Soil fertility status, nutrient uptake, and maize (*Zea mays* L.) yield following biochar and cattle manure application on sandy soils of Lombok, Indonesia

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Abstract

A field study was conducted to evaluate the effects of biochar application on soil fertility status, nutrient uptake, and maize yield in the sandy soils of semiarid Lombok, Indonesia during the rainy season of 2010–2011 and dry season of 2011. Three organic amendments (coconut shell biochar, CSB; cattle dung biochar, CDB; cattle manure, CM, and no organic amendments as control, C) constituted the treatments. Biochar application improved soil fertility status, especially soil organic C, CEC, available P, exchangeable K, Ca, and Mg, and increased nutrient uptake and maize yield. Soil organic C increased from about 0.9% (untreated soil) to about 1.20% (biochar and CM treated). Soils treated with biochar had consistently higher organic C contents, which also remained more stable compared to the soils treated with CM, implying the higher potential of biochar for soil carbon sequestration. The highest maize yield during the rainy season was noted for CM, followed by CDB and CSB (5.98, 5.87, and 5.71 Mg ha^{-1} respectively). However, yield of the second crop in one-time CM application treatment declined. This was not the case for maize yield on biochar treated soil.

Keywords: Cattle manure, Coconut shell, Exchangeable bases, Organic amendments.

Introduction

Sandy soils cover about 38,000 ha in the semiarid tropics of North Lombok, Indonesia and almost 30% of these have low fertility status. Major crops grown on these soils are maize (*Zea mays* L.) and cassava (*Manihot esculenta* Crantz). Low nutrient content (N, P, K, Ca, Mg), organic C (<1.0%), and low CEC (12 cmol) are, however, major production constraints of these soils (Suwardji et al., 2007). Although application of organic matters (i.e. manure, mulches, and composts) have frequently been shown to increase soil fertility, the benefits usually last only for one or two growing seasons due to the rapid mineralization of organic matter under the hot, humid tropical environment (Diels et al., 2004). This has made the practice expensive and therefore, the farmers refrain from organic matter addition to crops, often (Masulili et al., 2010). Biochar, a carbon-rich material obtained from heating organic biomass under limited oxygen conditions appears to be a more stable source of carbon and it remains in the soil for hundreds or even thousands of years (Lehmann et al., 2006).

The beneficial effects of biochar on soil properties have been reported by many and includes chemical (Yamato et al., 2006), physical (Chan et al., 2008), and biological changes in soil (Rondon et al., 2007). Improvements in plant growth and yield following biochar application also has been reported for a variety of crops, such as radish (*Raphanus sativus* L.: Chan et al., 2008), common beans (*Phasealus vugaris* L.: Rondon et al., 2007), soybean (*Glicine max* (L.) Merr.: Tagoe et al., 2007), and maize (Yamato et al., 2006). Although

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biochar recently has attracted considerable interest as a sustainable technology to improve soil fertility in the tropics, information on their potential to amend infertile sandy loam soils under maize cropping system in the semiarid tropics is rather limited. Furthermore, many local organic resources such as coconut shell and cattle dung available in Lombok (approximately 56,180 and 2, 830, 256 Mg per year, respectively in this area), which by and large remain under-exploited, are suitable for biochar production. Use of such residues for improving soil quality as well as crop productivity in the dry land farming systems of Lombok might be ecologically promising also. The present study was aimed to address the potential of biochar (produced from cattle dung and coconut shell) for improving fertility of sandy loam soils under maize cropping system in Northern Lombok.

Materials and Methods

The experiments were carried out at the dry land experimental station of Mataram University at Bayan District in northern Lombok, Indonesia (08º25'S, 116º 23'E; altitude 20.5 m above mean sea level). Annual rainfall of northern Lombok in 2010 was 1234.2 mm, distributed between December/January to April/May; mean air temperature was 31ºC and atmospheric humidity about 84%. Soils of the experimental sites were Ustipssamment (Soil Survey Staff, 1998) derived from volcanic ash containing pumice stone materials erupted from Mount Rinjani. The surface soil has a sandy loam texture (55% sand and 9% clay) with pH of 5.97 and had low soil organic carbon (0.89%) with poor nutrient status (0.13% N, 23.60 mg kg^{-1} extractable P, and 0.57 cmol kg^{-1} exchangeable K).

Biochars used in the study were produced from cattle dung and coconut shell. Coconut shell biochar (CSB) was prepared through auto thermal combusting of the shells in pits (1.0 m deep, 1.0 m wide, and 1.5 m long). Combustion was conducted for 9 to 10 h till the whole feedstock changed to black coloured chars and the temperature ranged from 190 to 280ºC (average 240ºC). Subsequently, banana stems and leaves were placed (10 cm thick) on the surface of the bulky chars and water was sprayed to cool it overnight. Cattle dung biochar (CDB) was prepared from sun dried cattle dung (15% water content), filled into two drums (56 cm diameter and 42 cm high) and heated on a stove constructed with brick (70 cm wide, 120 cm long, and 40 cm high). The drums were filled with 10 kg of dried dung and were sealed and combusted using sawdust and coconut fibre as fuels. Temperature during the charring process fluctuated between 200 to 330ºC (average 254ºC). Carbonizing was finished after 9 to 10 h when black smoky-coloured chars formed. The contents of the heated drums were removed from the stove and allowed to cool for 24 h. Water was sprayed on the surface of the drums to accelerate the cooling process.

The biochars were crushed and sieved (1.0 mm). Moisture content (% w/w) was measured by oven drying a 10 g sample for 24 h at 80ºC and pH measured in 1% (w/w) suspension prepared by diluting the biochar particles with deionized water (Ahmedna et al., 1998). The suspension was heated to 90ºC and stirred for 20 min to dissolve the soluble components and pH was measured using a pH meter (Jenway 3305) after cooling the biochar suspension to room temperature. Ash content was determined by dry combustion at 760ºC for 6 h using muffle furnace (Novak et al., 2009). Total C was determined using method described in ASTM D 3176 (ASTM, 2006). Total P was read with a spectro-photometer and K, Ca, Mg, and Na were measured using AAS (Shimatzu, Japan). The characteristics of the organic amendments used in the study are presented in Table 1.

Field trials were conducted in the wet season of 2010–11 (November 2010 to March 2011) and the dry season of 2011 (April to July 2011). Plots were established after clearing the vegetation and ploughing the field up to 20 cm depth using a hand tractor. The experimental variables included three organic amendments applied at the rate of 15 Mg ha^{-1}: CSB, CDB, cattle manure (CM), and a no organic amendment control (C). In the wet season of 2010–2011, the treatments were CSB, CDB, CM, and C. In the dry season of 2011, the CM treatment consisted of CM applied once for the first maize, and CM applied for first and second maize crops (i.e., CM applied at each planting time, CMT). Thus the complete treatments of the dry season were CSB,

Table 1. Characteristics of biochars used in the field experiment.

Biochar characteristics	Cattle dung biochar	Coconut shell biochar	Cattle manure
Water content (% w/w)	8.2	5.6	10.1
pH-H_2O	8.9	9.9	6.9
C (%)	23.5	80.6	10.2
N (%)	0.73	0.34	0.94
P (%)	0.57	0.10	0.62
C/N	32.2	237.0	10.9
K (%)	0.69	0.84	0.53
Ca (%)	0.51	0.40	0.65
Na (%)	0.15	0.12	0.35
Mg (%)	0.44	0.06	0.40
Potential CEC (cmol kg^{-1})	16.79	11.78	–
Ash (%)	75.34	7.36	–

CDB, CM applied once during the wet season (first maize crop), CMT, and C. The treatments were laid out in a randomized block design with four replications in plots of size 3.5 x 4.0 m.

The organic amendments were thoroughly incorporated in the soil to a depth of 10 cm and incubated for seven days by watering (± 80% field capacity). A week after biochar incubation, maize (Hybrid BC-2) was sown (one per hill) at 5 cm depth with a row spacing of 20 x 70 cm (100 plants per plot). Urea, superphosphate, and KCl were applied at the rate of 135 kg N ha^{-1}, 75 kg P_2O5 ha^{-1}, and 75 kg K_2O ha^{-1} respectively. While all P and K were applied basally, N was applied in two splits: 40% (54 kg N ha^{-1}) at 21 days after planting, and 60% (81 kg N ha^{-1}) at 45 days. Watering was done soon after incorporating biochar and manure, a day before sowing.

Before planting and after harvesting, four soil samples were taken from each plot to a depth of 20 cm following a zigzag pattern. The samples were mixed and a 0.5 kg sub-sample drawn for laboratory analysis. Soil properties evaluated includes pH, total N, available P, CEC, and exchangeable K. To study the soil organic C dynamics, soil samples (0–10 and 10–20 cm depth) were periodically collected (1, 2, 4, 7, 14, 28, 56, 105, 155, and 210 days after incubation) by driving a stainless steel ring cylinder of about 7.5 diameter. Four samples were taken from each plot following a zigzag pattern, mixed to form a composite sample, from which a 250 g subsample was taken for laboratory analysis.

Soil pH was determined in 1:2.5 ratio of soil: water, organic carbon by Walkley and Black method, and total N by Kjeldhal method; available P was extracted by Bray-1 method; CEC and exchangeable K using ammonium acetate at pH 7.0. Nitrogen, P, and K concentration in foliar tissues were also determined, and uptake calculated by multiplying top dry biomass with N, P, and K concentrations. The data were analyzed using ANOVA and the significance tested by Fischer‘s least significant difference (p=0.05) with MINITAB Version 13.

Results and Discussion

Biochar application (CSB and CDB) increased soil organic carbon (SOC) content, especially in the 0 to 10 cm soil layer (Fig. 1). The high organic C contents of soils treated with biochars also persisted even after the harvest of the second crop. Conversely, soil organic C in the CM treated plots were not significantly different from that without organic amendments after the harvest of the first and the second maize crops (Table 2), implying that the effect of CM on soil organic C do not last beyond one crop season. To maintain high soil organic matter levels, therefore, CM should be applied every year. Previous studies also confirm that under the wet conditions of tropics, organic C from cattle manure decomposed almost completely within one

Table 2. Soil characteristics of sandy loam at Lombok, Indonesia, after application of biochars and cattle manure under maize cropping system.

Organic amendments	pH		C (mg kg^{-1})		N (mg kg^{-1})		CEC (mg kg^{-1})		P (mg kg^{-1})		K (cmol kg^{-1})		Ca (cmol kg^{-1})		Mg (cmol kg^{-1})	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Cocconut shell biochar	6.49^{a}	6.46^{a}	1.15^{a}	1.13^{a}	0.12^{b}	0.14^{ab}	15.04^{a}	15.15^{a}	26.48^{a}	22.39^{ab}	0.75^{b}	0.78^{a}	2.44^{a}	2.54^{ab}	1.42^{b}	1.54^{b}
Cattle dung biochar	6.45^{a}	6.46^{a}	1.14^{a}	1.11^{a}	0.16^{a}	0.15^{ab}	15.10^{a}	15.14^{a}	26.24^{a}	21.67^{ab}	0.89^{a}	0.78^{a}	2.60^{b}	2.78^{b}	1.50^{a}	1.53^{b}
Cattle manure once	6.39^{b}	6.36^{b}	0.90^{b}	0.94^{ab}	0.14^{ab}	0.13^{b}	15.02^{a}	14.67^{ab}	25.66^{a}	20.95^{b}	0.76^{b}	0.71^{b}	2.38^{a}	2.15^{a}	1.40^{b}	1.45^{b}
Cattle manure at every planting	–	6.40^{ab}	–	0.98^{ab}	–	0.16^{a}	–	15.21^{a}	–	25.11^{a}	–	0.78^{a}	–	2.91b	–	1.83^{a}
Without amendment	6.29^{c}	6.32^{b}	0.87^{b}	0.89^{b}	0.11^{b}	0.13^{b}	13.34^{b}	13.40^{b}	23.59^{b}	14.44^{c}	0.70^{c}	0.70^{b}	2.22 ^{c}	2.08^{a}	1.37^{b}	1.32^{c}
Before exp[1)]	5.97	–	0.85	–	0.12	–	12.99	–	24.41	–	0.57	–	2.34	–	0.87	–

Mean with the same superscript letters within column do not differ significantly (p=0.05); 1st and 2nd denote rainy season (2010–11) and dry season (2011) maize crops; [1)] pre-treatment data.

season (Diels et al., 2004). Organic C of biochars with an aromatic structure, however, is more resistant to decomposition (Lehman et al., 2006). Trends in decomposition dynamics (Fig. 1) show that the value of the coefficient (for *t*) in the equation for CM treated soil was much higher than other treatments, implying that the rate of organic C decomposition from CM was faster. In fact, SOC of CM treated plots dropped by 18% within 14 days, which is much higher than the corresponding values for CSB and CDB (Fig. 1).

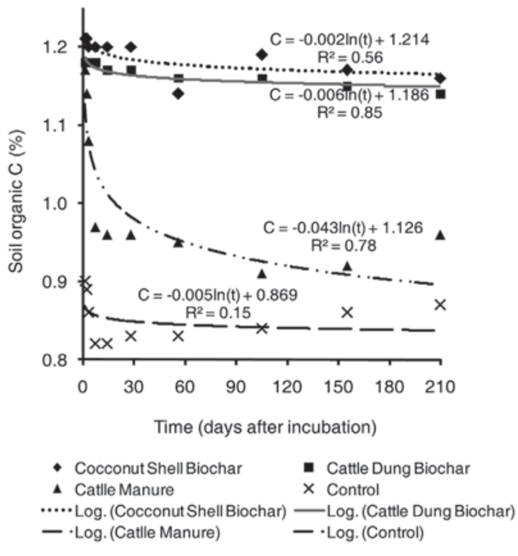

Figure 1. Soil organic C at 5–10 cm as a function of time after incubation of organic amendment treated soil at Lombok, Indonesia (LSD 5% for 1, 105 and 110 days after incubation are 0.15; 0.14 and 0.13% respectively).

Although a decrease in soil organic C, partly due to downward movement by percolation was expected, the data presented in Fig. 2 show that throughout the cropping season soil organic C at a depth of 15–20 cm was not significantly influenced by organic amendments. Implicit in this is that there was no significant downward movement of organic C from biochar. The drop in soil organic C observed is presumably due to decomposition (Cheng et al., 2006).

Apart from enriching soil organic C, application of biochar and CM improved other soil properties too (Table 2). Increase of soil pH following biochar appli-

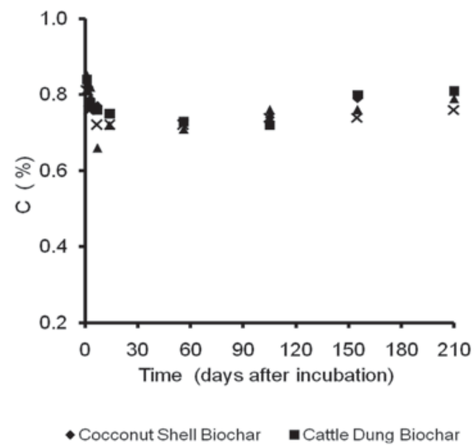

Figure 2. Effect of organic amendment application on soil organic at a depth of 15–20 cm on sandy loam at Lombok, Indonesia.

cation may be related to the alkaline nature of biochars (Table 1). Higher nutrient concentrations of biochar and CM treated plots compared to control is suggestive of the positive contribution of organic amendments to improve soil nutrient availability. However, to sustain these positive effects, CM should be applied every planting season, whereas a single application of biochar can maintain these positive attributes for a longer period of time (also see Islami et al., 2011).

In addition, the increase of CEC with addition of biochars will also minimize nutrient leaching, especially potassium and ammonium N. The increase nutrient availability and higher CEC observed in this study is consistent with the results of previous authors (Novak et al., 2009; Yamato et al., 2006). High surface negative charge resulting from oxidation of functional groups, mainly carboxylic and phenolic, on the outer surface of biochar particles and the high surface area of biochar will probably explain this higher cation adsorption (Cheng et al., 2006). This would in turn decrease the leaching of positively charged nutrient such as K, Ca, and Mg of soil treated with biochar, which is probably evident from Table 2. Application of organic amendments thus resulted in a significant increase of exchangeable Ca and Mg especially at 210 days after incubation. Highest values were recorded in CDB treated soils, whereas CSB and CM application were statistically at par. Although due to differences in the number of samples, the pre-treatment soil data were not included in the statistical analysis, the results presented in Table 2 clearly show that after planting maize, the properties of soil applied with CM was not substantially different from that before.

Improvements in soil fertility status with biochar application also were reflected in increased maize yields (Fig. 3) and uptake of N, P and K (Table 3). The positive response to biochar application in this study seems to be in concordance with the previous results reported in other tropical regions (Yamato et al., 2006). Furthermore, Fig. 3 shows that the positive effects of biochar on maize yield persisted during second crop season also, although it was not the case with CM. To maintain higher maize yields also, CM should be applied every planting season. The recalcitrant nature of biochar has been reported by many workers (Lehmann et al., 2006; Islami et al., 2011). However, this has not adversely affected the nutrient uptake by the maize crop, which is exemplified by the data in Table 3. It shows that nutrient uptake of maize grown on biochars treated soils was generally comparable to that of CM. The N,P, and K uptake of the second maize crop for biochar treated soil was also similar to that of the first crop.

Overall, this study confirms that biochar and cattle manure are valuable amendments for improving soil fertility and to sustain maize production in the sandy loam soils of semiarid North Lombok, eastern Indonesia. Although cattle manure application produced higher maize yields, in term of maintaining stability of soil organic C on a long term basis, application of biochar would be more promising. However, confirmation based on a long-term study of the cropping sequence, particularly in the semiarid tropical regions, may be necessary.

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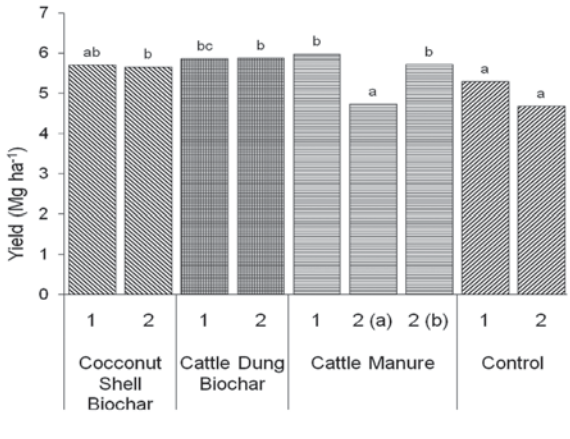

Figure 3. Effect of organic amendment on maize yield on sandy loam at Lombok, Indonesia (Bars with the same superscripts do not differ significantly; 1and 2 denote the first maize yield and the second maize yield respectively; for cattle manure 2 (a) indicates manure applied once and 2 (b) signifies manure applied every year).

Table 3. Nutrient uptake of maize treated with biochar and cattle manure on sandy loam at Lombok, Indonesia.

Organic amendments	Nutrient uptake (kg ha^{-1})					
	First crop			Second crop		
	N	P	K	N	P	K
Coconut shell biochar	102.19^{a}	14.35^{ab}	110.45^{ab}	107.73^{a}	13.09^{ab}	92.78^{ab}
Cattle dung biochar	103.12^{a}	16.81^{a}	123.04^{a}	105.72^{a}	13.60^{ab}	91.66^{ab}
Cattle manure applied once	110.54^{a}	15.92^{ab}	119.52^{a}	91.10^{b}	12.05^{b}	86.76^{b}
Cattle manure applied every planting	-	-	-	114.90^{a}	14.54^{a}	99.53^{a}
Control (without amendments)	87.31^{b}	12.25^{b}	98.65^{b}	76.59^{c}	9.27^{c}	62.81^{c}

Mean with the same superscript within single column do not differ significantly (p=0.05).

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