The Effect of Biochar on the Growth and N Fertilizer Requirement of Maize (*Zea mays* L.) in Green House Experiment

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Abstract

Greenhouse experiments were carried out to study the effect of biochar and other organic amendment (Chicken Manure, CM; and City waste compost, CW) using on the growth and N fertilizer requirement of maize. The first experiment was carried out to study the effect of biochar application to maize growth, and then continued to study the residual effect of biochar. The second experiment was carried out to study the effect of biochar application on nitrogen fertilizer requirement. The results show that the first season of maize biomass of organic amendment of treated soils did not significantly different from no organic amendment. However, organic amendment improved soil fertility status, especially increasing C-organic, N, K and CEC. The biomass of the second season maize of biochar of treated soil was higher compared to the other treatments. The second experiment shows that biochar application decreased N fertilizer requirement. To produce 3.23 Mg ha^{-1} biomass, it required 90 kg ha^{-1} N for 15 Mg ha^{-1} CM biochar treated soil, and 160 kg ha^{-1} for the non treated soil.

Keywords: Chicken manure, Poultry litter, Compost, Nitrogen efficiency, Organic amendments

1. Introduction

Since green revolution, it seems that application of inorganic fertilizer is hardly avoided in increasing crop production. The advantage of inorganic fertilizers, indeed, has been proven widely to have very spectacular results. It is able to make the production doubled, or even tripled compared to world crop production. However, the phenomena of decreasing soil quality, on the other hand to obtain the same yield, the rate of inorganic fertilizer application steadily increases from year to year. The application of chemical fertilizer is not also capable of maintaining yield increase (Islami *et al.*, 2011). In line with that, it has been widely realized that application of excessive inorganic fertilizer, especially nitrogen, causes soil deterioration and many environmental problems (Haynes & Naidu, 1998; Liu *et al.*, 2010; Vitosuek *et al.*, 1997).

The common technology for increasing fertilizer efficiency is integrated crop management which includes the application of organic manure and other organic materials to soil (Fageria & Baligar, 2005). However, it is known that under wet tropical condition, organic materials put into the soil will be decomposed very rapidly. It makes addition of organic materials will be done in a very high dosage and repeated yearly. In addition, to make higher cost of organic materials application, it is now realized that the rapid decomposition and mineralization of organic materials have a significant contribution to global warming (Jenkinson *et al.*, 1991).

By realizing those problems; some previous researchers try to use the more resistant organic matter such as "char" as the sources of soil organic materials applied to soil (Lehman *et al.*, 2003). This material, which is known as "agrichar" or more commonly term "biochar" has been proven to have the same positive as the organic manure or other organic materials as a soil amendment (Wolf *et al*., 2008). A lot of works have shown that biochar is able to improve soil properties, included soil pH, and CEC (Chan *et al.*, 2008; Masulili *et al.*, 2010), soil aggregation, soil water holding capacity and soil strength (Chan *et al.*, 2008), and to increase soil biology population and activity (Rondon *et al.*, 2007) . Observation of Steiner *et al*. (2007) indicates that in the long term, application of biochar increases plant nutrient availability and soil productivity. Increasing of crop yield with biochar application has been shown by Islami *et al*., (2011a), Sukartono *et al*., (2011) and Yamato *et al.,* (2004) for maize (*Zea mays* L.); Tagoe *et al*., (2008) for soybean (*Glicine max* (L) Merr.); and Islami *et al.,* (2011b) for cassava (*Manihot esculenta* Cranz).

One of the reasons for increasing crop yield with biochar application is the increasing of nitrogen utilization from the applied fertilizer (Steiner *et al.*, 2007; Widowati *et al.*, 2011). This is as the result from the decrease of nitrogen lost due the increase of soil CEC with biochar application (Chan *et al.*, 2008; Masulili *et al.*, 2010) or because of the biochar ability to inhibit N-NO3 transformation from N-NH4 released by fertilizer (Widowati *et al.*, 2011). The experiment reported here is aimed to know the possibility of decreasing nitrogen fertilizer requirement of maize with biochar application. The hypothesis behind this study is "if there is decrease in nitrogen loss due biochar application, then there is less nitrogen requirement to produce the same yield with that of obtained by the soil with no biochar application".

2. Materials and Methods

The experiments were carried out in the green house of Tribhuwana Tunggadewi University, Malang, Indonesia (7^o.48'.50" South and 112^o.37'41" East). During the experimental period the daily temperature varied from about $16^oC – 36^o$ C with relative humidity of about 43-86 %, and light intensity of 365-1997 lux).

Biochar was prepared by pyrolysis method as described by Masulili *et al*. (2010) with chicken manure and city waste as the feedstuffs. The chicken manure, consisted of sawdust materials and chicken manure, was collected from P.T. Charoen Pokhand Poultry enterprises and the city waste, consisted of plant materials and other organic waste, was collected from city waste collector of Malang city, Indonesia. These materials were sun dried to reach water content of about 17 % and then heated in the pyrolysis reactor at temperature of 500^o C for 2 hours 30 minutes for poultry litter (then it was called as chicken manure, CM, biochar) and 2 hours 5 minutes for city waste (then it was called as city waste, CW, biochar).

Biochar characteristics were analyzed by the method as described by Masulili *et al*. (2010). The characteristics of these biochars, together with their feedstuffs poultry litter and city waste, and the soil used for experiment are presented in Table 1.

<Table 1>

The studies consisted of two experiments; the first experiment was aimed to study the effect of biochar on maize growth, nitrogen absorption and soil nitrogen content after maize harvesting, and the second experiment was carried out to study the effect of biochar application on nitrogen fertilizer requirement. The treatments of the first experiment were: (1) control (without nitrogen fertilizer and without organic amendment), (2) 145 kg ha^{-1} N without organic amendment (N -No OM), (3) 145 kg ha^{-1} N with addition of 50 Mg ha^{-1}chicken manure (N+CM), (4) 145 kg ha^{-1} N with addition of 50 Mg ha^{-1} city waste compost (N+CW compost), (5) 145 kg ha^{-1} N with addition of 30 Mg ha^{-1} chicken manure biochar (N+CM biochar), (6) 145 kg ha^{-1} N with addition of 30 Mg ha^{-1} city waste biochar (N+CW biochar). All treatments were fertilized with 50 kg ha^{-1} P_2O_5 and 50 kg ha^{-1} K_2O. Biochar and fertilizer rate were calculated based on area of plastic poly bag used for growing the maize, and these 6 treatments were arranged in Completely Randomized Design with 4 replications and plant distance of 0.5 m X 0.5 m. The maize was planted on 5 June 2010 and harvested on 10 August 2010. To study the residual effect of biochar application, the second maize was grown on 5 September 2010 and harvested on 10 November 2010.

The treatments for the second experiment consisted of 5 levels on nitrogen fertilizer (0; 45; 90, 135 and 180 kg ha^{-1} N), and 4 levels of CM biochar (0; 15; 30 and 60 Mg ha^{-1}). These 20 treatment combinations were arranged in Completely Randomized Design with 3 replications. The maize was planted on 5 December 2010 and harvested on 10 February 2011.

The plastic poly bag of about 45 kg capacity with surface diameter of about 30 cm was filled with about 37 kg air dried soil, then biochar was applied and mixed to a depth of about 20 cm, after which it was watered to about field capacity and incubated for 7 days. Two seeds of maize, Bisma cv, were planted in each plastic poly bag, and after 2 weeks the maize was thinned left 1 plant/poly bag. All P, K and 1/3 N rate fertilizers were applied at the planting date, and 2/3 of N rate was applied at 30 days after planting. The maize was watered every 3 days to water content of field capacity, and it was harvested at the end of vegetative growth (65 days).

The data collected were: plant height, stem diameter, dry biomass, root length, nitrogen absorption, and soil properties which include organic C content, nitrogen content, and Cation Exchange Capacity (CEC). Plant height was measured from the soil surface to the highest part of the plant. Dry biomass determination was done by cutting above ground plant, and after which the plant was oven dried at temperature of 80^{o} C until it reached constant weight). Root length determination was done by measured all root with the methods of mapping.

Total plant nitrogen was extracted with wet sulfuric acid digestion (Horneck & Miller, 1998) and the nitrogen content in the sample was determined by Kjeldahl method. Then the efficiency of nitrogen fertilization was calculated by equation:

$$F_{eff} = \frac{\text{N absorption of the desired maize treatment} - \text{N absorption of maize the control}}{\text{Applied N}} \times 100\ \%$$

Soil organic C content was determined by Walkley and Black wet oxidation method (Soil Survey Laboratory Staff, 1992), nitrogen by Kjeldahl method (Bremner and Mulvaeny, 1982), and CEC was extracted by 1M NH_4Oac (buffered at pH 7.0), and exchangeable bases in the solutions were measured using AAS (Shimatzu). Available P was determined by Bray 1 solution.

ANOVA was used for analyzing the data, and if there was significant different, further analysis was done with LSD 5%.

3. Results and Discussion

Nitrogen application, both with and without organic amendment addition, improved plant growth by increasing plant height, stem diameter, root length and dry biomass of maize harvested at the end of vegetative growth (Table 2). Compared to N application only, addition of organic amendments increased root length, but did not significantly influence, plant height, stem diameter, and dry biomass. The same phenomenon was found for total nitrogen absorption. This result indicated the main limiting factors to increase biomass yield in the soil used for the study was nitrogen. Addition of 135 kg ha^{-1} N was enough to produce maize dry biomass of about 3 Mg ha^{-1}. Therefore, any addition of plant nutrient from organic amendments (Table 3; see also Widowati *et al*., 2011) did not improve (compared to N treatment) maize growth. The increase in root length with organic matter amendments was probably due the improvement of some soil physical properties, as has been suggested by Chan *et al.* (2008).

<Table 2>

Nitrogen application increased nitrogen absorption (Table 2). Addition of organic amendment to this applied maize nitrogen did not significantly influence nitrogen absorption. The absorption of nitrogen of fertilized maize crops varies from 62.45 kg ha^{-1} (nitrogen applied only) to 67.50 kg ha^{-1} (N + chicken manure) with the nitrogen absorption of 33.07 kg ha^{-1} for the control treatment (No N No OM).

The result (Table 2) shows that the highest fertilizer efficiency was (25.50 %) obtained by CM treatment. This figure does not necessarily reflect the real efficiency of CM treatment; because in this treatment the soil would get a higher nitrogen addition from the manure (see Table 1).

From biomass yield point of view, the growth of the second maize in the soil treated with biochar was better than the N treated soil (No OM). The result presented in Table 3 shows that the soil treated with biochar produced dry biomass of 3.34 Mg ha^{-1} (CM biochar) and 3.30 Mg ha^{-1} (CW biochar) which were significantly higher than maize biomass produced by N-No OM (2.39 Mg ha^{-1}). The second maize biomass produced by CM and CW compost treated soil, on the other hand, did not significantly different from maize biomass produced by N-No OM treated soil. This result indicated that there was a significant residual effect of biochar on the second maize growth, but not with CM and CW compost. Looking from soil properties (Table 4), this growth improvement could be explained from the higher nutrient availability in biochar treated soil, especially N and K.

<Table 3>

The higher nitrogen in organic amendment treated soil (compared to that of in the N only treated soil and the control) could originated from the nitrogen in the material it self (see Table 1), and to some extent caused by a lower of nitrogen leaching due increasing of soil cation exchange capacity (e.g. Masulili *et al*., 2010; Liang *et al.*, 2007), which in turn it would decrease plant nutrient lost (especially N-NH_4^+ and K^+). The further increase in soil nitrogen content in the biochar treated soil could be originated from retardation of N-NH_4^+ to N-NO_3^- transformation in biochar treated soil (Widowati *et al.,* 2011) which will further lowered nitrogen leaching.

The results in Table 3 also shows that soil organic-C in biochar treated soils were higher compared to chicken manure and city waste compost. This result indicated that biochar is organic material that resistant to decomposition as suggested by the previous workers (e.g. Lehman *et al.*, 2003; Chan *et al*., 2008). Furthermore, the data in Table 4 show that amendment application increased available P, exchangeable K, CEC and soil porosity at the harvesting of the first maize, but did not influence soil aggregation. The increase in soil P and K was thought originated from the P and K in material itself (Table 1), and the increase of CEC could be explained from phenolic and carboxyl groups in the organic amendment. After harvesting the second maize, organic C of CM treated soil did not significantly different from the control or N-No OM treated soils. This result indicated that Chicken Manure almost completely decomposed during this study (2 maize growing seasons). The biochar treated soils, on the other hand, had a significantly higher C-organic compared to other treatments. The biochar treated soils also possessed a higher N, exchangeable K and CEC.

<Table 4>

The result presented in Table 5 show that there was an interaction between biochar and nitrogen fertilization to maize biomass yield. Application of biochar without nitrogen fertilizer increased biomass yield from 1.81 Mg ha^{-1} (without biochar) to 2.75 Mg ha^{-1} (60 Mg ha^{-1} biochar). This increase could be come from the addition of plant nutrient from CM biochar, The data presented in Table 1 show that N-total in CM biochar is 1.9%, hence with 60 Mg ha^{-1} CM biochar, there would be an addition of about 190 kg ha^{-1} N. It is understood that not all of these nitrogen are in the form of available nitrogen, but surely some of these nitrogen could be used for maize growth. The highest maize biomass was about 3.30 Mg ha^{-1}, which obtained by 90 kg ha^{-1} N application on the 15 Mg ha^{-1} CM biochar treated soil. If the soil was not treated with CM biochar, this biomass yield was obtained by 180 kg ha^{-1} N application. Thus application of CM biochar reduced nitrogen fertilizer requirement of maize. The reduction of nitrogen in this study would, partly come from the addition on N from CM biochar (see Table 1), and to some extend the decrease of nitrogen lost with biochar application (Widowati *et al.*, 2011).

<Table 5>

To calculate the nitrogen requirement at any biochar rate, the data in Table 5 was analyzed with surface curve response, and the resulted equation is (see also Fig. 1):

$$Y = 1{,}691 + 0{,}0192\ N + 0{,}0273\ B - 0{,}000060\ N^2 - 0{,}000205\ B^2 - 0{,}000094\ NB$$

In which Y is maize biomass yield (Mg ha^{-1}), N is nitrogen rate (kg ha^{-1}), and B is biochar rate (Mg ha^{-1}).

With this equation we can calculate that with no biochar application, the highest maize biomass was obtained at 160 kg ha^{-1} N which would produce 3.22 Mg ha^{-1} maize biomass, and further increasing N rate would decrease the maize yield. In 15 Mg ha^{-1} CM biochar treated soil, this biomass yield could be obtained by 90 kg ha^{-1} N. The highest biomass yield in this treatment was 3.37 Mg ha^{-1} which obtained by 140 kg ha^{-1} N application.

4. Conclusions

The results of this study shows that the application of Nitrogen fertilizer, either with or without organic matter amendment increases maize biomass yield. The maize biomass of the first season maize of organic amendment treated soils does not significantly different with that of no organic amendment. However, organic amendment improves soil fertility status, especially increasing C-organic, N, K and CEC. The biomass of the second season maize of biochar treated soil is higher compared to the other treatments. The second experiment shows that biochar application decreases N fertilizer requirement. To produce 3.23 Mg ha^{-1} biomass, it requires 90 kg ha^{-1} N for 15 Mg ha^{-1} CM biochar treated soil, and 160 kg ha^{-1} for the non treated soil.

It shall be kept in mind that this conclusion is based on the green house condition. Therefore, any extrapolation to the field shall consider the field condition.

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Table 1. Some characteristics of soil and organic amendments used in the experiments

Characteristics	Soil	Chicken manure	CW compost	CM biochar	CW biochar
pH H_2O	6.37	7.1	7.9	9.0	9.6
Organic –C (%)	1.46	17.61	21.43	28.13	31.41
N Total (%)	0.19	2.02	1.81	1.9	1.67
C/N	7	8	11	10	18
P (%)	24.38	2.77	0.35	3.77	0.72
K (%)	0.75	2.44	0.82	1.48	0.93
CEC (cmol kg^{-1})	14.02	-	-	17.48	23.87
Clay (%)	23.67	-	-	-	-
Sand (%)	21	-	-	-	-

1) the units of available P (Bray 1) in the soil is mg kg^{-1}; and for the exchangeable K is cmol kg^{-1}

Table 2. Effect of biochar on maize height, stem diameter, root length and dry biomass, and nitrogen absorption at the end of vegetative growth (first season maize)

Treatment	Plant height (cm)	Stem diameter (cm)	Root length (cm $plant^{-1}$)	Dry biomass (Mg ha^{-1})	Total nitrogen absorption (kg ha^{-1})	Efficiency of N fertilization (%)
Control	99.76 a	1.85 a	1.25 a	1.89 a	33.07a	-
N-No OM	119.67 b	1.98 ab	1.62 b	3.06 b	62.45 b	21.76 a
N+Chicken manure	125.64 b	2.15 b	2.30 d	3.29 b	67.50 b	25.50 b
N+City waste compost	123.27 b	2.11 b	1.95 c	3.08 b	63.62 b	22.62 ab
N+CM biochar	120.39 b	2.10 b	2.18 cd	3.09 b	63.84 b	22.79 ab
N+CW biochar	123.42 b	2.01 ab	2.15 cd	3.11 b	63.46 b	22.51 ab

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

Table 3. Residual effect of biochar application on maize height, stem diameter, root length, dry biomass, and nitrogen absorption at the end of vegetative growth

Treatment	Plant height (cm)	Stem diameter (cm)	Root length (cm $plant^{-1}$)	Dry biomass (Mg ha^{-1})	Total nitrogen absorption (kg ha^{-1})	Efficiency of N fertilization (%)
Control	87.75	1.74 a	1.05 a	1.68 a	33.09 a	-
N-No OM	123.62 b	2.05 ab	1.45 c	2.39 b	54.25 b	15.67 a
N+Chicken manure	123.47 b	2.45 b	1.30 bc	2.97 bc	65.63 c	24.10 b
N+City waste compost	123.20 b	2.43 b	1.24 ab	2.85 b	64.12 c	22.98 ab
N+CM biochar	124.35 b	2.38 b	2.07 d	3.34 c	88.17 d	40.80 c
N+CW biochar	117.37 b	2.41 b	2.20 d	3.30 c	85.47 d	38.80 c

*) means followed by the same letters in the same column are not significantly different (p=0,05)

Table 4. Effect of biochar on some soil properties after the harvesting the first and second maize

Treatment	Organic-C (%)		N (%)		Available P (ppm)		Exchangeable K (cmol kg^{-1})		CEC (cmol kg^{-1})	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Control	1.39 a	1.20 a	0.11 a	0.09 a	21.56 a	19.45 a	0.67 a	0.69 a	14.14 a	13.22 a
N-No OM	1.41 a	1.15 a	0.18 ab	0.17 ab	22.54 a	23.54 ab	0.75 a	0.74 ab	13.78 a	14.18 a
N+Chicken manure	2.28 b	1.98 ab	0.25 b	0.20 b	36.25 b	26.28 b	1.16 ab	1.05 ab	17.24ab	16.20 ab
N+City waste compost	2.46 b	2.06 b	0.29 b	0.21 bc	34.76 b	27.78 b	1.45 bc	1.19 bc	16.25 ab	17.30 ab
N+CM biochar	3.14 d	3.14 c	0.24 b	0.39 c	40.26 b	29.45 b	1.98 c	2.18 c	19.27 b	19.27 b
N+CW biochar	3.21 d	3.18 c	0.21 b	0.31 c	38.76 b	30.04 b	2.01 c	2.14 c	19.68 b	18.34 b

1) Means followed by the same letters in the same column are not significantly different (p=0,05)

Table 5. Effect of FYM biochar and nitrogen application on maize biomass (Mg ha^{-1}) at the end of vegetative growth

CM biochar (Mg ha^{-1})	N fertilizer (kg ha^{-1})				
	0	45	90	135	180
0	1.61 a	2.13 b	3.11 de	3.13 def	3.23 ef
15	2.06 b	3.32 f	3.31 ef	3.29 ef	3.30 ef
30	2.11 b	2.99 d	3.26 ef	3.24 ef	3.28 ef
60	2.75 c	3.00 d	3.19 def	3.28 ef	3.29 ef

Means followed by the same letters are not significantly different (p=0,05)

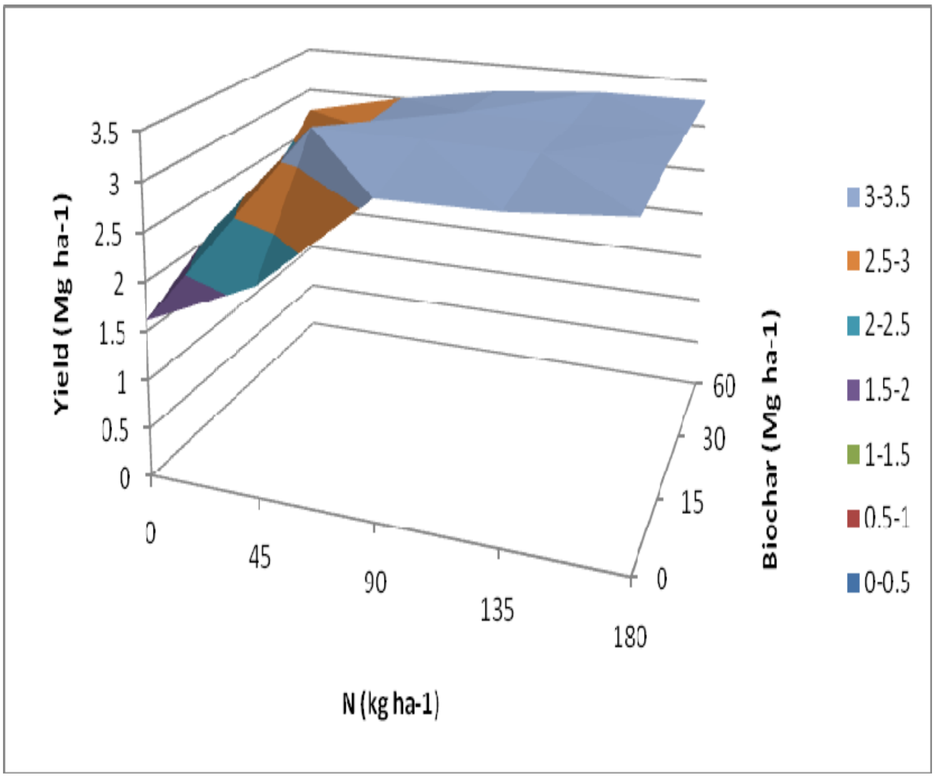

Figure 1. Curve response of maize biomass yield to nitrogen and biochar application