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Maize Yield and Associated Soil Quality Changes in Cassava + Maize intercropping Syste After 3 Years of Biochar Application

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ABSTRACT

Field experiments were carried out to study the effects of biochar on Maize (*Zea mays* L) yield and the associated soil quality changes in the degraded uplands of East Java, Indonesia from September 2009 to October 2011. The experimental treatments consisting of two cropping system, namely: 1) maize intercropped with cassava (*Manihot esculenta* Cranz), 2) maize monoculture; and 3 treatments of organic amendments, i.e: 1) without organic amendment, 2) farm yard manure (FYM), 3) biochar from FYM. The addition of FYM and FYM biochar improved soil quality and maize and cassava yield as well as the land use efficiency. The highest yield in maize+cassava intercropping was obtained by FYM treatment (4.06 Mg ha^{-1}), whereas for the monoculture maize was obtained by FYM treated maize (4.56 Mg ha^{-1}). The highest LER was obtained by maize + cassava intercropping treated with FYM biochar, i.e. 1.59 for the first year panting and increased to 1.78 in the second year planting. The beneficial effect of FYM lasted for a year, whereas that of treated with biochar was still exist until the harvesting of the third year maize.

Key words: Organic amendments; farm yard manure; soil organic-C; yield stability

INTRODUCTION

In Indonesia, maize is the most important food crops after rice, however the average yield is very low, i.e. 4.9 Mg ha^{-1} (1), this is far below the potential yield of about 8 Mg ha^{-1}. One of the reason for this low yield because mostly maize is planted on upland soil with low soil fertility status due to low soil organic matter content. As a consequence of this low soil organic matter, the soil usually has a low nitrogen and phosphor content.

The common treatment to increase the fertility and productivity of these soils is to increase soil organic matter by adding organic manure, such as compost or farm yard manure. However, it is now understood that this practice possess some limitations, one of them is that under wet tropical condition, ithese organic manure are undergo a rapid decomposition so that the organic manure should be added every year (2). Rapid decomposition of organic manure has also attributed as one as the major contributor of global warming gas (3). To overcome this problems, some workers, e.g. Lehman et al. (4) suggested to use the more recalcitrance organic matter resources such as Biochar.

The beneficial effects of biochar in improving soil properties have been shown by many workers, these includes soil organic C (3,4,5); CEC (3,6,7) and some soil physical properties (3,7). The increase in crop yield with biochar application has been reported occurred on many crops, these include: cowpea (8), soybean (9), Cassava (10), and upland rice (11). Although biochar application on maize has also been studied by many workers (8, 12,), it seems there is no study has been done for maize planted in intercropping system with cassava. Yamato et al. (8) and Rodríguez et al. (12) studied the effect of biochar on maize grown on acid soil, and Sukartono (6) on sandy soil, all are for monoculture maize

The objective of the experiment described here was to study the effect of biochar on the yield and land use efficiency of maize grown in intercropping system with cassava The study was also investigated the soil quality changes with application of biochar. The beneficial FYM biochar application was compared with the conventional farm yard manure. With the recalcitrant properties of C-organic in biochar, it was expected that in the future biochar sould be use as the base of soil organic management in maize + cassava intercropping system.

2. MATERIALS AND METHODS

The experiment was done on Brawijaya Experimental Field Station at Jatikerto, Malang, Indonesia (08º03' S, 112º30' E; 228 m above sea level). The soil of the experimental site belongs to Inceptisols with an effective depth of about 25 cm. Some properties of the soil are presented in Table 1.

The experiment was started on September 2009 and the third maize was harvested on October 2011. Usually the experimaent station has a distinct wet and dry seasons, with rainy season starting from September and ended in April the following year. From the data of the Climatology Station of Karangkates Dam, East Java, Indonesia, the average (1998 to 2008) annual rainfall is about 1,800 mm. However, during period of the study the experimental site received an unusual annual rainfall of 2,435 mm, which was distributed throughout the year. The average daily temperature was 28^{o}C and varied from 25^{o}C at night to about 32^{o}C in the afternoon.

The treatments tested in these experiments consisted of 2 cropping system and 3 organic amendments application. The two cropping studied were two: (1) maize intercropped with cassava, and (2) monoculture maize monoculture. The organic amendments treatments were: (1) without organic amendments, (2) farm yard manure (FYM), and (3) biochar from FYM. These treatments were arranged in a randomized block design with three replications in plots of size 6.25 x 6.0 m.

Farm yard manure (FYM) was collected from farmers at Jatikerto village, Malang, Indonesia. To make biocahr, the FYM was sun dried until reaching water content at about 15%.

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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 fuel as the combusting material. With this combustion, temperature of the materials in the drum reached up to 300°C (range 240 -300°C) and biochar was harvested within 8-10 h. The characteristics of FYM and biochar used in this study are presented in Table 1.

Table 1. Characteristics of the soil, farm yard manure (FYM), FYM biochar used in the experiment

Soil/Organic amendments	pH	C %	N %	P %	K %	CEC cmol
Farm yard manure (FYM)	6.5	19.28	1.43	0.39	0.42	-
FYM biochar	7.9	25.55	0.78	0.82	0.79	17.7
Soil	6.4	0.95	0.09	2.1*)	1.56*)	12.5

*) P and K in the soil is expressed in ppm and cmol kg^{-1}

The maize cultivar planted in this experiment was "Pioneer", a hybrid cultivar, and cassava cultivar used was 'Faroka', a high yielding bitter cassava. Cassava was planted at a spacing of 1.25 x 1.0 m without ridges, and the maize intercrop was planted in between the cassava rows at 1.25 x 0.30 m. With this system there were 5 rows of cassava and maize with population of 30 plants/plot. The monoculture maize was planted at a distance of 0.75 x 0.30 m, and hence there 8 rows of maize.
The rate of biochar was determined based on the study of Chan et al. (7) which showed that application of 10-20 Mg ha^{-1} already had a significant effect on the crop yield. Hence biochar was applied at a rate of 15 Mg ha^{-1}, and to obtain the same amount of organic C (see Table 2), then FYM was applied at a rate of 20 Mg ha^{-1}. All treatments were given 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 $Ca(H_2PO_4)_2$. For the intercropping system, fertilizers were applied on either side of the cassava rows at a distance of about 25 cm from cassava plant. The same practice was done for monoculture maize. 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 one third after harvesting the maize intercrop.
The data collected include crop yield, both maize and cassava, soil properties before the experiment and soil properties after harvesting the first crops (maize and cassava), the second crops (maize and cassava), and the third maize. Crop yield was obtained by harvesting all plants, except for the outer rows. The yield of maize was calculated based on the sun dry weight (water content of about 14 – 18%), and the yield of cassava was on fresh tuber yield based.
Soil samples were taken to a depth of about 20 cm, and sampling was done following a zigzag system (4 sub-samples from each plot), mixed, and then a 0.5 kg composite sample of each was processed for laboratory analysis. Soil pH (H_2O,1:1) was read with a pH meter (Jenway 3305); the Walkley and Black method (13) employed for soil organic carbon determination; and total Nitrogen was determined with the Kjeldahl method (14). Available P was extracted with Bray II solution and then the P concentration in the solution was measured with spectrophotometer (Vitatron Scientific Instruments Dieren, the Netherlands). CEC and Exchangeable K was extracted with CH_3COONH_4 (I N; pH 7.0 and the concentration was read with AAS (Shimatzu *AA* 6800, Shimatzu Corp., Kyoto, Japan). Soil bulk density was determined by using undisturbed soil sample, and soil aggregation was measured according to the method of Yoder (15).

Statistical analysis was done for each crop for each year, and for Land Equivalent Ratio (LER). LER was calculated by equation (1):

$$LER = RY_1 + RY_2 \quad (1)$$

In which RY_1 is relative yield of maize, i.e. the yield ratio of maize intercrop to the monoculture maize; and RY_2 is the relative yield of cassava, i.e. the yield ratio of cassava intercrop to the monoculture monoculture cassava.
ANOVA was conducted to determine the differences between treatments. Significant differences among the treatments were tested using LSD at 5% level.

RESULTS AND DISCUSSION

The experimental results presented in Table 2 show that in all year of planting, maize yield was influenced by cropping system and organic amendments. In the first year organic amendments application increased maize yield, both in maize intercropped with cassava and maize monoculture. The increase in maize yield with organic amendments was thought partly due to the addition of plant nutrient, and partly due to improvement of soil properties (see Table 4 and 5). The highest yield (4.56 Mg ha^{-1} was obtained by maize monoculture with FYM treatment. However, its beneficial effect only lasted for one year. In the second and third year, the yield of decreased steadily and did not significantly different with maize monoculture without organic amendment maize.
Furthermore, the results in Table 2 also show that the yield of No-organic amendments and FYM maize, both in cassava+maize and maize monoculture decreased with year of planting. These results indicated that at Jatikerto soil, sustainable maize yield could not achieved by inorganic chemical only. The same phenomenon was observed for maize yield applied with FYM. The lower yield of FYM treated maize in the second and third year indicated that the FYM applied was almost completely decomposed, so that its positive effects diminished. With its recalcitrant properties (4,6), biochar is more resistant to be decomposed and hence its beneficial effects continued till the third year maize.
The effect of organic amendments application on cassava yield, both in the intercropping and monoculture system is presented in Table 3. In the first year cassava, application of FYM and FYM biochar increased cassava yield. However, it was not the case for the second year cassava. In both cropping system the second year yield of No-OM and FYM applied cassava was much lower compared to the first year yield. Thus, either with chemical fertilizers only or chemical fertilizers+FYM application, the soil could not cot stabilized cassava yield in both cropping system.

Table 2. Effect of organic amendments on the yield of maize intercropped with cassava and monoculture maize

Treatments		Maize yield (Mg ha^{-1})		
		2009	2010	2011
Maize+cassava	No-OM	3.06 a A	2.73 a B	2.06 a C
Maize+cassava	FYM	3.62 bc A	2.69 a B	2.15 a C
Maize+cssava	FYM biochar	4.06 c A	4.13 c A	3.89 c A
Maize monoculture	No-OM	4.09 cd A	3.62 b B	3.06 b C
Maize monoculture	FYM	4.56 d A	3.87 bc B	3.19 b C
Maize monoculture	FYM biochar	4.17 d A	3.99 bc B	4.06 c C

1) means followed by the same letters in the same column and/or row are not significantly different (p=0.05). The lowercase letters were used to differentiate between treatments, and the capital letters were used to differentiate between years of planting.

Different phenomena were observed for cassava treated with biochar. In the first year, the yield in monoculture of this treatment was lower compared to FYM treated cassava. However, the second year yield of biochar treated cassava was relatively constant and much higher compared to that of FYM cassava. Again, this result indicated the recalcitrant organic –C in biochar as has been suggested by many workers (4,6).
It is interesting to study the sustainability with land use efficiency. Land use efficiency was expressed as Land Equivalent Ratio (LER) which was calculated based on equation (1) with the yield of the no-organic amendments maize and cassava monoculture in the first year as the base of calculation. The results in Table 3 show that intercropping of maize and cassava applied with biochar was not only possessed the highest LER, but LER increased with time (from 1.59 in the first year to 1.78 in the second year. It seems that the addition of organic-C and some plant nutrient maize biomass in intercropping system affected the second year crops. Based on these results, in order to obtain sustainable production, the practice of cassava + maize intercropping system applied with biochar, especially that of made from farm yard manure, was highly recommended

Table 3 Land Equivalent Ratio (LER) of cassava + maize intercropping, as inluenced by organic amendments application.

Treatments	1st year			2nd year		
	maize yield Mg ha-1	cassava yield Mg ha-1	total LER	maize yield Mg ha-1	cassava yield Mg ha-1	total LER
Cassava+maize No-OM	3.06 a	16.44 a	1.28 bc	2.73 a	14.40 a	1.12 b
Cassava+maize FYM	3.62 bc	17.70 ab	1.46 cd	2.69 a	13.73 a	1.10 b
Cassava+maize biochar	4.06 c	18.33 b	1.59 d	4.13 c	23.20 b	1.78 c
Cassava No-OM	-	30.67 c	1.00 a	-	22.35 a	0.72 a
Cassava FYM	-	34.48 d	1.12 ab	-	25.85 a	0.84 ab
Cassava biochar	-	32.66 cd	1.06 ab	-	32.06 b	1.04 b
Maize No- OM	4.09 c	-	1.00 a	3.62 b	-	0.86 ab
Maize FYM	4.56 d	-	1.15 ab	3.87 bc	-	0.94 ab
Maize biochar	4.17 cd	-	1.02 a	3.99 c	-	0.98 ab

1) means followed by the same letters in the same column are not significantly different (p=0.05).

Biochar application improved some soil chemical properties (Table 4) and some soil physical properties (Table 5). The result in Table 4 show that biochar and FYM increase soil organic-C, N, P and CEC. However, in third year maize these amendments only influenced soil organic-C and CEC, but organic-C of FYM soil treated was much lower compared to that of the same treatment at the first year maize. This result supported the hypothesis that organic-C from FYM was mostly already decomposed during the first year planting year.

Table 4 Effect of biochar application on some soil chemical properties after harvesting the first and third maize on various cropping system

Treatments	Chemical properties after the first maize (2009)					Chemical properties after the third maize (2010)				
	C (%)	N (%)	P (ppm)	CEC (cmol)	K (cmol)	C (%)	N (%)	P (ppm)	CEC (cmol)	K (cmol)
Cassava+maize No-OM	1.04 a	0.10 a	11.56 b	15.15 a	1.52	0.91 a	0.08	11.64	14.73 a	1.44
Cassava+maize FYM	1.91 b	0.11 ab	12.45 d	14.74 a	1.59	1.40 a	0.09	12.12	16.92 abc	1.62
Cassava+maize biochar	2.53 c	0.12 ab	12.35 d	18.30 b	1.76	2.55 b	0.10	12.20	18.64 c	1.70
Cassava monoculture NoOM	0.99 a	0.09 a	10.95 abc	14.76 a	1.49	0.90 a	0.09	10.47	14.35 a	1.47
Cassava monoculture FYM	2.04 b	0.10 a	12.50 d	14.78 a	1.56	1.12 a	0.09	11.12	14.02 a	1.58
Cassava monoculture FYM biochar	2.55 d	0.13 b	12.16 cd	18.40 b	1.66	2.50 b	0.10	12.22	18.08 c	1.64
Maize monoculture NoOM	0.95 a	0.09 a	10.90 ab	14.73 a	1.55	0.92 a	0.09	10.42	14.25 a	1.48
Maize monoculture FYM	1.96 bc	0.10 a	12.55 d	14.84 a	1.60	1.20 a	0.09	11.14	14.92 ab	1.60
Maize monoculture biochar	2.61 d	0.12 ab	12.20 cd	18.39 b	1.64	2.55 b	0.10	12.22	17.59 b	1.66

1) means followed by the same letters in the same column are not significantly different (p=0.05).

Table 5 Effect of biochar application on some soil physical properties after harvesting the first and third maize on various cropping system.

Treatments	Physical properties after the first maize (2009)			Physical properties after the third maize (2010)		
	Bulk density (Mg m^{-3})	Porosity (%)	Mean weight diameter (mm)	Bulk density (Mg m^{-3})	Porosity (%)	Mean weight diameter (mm)
Cassava+maize No-OM	1.21 d	54,34	1.95 a	1.20 b	54.72	1.75 a
Cassava+maize FYM	1.12 a	57.74	2.56 b	1.16 ab	56.33	2.30 b
Cassava+maize FYM biochar	1.12 a	57.74	2.62 b	1.12 a	57.74	2.62 b
Cassava monoculture No-OM	1.20 cd	54.72	1.75 a	1.22 c	53.97	1.75 a
Cassava monoculture FYM	1.18 bc	55.48	2.78 b	1.22 c	53.97	2.78 b
Cassava monoculture FYM biochar	1.15 ab	56.61	2.45 b	1.16 a	56.33	2.45 b
Maize monoculture No-OM	1.19 bcd	55.10	1.68 a	1.22 c	53.97	1.68 a
Maize monoculture FYM	1.16 abc	56.33	2.75 b	1.21 bc	54.34	2.75 b
Maize monoculture FYM biochar	1.16 abc	56.33	2.69 b	1.14 a	56.99	2.69 b

1) means followed by the same letters in the same column are not significantly different (p=0.05).

The results in Table 5 show that application of both FYM and FYM-biochar decreased soil bulk density and increase aggregation, but after harvesting the third year maize the positive effect of FYM on soil bulk density diminished. The increase in soil aggregation with organic amendments was a logic consequence of increasing soil organic-C (Table 4), and to some extend might be due to the increasing soil micro-organism as suggested by Chan et al. (7)

CONCLUSION

The addition of FYM and FYM biochar improved soil quality and maize and cassava yield as well as the land use efficiency. The highest yield in maize+cassava intercropping was obtained by FYM treatment (4.06 Mg ha^{-1}), whereas for the monoculture maize was obtained by FYM treated maize (4.56 Mg ha^{-1}). The highest LER was obtained by maize + cassava intercropping treated with FYM biochar, i.e. 1.59 for the first year panting and increased to 1.78 in the second year planting. The beneficial effect of FYM lasted for a year, whereas that of treated with biochar was still exist until the harvesting of the third year maize.

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