Journal of Tropical Agriculture 49 (1-2) : 40-46, 2011

Biochar for sustaining productivity of cassava based cropping systems in the degraded lands of East Java, Indonesia

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Received 1 July 2011; received in revised form 19 September 2011; accepted 20 September 2011

Abstract

Field experiments were carried out to explore the beneficial effects of biochar on the productivity of cassava (*Manihot esculenta* Crantz) based cropping system in the degraded uplands of East Java, Indonesia from September 2009 to May 2011. Two cropping systems namely cassava + maize (*Zea mays* L.) and cassava + peanuts (*Arachis hypogaea* L.) and five organic amendments, namely farm yard manure (FYM) applied once at the start of the experiment, FYM applied every year, biochar from FYM, biochar from cassava stem, and no FYM as control were evaluated. With no FYM addition, yield of cassava and maize during the succeeding year declined from 17.1 to 13.7 Mg ha^{-1} and from 3.6 to 2.7 Mg ha^{-1} respectively. Organic amendments improved soil fertility and crop yields. For cassava + maize intercropping, the beneficial effects of FYM (20 Mg ha^{-1}), however, lasted for only one year; nonetheless for cassava + peanut intercropping it persisted for two years. Increases in cassava and maize yield following biochar application (15 Mg ha^{-1}), however, continued for two years after planting, implying its potential for sustaining crop production over longer periods. Soil organic matter content in the FYM treatment also was high for a year, whereas in the biochar treatment it remained high well after the harvest of the second year cassava crop (20.3 to 25.8 g kg^{-1} soil C as against 10.3 to 11.2 g kg^{-1} for treatments without organic amendments), implying the profound potential of biochar for soil carbon sequestration owing to its recalcitrant nature.

Keywords: Recalcitrant soil C, Sustainable production, Soil organic matter, Soil carbon sequestration.

Introduction

Indonesia is one of the main cassava (*Manihot esculenta* Crantz) producing countries of the world where cassava is the most important tuber crop and the third important food crop after rice (*Oryza sativa* L.) and maize (*Zea mays* L.). In terms of cassava planting area, Indonesia is the largest grower in Asia (Howeler, 2008). As regards to production, however, Indonesia is ranked second after Thailand. In 2004, with 1.3 million ha of harvested lands, Indonesia produced 19.2 Tg (10^{12} g) of cassava tubers, whereas Thailand, with only 1.05 million ha of cassava, harvested 20.4 Tg of cassava tubers. The national average yield for Indonesia is still low and has not increased significantly since 1984 (approximately 14.0 Mg ha^{-1}), which is lower than India (26.3 Mg ha^{-1}), Thailand (19.4 Mg ha^{-1}), and China; the latter has just 240,000 ha of cassava but produces 3.9 Tg cassava tubers.

Of about 1.3 million ha of cassava in Indoensia, 55% is in Java, where cassava is planted on degraded or nearly degraded lands (Islami et al., 2011) by the small farmers in intercropping systems involving maize or legume crops such as peanuts. These sites usually have a low soil fertility status with depth less than 30 cm, stony, or gravelly and are characterized by very low organic matter content (8.4 g kg^{-1}), nitrogen (0.5 g kg^{-1}), phosphorus (7.61 mg kg^{-1}), and micronutrients such as zinc and iron (Howeler, 2008). Addition of inorganic fertilizers may increase cassava yields, but is incapable of maintaining yield stability over long periods (Islami et al., 2011).

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Considering the fact that soil organic matter in degraded land is very low, the simplest technology to improve soil productivity and stabilize crop yield is the addition of organic amendments (Amanullah et al., 2007; Islami et al., 2011). The main limitation of organic matter addition, especially in the wet tropical condition, however, is its rapid decomposition, necessitating repeated additions during every planting season, which is impractical in view of the difficulty to source enough organic manures. Some workers have therefore evaluated recalcitrant organic materials such as "biochars" for their ability to improve soil properties, carbon sequestration (e.g. Glaser et al., 2002; Lehman et al., 2003; Liang et al., 2006), and to increase crop yields (Yamato et al., 2006; Chan et al., 2008). Although increases in cowpea and maize yields (Yamato et al., 2006), soybean (Tagoe et al., 2008), upland rice (Asai et al., 2009), and lowland rice (Masulili et al., 2010) following biochar application have been reported, there seems to be no such study on cassava. The objective of the present experiment therefore was to evaluate the potential of biochar for soil organic matter management in cassava-based cropping system, especially its effect on crop yield, yield stability, and residual soil fertility. The hypothesis tested is whether the beneficial effects of biochar as organic amendments in cassava based cropping system would last longer compared to that of the conventional organic manures such as farm yard manure and would promote soil carbon sequestration.

Materials and Methods

The experiment was carried out on Brawijaya Experimental Field Station at Jatikerto, Malang, Indonesia (08º03' S, 112º30' E; 228 m above sea level) during the period from September 2009 to May 2011. The soil of the experimental site has a depth of about 25 cm with clay loam texture (pH 6.49, organic C 6.5 g kg^{-1}, total N 0.8 g kg^{-1}, available P 11.1 mg kg^{-1}, exchangeable K 1.56 cmol kg^{-1}: Howeler et al., 2008). The site experiences distinct wet and dry seasons. As per the data from the Climatology Station of Karangkates Dam, East Java, Indonesia, the average (1998 to 2008) annual rainfall is about 1,800 mm with the rainy season from mid-November to early March. However, during period of our study, the experimental site received an unusual annual rainfall of 2,435 mm, which was distributed throughout the year. The average daily temperature was 28ºC and varied from 25ºC at night to about 32ºC in the afternoon.

Farm yard manure (FYM) biochar was produced from FYM collected from the farmers at Jatikerto village, Malang, Indonesia. It was sun-dried until the water content was about 15%. About 10 kg sun-dried FYM was put in a stainless steel heating drum of 50 cm height and 40 cm diameter, sealed, and heated on a simple brick stove with sawdust as the combusting material. During combustion, temperature of the materials in the drum reached up to 300ºC (range 240 to 300ºC) and biochar was harvested within 8–10 h. Cassava stem biochar was prepared from the unused stem of the previous cassava crops by the traditional method of autothermal combusting in a pit of about 1.5 x 1.5 x 1.0 m. Temperature recorded in this system varied from 200 to 370ºC, and the chars were harvested within 48h. The biochar from these processes was cooled, dried, and then ground to pass through 1.0 mm sieve to create the char for field application. The characteristics of FYM and biochar used in this study are presented in Table 1.

The experimental variables included two intercropping systems: cassava + maize and cassava + peanuts, with five organic amendments, i.e. FYM applied once at the start of the experiment, FYM applied every year, biochar from FYM, and biochar from cassava stem (CS), and without FYM as control. The treatment combinations were: (1) cassava + maize with FYM

Table 1. Characteristics of the farm yard manure (FYM), biochar made from FYM and biochar made from cassava stem.

Organic amendments	pH	C (g kg^{-1})	N (g kg^{-1})	P (g kg^{-1})	K (g kg^{-1})	CEC cmol
Farm yard manure (FYM)	6.5	192.8	14.3	3.9	4.2	–
FYM biochar	7.9	255.5	7.8	8.5	7.9	17.7
Cassava stem biochar	8.1	404.2	0.9	2.1	9.4	12.5

applied once at the start of the experiment, (2) cassava + maize with FYM applied every year (3) cassava + maize with FYM biochar, (4) cassava + maize with CS biochar (5) cassava + maize without organic amendment, (6) cassava + peanuts with FYM applied once at the start of the experiment, (7) cassava + peanuts with FYM applied every year, (8) cassava + peanuts with FYM biochar, (9) cassava + peanuts with CS biochar, and (10) cassava + peanuts without organic amendment. These treatments were arranged in a randomized block design with three replications in plots of size 6.25 x 6.0 m. The cassava cultivar used was 'Faroka', a high yielding bitter cassava; maize, and peanuts cultivars used were "Pioneer 2" and "Turangga" respectively. To ensure biological nitrogen fixation, peanut seeds were inoculated with *Rhizobium* obtained from Gajah Mada University, Yogyakarta, Indonesia. Cassava was planted at a spacing of 1.25 x 1.0 m without ridges, and the intercrops were planted in between the cassava rows at 1.25 x 0.30 m for maize and 0.40 x 0.30 m for peanuts. With this system there were five rows of cassava and maize with population of 30 plants per plot, and 15 rows of peanuts with a population of 260 plants per plot. After harvesting the intercrops, ridges were made for cassava.

Biochar was applied at a rate of 15 Mg ha^{-1} just once to the first crop. This rate was based on the experimental result of Chan et al. (2008), which showed that application of 10 to 20 Mg ha^{-1} had a significant effect on crop yields. FYM was applied at a rate of 20 Mg ha^{-1} to maintain equivalent amount of organic C (see Table 2). All treatments were fertilized with 400 kg urea (45% N) ha^{-1}, 100 kg SP36 (36% P_2O5) ha^{-1}, and 100 kg KCl (50% K_2O) ha^{-1}. SP36 is a commercial product of PT Petrokimia, Gresik, Indonesia with chemical formula $Ca(H_2PO_4)_2$. Fertilizers were applied on either sides of the cassava rows at a distance of about 25 cm from the cassava plant. All P and K fertilizers were applied at planting time, and N was applied in three splits: one-third at planting, one-third 30 days after planting, and the remaining one-third after the harvest of the intercrops.

Data on crop yield and soil properties before and at harvest of the second cassava crop were collected. Crop yield was obtained by harvesting all plants, except for the outer rows. The harvesting area for cassava, maize, and peanuts were 3.75 x 4.0 m; 3.75 x 5.4 m; and 4.8 x 5.4 m respectively. Yields of maize and peanuts were expressed on sun dry basis (water content of about 14 to 18%) and that of cassava was on fresh tuber yield basis. Four soil samples (to a depth of 20 cm) of about 0.5 kg each were collected in a zigzag pattern from each plot, mixed, and then a 0.5 kg composite sample of each was drawn for laboratory analysis. Soil pH was determined in H_2O (1:1) with a pH meter (Jenway 3305); soil organic carbon following the Walkley and Black method (Soil Survey Laboratory Staff, 1992), and total Nitrogen adopting the Kjeldahl method (Bremner and Mulvaney, 1982). Soil P was extracted with Bray II solution and its concentration measured with a spectrophotometer (Vitatron Scientific Instruments Dieren, the Netherlands). Exchangeable K was extracted with CH_3COONH_4 (I N; pH 7.0 and the concentration measured with AAS (Shimatzu *AA* 6800, Shimatzu Corp., Kyoto, Japan).

Undisturbed soil samples to a depth of about 10 to 15 cm (two from each plot) were taken for determining the available soil water content. Gravimetric soil moisture content was determined with a pressure plate apparatus at a matric potential, ψm, of –33 kPa (field capacity, FC) and –15 MPa (wilting point, WP) and the volumetric soil water content (θ) calculated by multiplying the gravimetric soil water content with soil bulk density. Available soil water content was obtained by subtracting volumetric content at FC with that at WP. Data on crop growth and yield were statistically analysed for each crop every year. With this approach, there were five treatments for maize and peanuts, and 10 treatments for cassava. ANOVA was used to determine the differences between treatments. Significant differences among the treatments were tested using LSD at 5% level.

Results and Discussion

Intercrop yields

Farm yard manure and biochar application increased the yield of maize intercropped with cassava (Table 2).

Table 2. Effect of organic amendments on maize and peanut yield in cassava based intercropping system at Jatikerto, Malang, Indonesia.

Treatments	Maize yield in cassava + maize system (Mg ha^{-1})		Peanut yield in cassava + peanuts system (Mg ha^{-1})	
	2009–10	2010–11	2009–10	2010–11
No organic amendments	3.06^{a}	2.73^{a}	1.01	0.71^{a}
FYM 20 Mg ha^{-1} once	3.62^{bc}	2.69^{a}	1.20	0.92^{ab}
FYM 20 Mg ha^{-1}) yearly	3.49^{ab}	4.06^{b}	1.19	1.32^{c}
FYM Biochar 15 Mg ha^{-1} once	4.06^{c}	4.13^{b}	1.08	1.09^{bc}
Cassava stem biochar 15 Mg ha^{-1} once	3.49^{ab}	3.60^{b}	1.06	0.98^{ab}

Means followed by the same letters in the same column are not significantly different (p=0.05); in treatments with organic manure addition once it was made in the first year.

During the first year of the experiment, maize without organic amendment produced 3.06 Mg ha^{-1}, which increased to 3.62 Mg ha^{-1} for 20 Mg ha^{-1} FYM treatment and to 4.06 Mg ha^{-1} for 15 Mg ha^{-1} FYM biochar. This yield increase could be a logical consequence of the soil fertility improvement resulting from organic matter application (Table 3). As can be seen from Table 3, the initial soil organic matter content was very low (9.5 g kg^{-1} C), however, the amendments increased soil organic matter, total N, available K, and available water holding capacity. During the second year of the trial, maize yield in the FYM treatment once at the start of the experiment decreased from 3.62 Mg ha^{-1} to 2.69 Mg ha^{-1}. This clearly suggests that the beneficial effect of FYM did not last beyond one crop cycle. To maintain sustained productivity, therefore, repeated annual additions of FYM may be necessary. The data presented in Table 2 also show that cassava stem biochar application did not significantly influence maize yield compared to treatments without organic amendment, presumably because of its low N content (Table 1). Nitrogen supplies from organic amendment thus may play an important role in increasing maize yield.

Yield of peanuts planted in cassava + peanuts intercropping system also was not significantly influenced by organic amendment application during the first year of experimentation (1.01 Mg ha^{-1} to 1.19 Mg ha^{-1}: Table 2). Peanuts, with the help of *Rhizobium* bacteria, can probably fulfil its own N requirement through atmospheric N fixation. However, continuous planting of intercrops in the cassava-based cropping system with FYM applied once decreased the maize and peanut yields (Table 2). It can be surmised that under the conditions of the wet tropical regions, organic C from FYM is mostly decomposed within one year of application. Higher maize productivity, however, could be maintained if FYM is applied regularly every year. Addition of biochar, on the other hand, could maintain higher maize and peanut yields over the succeeding years (Table 2). This is not surprising as organic C of biochar is more stable (Glaser et al., 2002) and the beneficial effect will last longer compared to conventional organic manure such as FYM.

Cassava yield

Application of FYM and biochar from FYM significantly increased the yield of cassava intercropped with peanuts (Fig. 1). Cassava intercropped with peanut produced significantly higher yield when FYM (21.66 Mg ha^{-1}) or biochar made from FYM (21.44 Mg ha^{-1}) were applied, compared to the productivity obtained without organic amendments (18.88 Mg ha^{-1}). The latter, however, was statistically at par with that of biochar from cassava stem (20.44 Mg ha^{-1}). Likewise, cassava + maize without organic amendment yielded 14.44 Mg ha^{-1} of cassava, which was not significantly different from that with organic amendments. Figure 1 also shows that with the same organic amendments, yield of cassava intercropped with maize was significantly lower than that of cassava + peanuts. This is reasonable because there will be less competition for cassava intercropped with peanuts compared to that with maize, both for light and plant nutrients.

Planting cassava + maize without organic amendment or with FYM applied in the first year decreased cassava yield (Fig. 1) during the second year of experimentation. Such reductions in crop yield, however, could be avoided if FYM (every year) or biochar applications are made. Comparing the two cropping systems, the inter annual differences in cassava yields were also more in cassava + maize compared to cassava + peanuts, implying the potential for site quality deterioration in the former. Biochar application, however, could sustain cassava productivity in such situations. For cassava intercropped with peanuts the yield was relatively stable at about 18 Mg ha^{-1} (even without organic amendments), which increased to 21 (FYM applied once) in the second year, implying the beneficial effects of N fixation by peanuts. If FYM was applied at every planting season, cassava yield further increased to 24.80 Mg ha^{-1}, which was significantly higher than the other treatments.

Soil properties

Soil organic C, N, available P, CEC, exchangeable K and soil water availability in the soil treated with biochar were higher compared to untreated soil and that before experiment (Table 3). To maintain soil organic C, however, application of FYM every planting season was necessary, implying that organic C from FYM has mostly decomposed within one year. Conversely, organic C of biochar was still relatively stable at least until the harvesting of the second year cassava, presumably because of to the presence of certain aromatic compounds (Glasser et al., 2002; Liang et al., 2006), signifying a higher soil carbon sequestration potential for biochar over that of conventional organic manures.

The higher CEC in soils applied with biocahar and FYM (applied yearly) could be explained due to the high surface negative charge resulting from oxidation of carboxylic and phenolic groups of biochar (Liang et al. 2006). CEC of the soil treated with FYM applied once in the first year cassava, on the other hand, did not differ

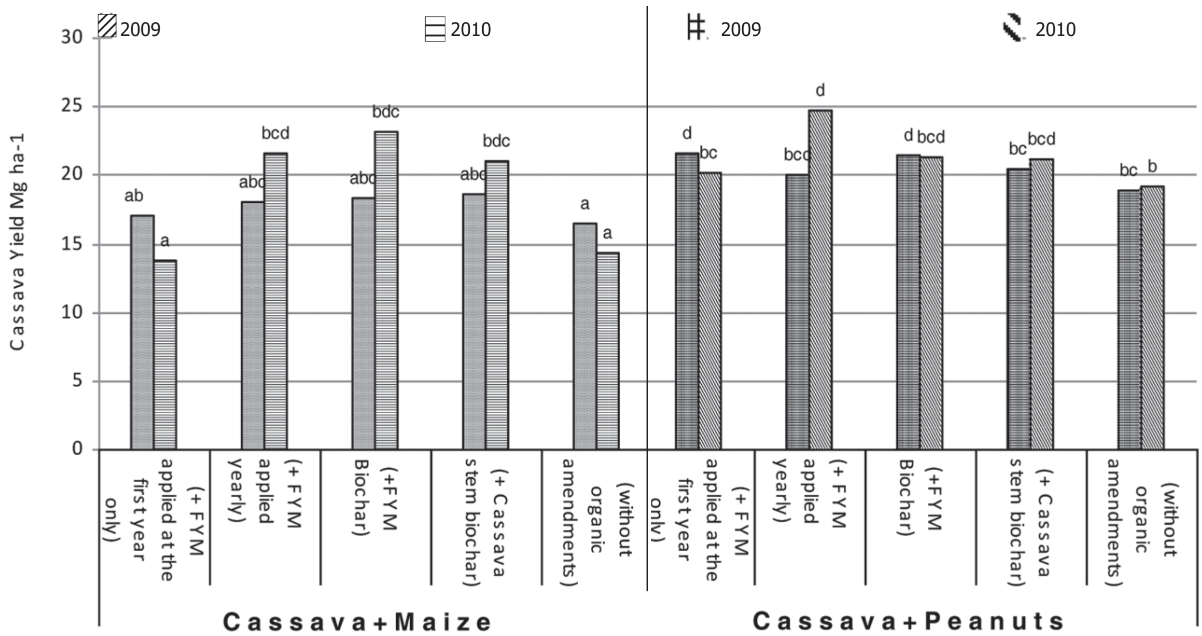

Figure 1. Effect of organic amendment on cassava yield intercropped with maize and peanuts System at Jatikerto, Malang Indonesia. Means followed by the same letter for the same year is not significantly different (p=0.05).

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 ($mg\ kg^{-1}$)	CEC cmol	K cmol	Available water (%)
Before experiment	9.5^{a}	0.8^{a}	11.1	15.64^{a}	1.56^{ab}	15.56^{a}
Cassava + maize (20 Mg ha^{-1} FYM once)	11.2^{abc}	1.2^{bc}	12.4	14.78^{a}	1.58^{abc}	16.22^{ab}
Cassava + maize (20 Mg ha^{-1} FYM yearly)	19.7^{abcd}	1.4^{c}	11.8	17.68^{bc}	1.76^{bc}	17.24^{b}
Cassava + maize (15 Mg ha^{-1} FYM biochar once)	25.2^{d}	1.4^{c}	12.1	18.32^{c}	1.64^{abc}	17.15^{b}
Cassava + maize (15 Mg ha^{-1} cassava stem biochar once)	25.8^{d}	1.2^{bc}	11.6	17.64^{bc}	1.78^{c}	16.88^{b}
Cassava + maize (without organic amendments)	10.5^{ab}	1.1^{b}	11.6	15.16^{ab}	1.62^{abc}	15.67^{ab}
Cassava + peanuts (20 Mg ha^{-1} FYM once)	21.8^{abcd}	1.4^{b}	10.9	15.27^{abc}	1.56^{ab}	15.72^{ab}
Cassava + peanuts (20 Mg ha^{-1} FYM applied yearly)	23.3^{bcd}	1.4^{c}	11.1	16.73^{abc}	1.71^{bc}	16.76^{b}
Cassava + peanuts (15 Mg ha^{-1} FYM biochar once)	24.5^{cd}	1.3^{bc}	12.3	17.94^{bc}	1.75^{bc}	17.42^{b}
Cassava + peanuts (15 Mg ha^{-1} cassava stem biochar once)	20.3^{abcd}	1.2^{bc}	11.8	17.35^{abc}	1.77^{c}	17.96^{b}
Cassava + peanuts (without organic amendments)	10.3^{ab}	1.2^{b}	11.8	14.87^{ab}	1.49^{a}	14.37^{a}

Means followed by the same letters in the same column are not significantly different (p=0.05); in treatments with organic manure addition once it was made in the first year.

significantly either with no organic matter application or with that before the experiment (Table 3). Overall, our results show that application of inorganic fertilizers alone could not sustain inter crop productivity in cassava based cropping system in the marginal or degraded soil of Jatikerto, Malang, Indonesia. It is, therefore, essential to apply organic amendments both for improving soil fertility status, and stable crop yields. If FYM is used for soil amendment, it should be applied every planting season. The stability of organic C from FYM, however, can be increased by processing it as biochar, which is more recalcitrant. Cassava stem also is a potential feedstuff for biochar production. Converting conventional organic materials to biochar would increase production cost, however. Nonetheless, since the beneficial effects of biochar may last for a longer period, it will be advantageous.

Acknowledgements

The research was partly funded by Directorate of Higher Education, The Ministry of Indonesian National Education through Research Grant for PhD Studies Scheme. Thanks to the reviewers for their valuable comments.

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