organic) remained high after the second year's harvest of the cassava crop, compared to treatment without an organic amendment, which would produce 10.3–11.2 g kg^{-1}.

This research makes an important contribution in understanding the effectiveness of intercropping patterns and the use of organic fertilizers in increasing cassava and corn yields, and shows how biochar increases organic carbon content in soils and maintains soil fertility over a longer period of time. However, there are limitations to this study, especially related to the limited duration of the study to only 2 years and the lack of data on the variability of environmental conditions and the scale of application of this method in different types of soils and climates. Further research prospects include exploring the long-term impacts of these cropping and fertilization patterns, their effects on other environmental aspects such as greenhouse gas emissions, and the development of techniques that can be applied more broadly and efficiently on a larger scale to support sustainable agriculture.

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