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Differences in Biochar Sources for Controlled Nitrogen Loss in a Hybrid Maize Agroforestry System with *Melaleuca cajuputi*

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Highlights:

- *Melaleuca cajuputi* and rice husk can be utilized as biochar.
- Mixing *Melaleuca cajuputi* and rice husk biochar with urea fertilizer reduced nitrogen loss by 70.90% and 72.52%, respectively.
- Mixing *Melaleuca cajuputi* and rice husk biochar with urea fertilizer increased the seed yield of hybrid maize by 28.60% and 37.94%, respectively.

Abstract. Biochar is used to improve soil fertility and control nitrogen loss in soil. This study aimed to evaluate the difference between biochar sources, namely *Melaleuca cajuputi* waste and rice husk, for controlled nitrogen loss in hybrid maize planted between *Melaleuca cajuputi* stands. A split-plot design with three replications was used. The main plot was composed of biochar sources (BS), i.e., without biochar application (WB), *Melaleuca cajuputi* biochar (MCB), and rice husk biochar (RHB). The subplot was the urea fertilizer dosage, i.e., 0, 150, 300, and 450 kg/ha. The observation parameters were nitrate reductase activity (NRA), total chlorophyll (TC), leaf photosynthesis rate (LPR), nitrogen loss (NL), nitrogen use efficiency (NUE), and seed yield per hectare (SY). The data were analyzed with ANCOVA and LS-means. The results showed that there was no significant difference between mixing MCB or RHB in UF for all hybrid maize parameters, whereas significant differences were observed with WB. The NL values of MCB and RHB were 13.85 and 13.08 kg/ha N, i.e., NL was significantly reduced by 70.90% and 72.51%, and the percentage of SY increased by 28.60% and 37.94% compared to WB, respectively.

Keywords: *agroforestry system; hybrid maize; Melaleuca cajuputi biochar; nitrogen loss; rice husk biochar; urea fertilizer.*

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1 Introduction

Maize is the second leading commodity after rice in Indonesia [1]. The average import of maize in Indonesia in 2018 was ± 738.37 thousand tons [2]. One solution is to intensify the areas between *Melaleuca cajuputi* stands, increase the N fertilization efficiency, and reduce N losses [3-4].

Nitrogen is an essential element for photosynthesis in plants [5]. For example, hybrid maize consumes large amounts of N fertilizer for growth and development [6]. Nitrogen deficiency reduces the yield of hybrid maize by 29.38%, whereas the average loss of N through various leaching processes (NO_3^- and NH_4^+ emissions [N_2O, NH_3, and NO]) is 227.46% [7-8]. Biochar is a product of the pyrolysis of organic materials and has several functions, such as absorbing CO_2 in the atmosphere, improving soil physical and chemical fertility, and increasing fertilizer efficiency and yields [9]. The application of 13.29 tons/ha *Melaleuca cajuputi* biochar and 245.35 kg/ha urea fertilizer could reduce urea fertilizer and N loss in hybrid maize by 18.22% and 46.81%, respectively [10].

Nurmalasari, *et al*. [10] reported that the application of *Melaleuca cajuputi biochar* could improve the physiological activity of hybrid maize (nitrate reductase activity, total chlorophyll, leaf photosynthesis rate, nitrogen use efficiency) and yields of 35.28%, 19.55%, 18.09%, 27.96%, and 61.78%, respectively, compared to without the application of *Melaleuca cajuputi* biochar. However, *Melaleuca cajuputi* as a source for biochar is difficult to find; therefore, alternative materials for biochar preparation such as rice husk should be investigated. Rice husk is abundantly available and can be used for biochar production [11].

This study aimed to evaluate different biochar sources for nitrogen loss in a hybrid maize agroforestry system with *Melaleuca cajuputi*. This study provided an alternative to *Melaleuca cajuputi* as a biochar source, which could be used to amend the soil and increase the yield of hybrid maize.

2 Materials and Methods

2.1 Study Area

This study was conducted in the wet season, from October 2019 to February 2020, at the Menggoran Forest Resort, Playen Forest Section, Yogyakarta Forest Management District, Indonesia. The altitude of the study site was ±150 m above sea level. This area has a ustic moisture regime (annual mean temperature, relative humidity, and precipitation of 29.38 ºC, 81.90%, and 1,182 mm year^{-1}, respectively) [3,12].

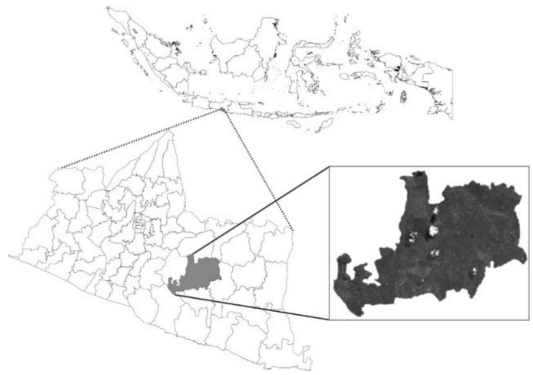

Figure 1 Geographical locations of the study area (latitude 7º 52’ 59.5992” S to 7º 59’ 41.1288” S and longitude 110º 26’ 21.462” E to 110º 35’ 7.4868`” E).

The soil type was Lithic Haplusterts [3,12] and the soil texture was dominated by clay. The cation exchange capacity was classified in the high category (57.78 cmol$^{(+)}$/kg), and the pH (H_2O) was alkaline (8.18). Soil organic carbon (2.62%), total nitrogen (0.13%), available phosphorus (7 ppm), and available potassium (0.41 cmol$^{(+)}$/kg) were classified in the low category.

2.2 Multi-Environmental Trials (MET) Setup

A split-plot design with three replications was prepared. The main plot was composed of biochar sources (BS), i.e., without biochar (WB), *Melaleuca cajuputi* biochar (MCB), and rice husk biochar (RHB). The subplot was the dose of urea fertilizer (UF), i.e., 0, 150, 300, and 450 kg/ha. The analysis results of urea used in this study indicated 45.57% N. Biochar was made from the waste of rice husk and distilled *Melaleuca cajuputi* leaves (Figure 2). Alam *et al*. [12] demonstrated that the contents of pH (H_2O), C, H, N, and O in the MCB were 8.21, 72.48%, 2.32%, 0.17%, and 22.44%, respectively, while in the RHB they were 8.02, 34.60%, 4.23%, 0.47%, and 31.70% (Table 1) [13-14].

Table 1 Comparison of nutrient content between *Melaleuca cajuputi* biochar (MCB) and rice husk biochar (RHB).

Biochar	Nutrient Content				
Sources	pH (H_2O)	C (%)	H (%)	N (%)	O (%)
MCB	8.21	72.48	2.32	0.17	22.44
RHB	8.02	34.60	4.23	0.47	3.70

This experiment used the Pioneer 21 variety. The experimental plots were placed between *Melaleuca cajuputi* stands of 24 m^2 (6 x 4 m). The harvest area for hybrid maize was 20 m^2 and did not include border crops. Soil tillage before planting the hybrid maize was done with minimum tillage. The hybrid maize planting was done by direct seeding with a spacing of 70 x 20 cm and one seed per planting hole. MCB and RHB were applied when the hybrid maize reached 1 week after sowing. UF was twice applied, when the hybrid maize reached one week after sowing and when it reached five weeks after sowing. No irrigation was done because the field was in a rainfed area.

(a) (b)

Figure 2 (a) Waste of distilled *Melaleuca cajuputi* leaves and (b) *Melaleuca cajuputi* biochar after pyrolysis.

2.3 Hybrid Maize Variables

The observation parameters were nitrate reductase activity (NRA) [15], total chlorophyll (TC) [16], leaf photosynthesis rate (LPR) [17], nitrogen loss (NL) [18], nitrogen use efficiency (NUE) [19], and seed yield per hectare (SY). The seeds were dried in the sun to reach 11% of moisture levels [20-21]. Sampling for parameters TC, NRA, and LPR was carried out when the hybrid maize entered the maximum vegetative phase at eight weeks after sowing and the seed yield parameters were sampled at 14 weeks after sowing.

2.4 Statistical Analysis

The models had to be evaluated so that assumptions can be fulfilled. Normality and heterogeneous variance tests were conducted using a Q-Q plot and a residual versus value graph [22]. The data were analyzed through analysis of covariance (ANCOVA) and least-squares means (LS-means) [22] by using PROC MIXED in SAS 9.4 software [23].

3 Results and Discussion

3.1 Estimated Responses of Hybrid Maize Parameters

ANCOVA revealed that BS and UF significantly differed in terms of NRA. BS showed a significant difference and had a linear pattern in terms of the rate of UF (Figure 3).

Table 2 Comparison lines of the least-square means of biochar for all hybrid maize parameters.

Biochar Sources	Hybrid Maize Parameters					
	NRA	TC	LPR	NL	NUE	SY
WB	3.59[b]	0.73[b]	418.45[b]	47.59[a]	8.65[b]	5.18[b]
MCB	4.09[a]	0.78[a]	437.98[a]	13.85[b]	10.14[a]	6.66[a]
RHB	4.25[a]	0.81[a]	449.22[a]	13.08[b]	10.83[a]	7.15[a]

- LS-means with the same letter were not significantly different
- WB: without biochar; MCB: *Melaleuca cajuputi* biochar; RHB: rice husk biochar
- NRA: nitrate reductase activity (μmol NO_2^-/g/h); TC: total chlorophyll (g/g leaf); LPR: leaf photosynthesis rate (μmol CO_2/m^2/s); NL: nitrogen loss (kg/ha N); NUE: nitrogen use efficiency (kg grain/kg $N_{fertilizer}$); SY: seed yield (tons/ha).

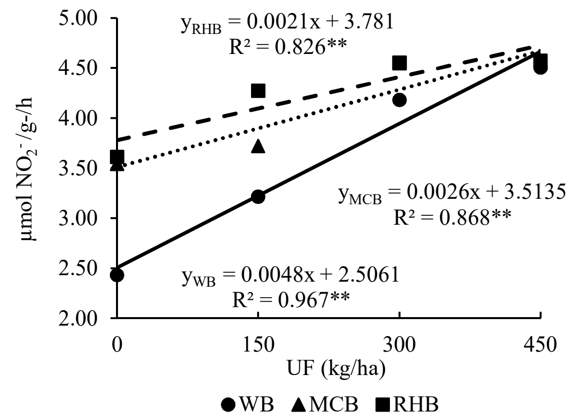

Figure 3 Nitrate reductase activity (NRA) of hybrid maize against biochar source (BS) and urea fertilizer (UF) dosage.

The results for MCB and RHB differed significantly from WB. The application of MCB and RHB in the UF yielded significantly higher NRA, at 4.09 and 4.254 μmol NO_2^-/g/h, respectively, compared to WB, at 3.59 μmol NO_2^-/g/h. The application of MCB and RHB significantly increased the NRA, by 14.20% and 18.66%, respectively, compared to WB (Table 1). The optimum values for MCB and UF in upland rice could increase NRA by 17.72% compared with a single application of urea [24]. TC differed very significantly between the BS and UF treatments. The application of BS showed a significant difference and had a linear pattern with the UF dosage (Figure 4). MCB did not differ from RHB, whereas MCB and RHB differed significantly from WB. Mixing MCB and RHB with the UF doses yielded significantly higher TC values, at 0.78 and 0.81 g/g leaf, respectively, compared to WB (0.59 g/g leaf); the TC percentage increase was 7.29% and 10.87%, respectively, compared to WB (Table 1). Shareef, *et al.* [25] demonstrated that biochar application significantly increases TC in maize. The application of biochar in the soil positively correlates with chlorophyll content, increases PS II activity, and facilitates electron transport, thereby increasing photosynthesis rates [26].

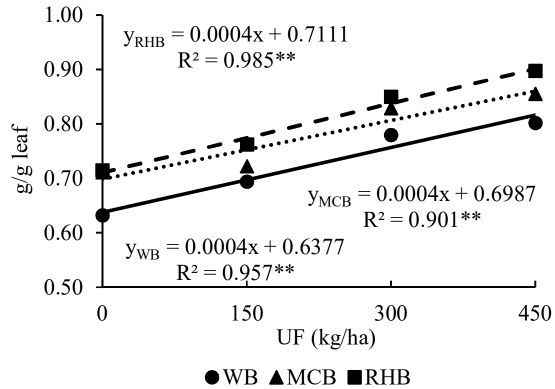

Figure 4 Total chlorophyll (TC) of hybrid maize against biochar source (BS) and urea fertilizer (UF) dosage.

The BS and UF treatments differed very significantly in terms of LPR. The BS treatment showed a very significant difference and had a linear relationship with UF dosage (Figure 5). MCB and RHB exhibited significant and very significant differences, respectively, compared to WB, while there was no significant difference between MCB and RHB. The highest LPR values for MCB and RHB were 437.98 and 449.22 µmol $CO_2/m^2/s$, respectively, whereas the highest LPR value for WB was 418.45 µmol $CO_2/m^2/s$.

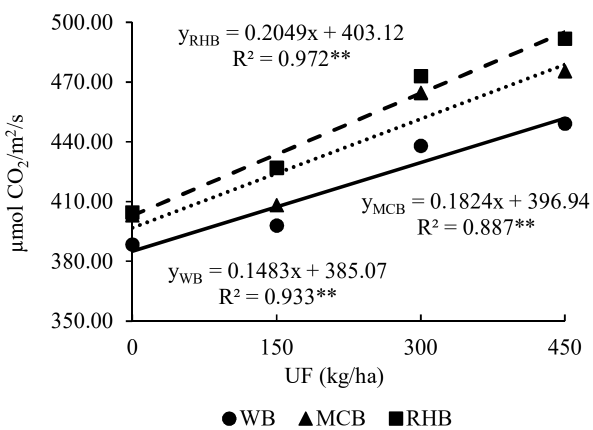

Figure 5 Leaf photosynthesis rate (LPR) of hybrid maize against biochar source (BS) and urea fertilizer (UF) dosage.

The percentage increase in LPR for MCB and RHB was 4.67% and 7.35%, respectively, compared to WB (Table 1). Efthimiadou, *et al*. [27] reported that the use of organic matter in maize plants increased LPR by 49.65% compared to without organic matter. The increase in LPR in maize was significantly affected by UF. Nitrogen in maize leaf tissue participates in photosynthesis, and the photosynthesis rate is closely associated with the N content in leaves [28].

There was a significant difference in NL between the BS and UF treatments. The application of BS made a very significant difference and had a linear relationship with UF dosage (Figure 6). Mixing MCB and RHB in the UF doses differed significantly from WB, while there was no significant difference between MCB and RHB. MCB and RHB had significantly lower NL compared to WB. The NL values for WB, MCB, and RHB were 47.59, 13.85, and 13.08 kg/ha N, respectively.

The application of MCB and RHB significantly reduced NL by 70.90% and 72.51%, respectively, compared to WB (Table 1). The application of biochar can reduce NO_3^--N leaching, N_2O emissions, and NH_3^+ volatilization [29]. Alam, *et al*. [12] state that the application of 2.89 tons/ha of biochar, 2.27 tons/ha of compost, and 67.85 kg/ha of ammonium sulfate reduced NL by 21.66% compared to a single application of ammonium sulfate fertilizer.

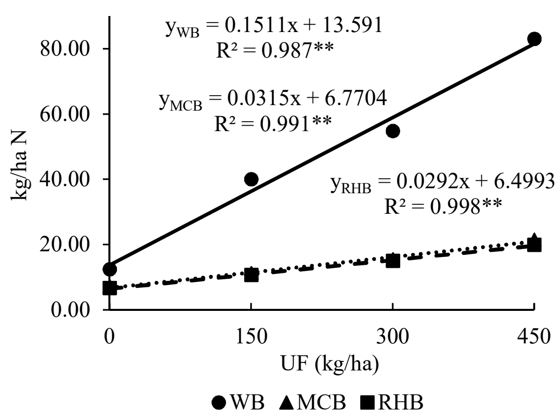

Figure 6 Nitrogen loss (NL) of hybrid maize against different biochar sources (BS) and urea fertilizer (UF) doses.

There was a significant difference in NUE between the BS and UF treatments. The application of BS made a very significant difference and had a linear relationship with UF dosage (Figure 7). Mixing MCB and RHB in the UF doses yielded a significant and very significant difference in NUE, respectively, compared to WB, while there was no significant difference between MCB and RHB. MCB and RHB had the highest NUE, at 10.14 and 10.83 kg grain/kg $N_{fertilizer}$, whereas WB had the lowest NUE, at 8.65 kg grain/kg $N_{fertilizer}$. The NUE percentage increase was 17.28% and 25.22% for MCB and RHB, respectively, compared to WB (Table 1). The relationships between N accessibility, uptake, and remobilization in maize were influenced by soil N supply. A low N supply following anthesis can lead to early leaf senescence because the development of grain requires more N than the maintenance of vegetative tissues [28].

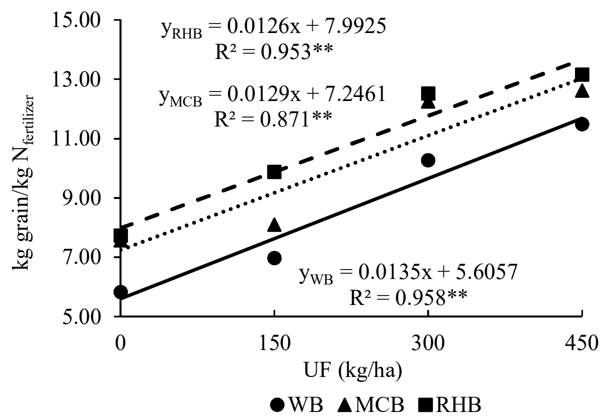

Figure 7 Nitrogen use efficiency (NUE) of hybrid maize against biochar source (BS) and urea fertilizer (UF) dosage.

The SY parameter showed a significant difference between the BS and UF treatments. The application of BS made a very significant difference and had a linear relationship with UF dosage (Figure 8). Mixing MCB and RHB in the UF doses yielded very significant differences compared to WB. MCB and RHB had significantly higher SY values, at 6.66 and 7.15 tons/ha, respectively, compared to WB (5.18 tons/ha).

The SY percentage increase was 28.60% and 37.94% for MCB and RHB, respectively, compared to WB (Table 1). Yeboah, *et al*. [30] demonstrated that the application of 5 tons/ha of biochar increased maize productivity compared to when biochar was not applied. Faloye, *et al*. [31] and Mete,*et al*. [32] observed an increase in crop yield when biochar and inorganic fertilizer were combined. Our results were consistent with those of Liu, *et al*. [33], who demonstrated that the combination of biochar and fertilizer in low-fertility soil had a more significant effect on crop yield than a single application.

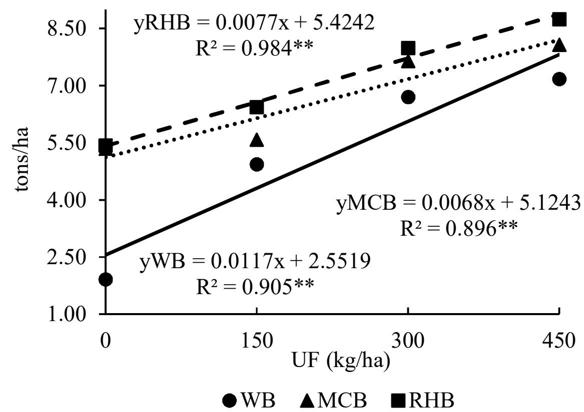

Figure 8 Seed yield (SY) of hybrid maize against biochar source (BS) and urea fertilizer (UF) dosage.

3.2 Interaction between Biochar Sources with Urea Fertilizer

ANCOVA showed interaction between BS and UF in NRA and NL, whereas TC, LPR, NUE, and SY showed no interaction between biochar source and UF dosage (Figure 1-6). Biochar is used as an amendment of soil to increase its physical and chemical fertility. This ability of biochar is attributed to the composition of organic compounds, which can increase soil fertility by increasing soil organic carbon (SOC) and ash material containing essential macro and micronutrients for plants [34]. Badu, *et al*. [6] reported a significant interaction between biochar application and N fertilization in maize.

Increasing the application of biochar significantly decreases the NO_3^- concentration in soil [35]. Biochar adsorbs, releases, and stimulates N mineralization in soil [36]. It increases growth and yield because of the prolongation of N and P retention time [37]. A study in southern China has shown that NPK with biochar fertilization increasedmaize biomass by 75% compared to a single NPK application [38]. Gathorne-Hardy, *et al*. [39] found that barley yield increased by more than 30% when biochar and N fertilizer were applied together.

Haider, *et al*. [40] reported that there was a positive interaction between biochar and nitrogen fertilization. The function of biochar is to release the nitrogen slowly so that it becomes more efficient and can be utilized by plants. This is because biochar has a high CEC, which enables it to absorb and release nitrogen [41].

4 Conclusions

MCB and RHB did not significantly differ from each other when mixed in UF in terms of all the sampled hybrid maize parameters, whereas they did significantly differ from WB. The NL values of MCB and RHB were 13.85 and 13.08 kg/ha N, i.e., a significant NL reduction by 70.90% and 72.51% compared to WB, and the percentage of SY increased by 28.60% and 37.94% compared to WB, respectively.

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