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Balance of Nitrogen in Plant-Soil System with the Presence of Compost+Charcoal

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ABSTRACT

The benefit of charcoal for growing crops has been well established. In a tropical sub-optimal soil, however, use charcoal only may not provide sufficient nutrient to crops. Therefore, adding compost with charcoal is expected to not only provide nutrition also improve soil biology and chemical properties. A greenhouse experiment was carried out to investigate the effect of Compost+Charcoal (CC) on soil properties and their effect on plant top biomass of maize (*Zea mays*) and cowpea (*Vigna unguiculata*). The treatments were maize and cowpea grown on a) soil only, and b) treated with CC only. In order to estimate the N balances in the plant-soil system, main parameters were measured, namely the amount of nitrogen (N) from soil mineralisation, leached N and N uptake. The results showed that the use of CC caused the net N balance in the plant-soil system to decrease. The negative N balance may be due to N loss via denitrification resulting from higher water holding capacity of the soil treated with CC than soil only. The N loss due to denitrification might be minimised by managing the watering system when charcoal is present in the soil. It was also found that CC application only significantly increased dry matter yield and N uptake of maize, but, it did not have the same result with cowpea. The effect of CC in decreasing the leaching of N was only noticed in the early growth of maize and cowpea. However, the significant decrease of N leaching was affected by maize and cowpea.

Keywords: Charcoal+compost, nitrogen, plant soil system, leaching, maize and cowpea, water holding capacity

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INTRODUCTION

Upland soils in Kalimantan Island have not been optimally utilised for growing food crops. The soils are inherently infertile due to their low pH, CEC and nutrient availability. Therefore, growing food crops in such soils need high input in order to obtain good yield.

It was found biochar improved fertility in Brazilian soil up to 3 times and the C remains in the soil for thousands of years (Lehmann, 2007). A review by Spokas et al. (2012) concluded that application of biochar can have positive results in agricultural production, but there has also been a report of no benefits to crop yield (Schnell et al., 2012) or even negative yield responses (Lentz & Ippolito, 2012).

In highly weathered and infertile soils, Ippolito et al. (2012) reported benefits of biochar application. Purnomo et al. (2014) and Purnomo et al. (2014) found the use charcoal increased yield of chili (*Capsicum frutecens)* and cowpea (*Vigna enguiculata),* respectively*,* but it did not produce significant yield of cowpea. This was due to low soil nutrient replacement. On the other hand, use of 50% compost + 50% charcoal treatment was able to obtain cowpea and chili yields similar to 100% compost use. This means that the reduction in proportion of compost to 50% may decrease the emission of CO_2. Information on how the presence of CC in changing the N balance in plant-soil system was limited. Therefore, this study takes the opportunity to investigate the effect of CC and plant on N balance in plant-soil system.

MATERIALS AND METHODS

Experimental Site and Soil Properties

This was a greenhouse experiment carried out at the Faculty of Agriculture, University of Borneo Tarakan. The treatments applied are shown in Table 1. Each of the treatment was repeated four times and they were arranged in a completely randomised block design as the soil mixing was carried out based on each core where soil samples were collected.

Table 1
Soil treatments

Treatments	0	+*Zea mays*	+*Vigna unguiculata*
0	√	√	√
+ CC[1]	√	√	√

Note. [1]the charcoal was made from chicken litter, and thi procedure is explained in "Application of rice husk charcoal" by FFTC Practical Technology, 2001.

The properties of soil used for the experiment are shown in Table 2. The soil properties are explained later.

Table 2
*The change of soil properties after CC addition**

Sample	C[1]	N[2]	C/N	P[3]	K[4]	Ca[4]	Mg[4]	K[4]	Na[4]	CEC[5]	pH[6]	Base saturation	Particle size analysis[7]		
													Clay	Silt	Sand
	Total (%)			Total (mg kg^{-1})		cmol(+) kg^{-1}							%		
Soil only	1.8 (Low)**	0.1 (Very low)	12	66 (Low)	1130 (Very high)	1.5 (Very low)	0.7 (Low)	1.4 (Very high)	0.8 (High)	6.9 (Low)	4.88 (Acidic)	65 (High)	10	24	66
Soil+CC	2.6 (Moderate)	0.24 (Moderate)	11	484 (Very high)	3321 (Very high)	3.6 (Low)	1.3 (Moderate)	5.1 (Very high)	2.5 (Very high)	13.4 (Low)	6.59 (Neutral)	98 (Very high	7	19	75
Changes (%) as affected by CC	42	85	-14	630	194	149	81	256	199	95	35	50	-35	-21	13

Notes. *Procedures of measurements are adapted from [1] "A rapid and precise method for routine determination of organic carbon in soil" by Yeomans, J.C. and Bremner, J.M., 1988, *Communications Soil Science and Plant Analysis, 19*, pp. 1467-1476; [2] "Nitrogen-Total" (pp. 595-624) by Bremner, J. M. & Mulvaney, C. S., 1982, Madison, America: ASA; [3] "Phosphorus" (pp. 403-430) by Olsen and Sommers 1982, Madison, America: ASA; [4] "Exchangeable cations" (pp. 159-166) by Thomas, G. W., 1982, Madison, America: ASA; [5] "Cation exchange capacity" (pp. 149-158) by Rhoades, J. D., 1982, Madison, America: ASA; [6] "Soil pH and lime requirement" (pp. 199-224) by McLean, E. O., 1982, Madison, Wisconsin: ASA; [7] "Particle size analysis" (pp. 383-412) by Gee, G.W. & Boulder, J.W., 1986, Madison, America: ASA; **The values were categorized as described in "Land Suitability for Agricultural and Silviculture Plants" by Djaenuddin, D. et al., 1994, *Laporan Teknis No. 7*. Versi 1.0. April 1994. Bogor: Center for Soil and Agroclimate Research.

Treatment Details and Application

Treatments used in the experiment are shown in Table 1. The compost and charcoal were made from chicken litter. About 100g of compost and charcoal were placed in each per pot (2 kg of air dried soil). The CC was mixed before they were placed in a 10 cm diameter PVC tube. Prior to sowing, the soil was watered to reach its field capacity and incubated for a night. Five seeds of maize or cowpea were sown for each dedicated pot. After emerging, one plant was maintained. The plants were grown for six weeks. During plant growth soil water was maintained at its capacity. At the 1st and 4th week after emerging, the plants were continued to be watered until leachate was noticed. Detail of the sampling times and pot arrangements are shown in Figure 1.

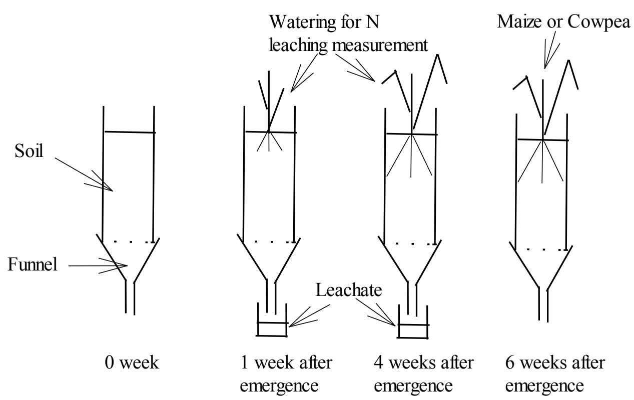

Figure 1. Detail of the sampling times and pot arrangement

Measurements

Soils, leachates and plant tops were measured. Soil analyses were conducted before and after the treatments and at harvest time and selected soil properties were determined soil before and after treatments. The results can be seen in Table 2. Before sowing and at harvest, the amounts of soluble NH_4^+ and NO_3^- in the soil were measured by extracting *c* 40g of fresh soil in 200 mL of 0.01 M $CaCl_2$ (Houba et al., 1994). The amounts of NH_4^+ and NO_3^- in the leachate were directly measured using a reflectometer. The WHC was estimated by subtracting the amount of water used for leaching and the amount of leachate. At harvest time, plant tops were harvested 1cm above the soil surface. Dry matter and N content of the plant tops were measured using method described in Jones (2001).

Calculation

Soil N mineralisation and N balance in plant-soil system were measured. The soil N mineralisation was calculated as follows:

Soil N mineralisation= $(NH_4^+ + NO_3^-)_{tf}$ - $(NH_4^+ + NO_3^-)_{t0}$ [1]

where tf= at harvest and t0= before sowing. N balance in plant-soil system was estimated using formula the below:

N uptake= N mineralised + N leached [2]

Statistical Analysis

Data analysis was conducted using a F test to show if there were differences among the treatments applied, followed by a LSD test to observe which treatment was most statistically significant. A standard error of means was used to show data variation. Except for calculating results of N balance in plant-soil system, the variation of results was shown using standard error of means.

RESULTS AND DISCUSSION

Changes of Soil Properties

Table 2 shows change in soil properties after adding CC. Before the CC application, the soil was considered as infertile. Most of the soil properties were categorised as low, except for exchangeable K and cation base saturation.

It was found that addition of CC changed all the soil chemical properties which contributed to better plant growth. However, the addition of CC did not change the soil texture class which was sand (Table 2).

Changes in WHC

The effects of CC addition on Water Holding Capacity (WHC) a week after the plant emergence are shown in Figure 2a. It was revealed that the addition of CC significantly increased the WHC of the soil. Effects of growing plant

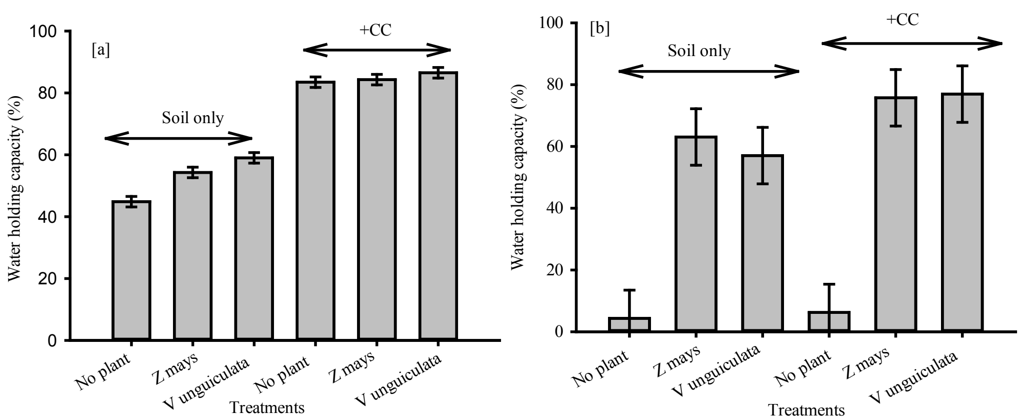

Figure 2. The effects of CC addition and plant on water holding capacity (WHC) at [a] 1 week and [b] 4 weeks after emergence

without use of CC was also observed. It was observed in the absence of CC, plant root may have a role in holding water through root surface charges (Liu et al., 2016).

At 4 weeks after emergence, however, the effect of CC application on soil WHC disappeared both in soils without- and with CC (Figure 2b). Instead, the growing crop became more obvious in holding the water. It seems that the presence of plant may overwhelm the effect of CC.

Leaching of N

Leaching of NH_4^+, NO_3^- and N at 1 week and 4 weeks after emergence are shown in Figures 3. During 1st week after emergence it was observed the leaching of NH_4^+ was much less than that of NO_3. It was also noticed that without use of CC, there was no effect on plants. On the other hand, when CC was added, the NO_3^- leaching decreased, except when the maize crop was present (Figure 4b). The reduction of N (NH_4^+ and NO_3^-) originally from manure due to biochar addition also observed by Yao et al. (2012). The pattern of NO_3^- leaching was similar to N leaching (Figure 4c).

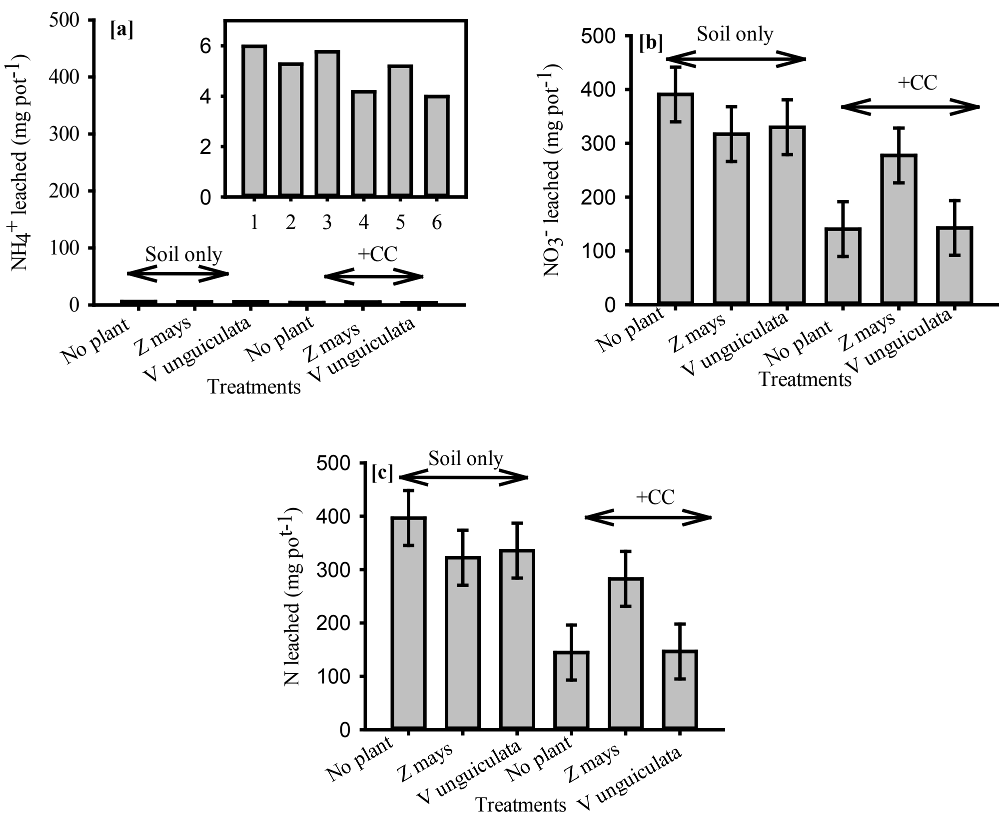

Figure 3. The effects of CC addition and plant on the leaching of [a] NH_4^+, [b] NO_3^- and [c] N at 1 week after emergence

Except for NH_4^+ (Figure 3a), the NO_3^- and N leaching patterns 4 weeks after emergence were different compared with 1st week after emergence (Figure 3). As for NO_3^- leaching (Figure 4b), the effect of CC on leaching disappeared. Instead, the presence of plants decreased the NO_3^- leaching from the soil. This may due to some amount of the dissolved NO_3^- was taken up, less amount of the leachate collected or some of the NO_3^- entered the charcoal pores. Similar pattern of N leaching was also observed (Figure 4c).

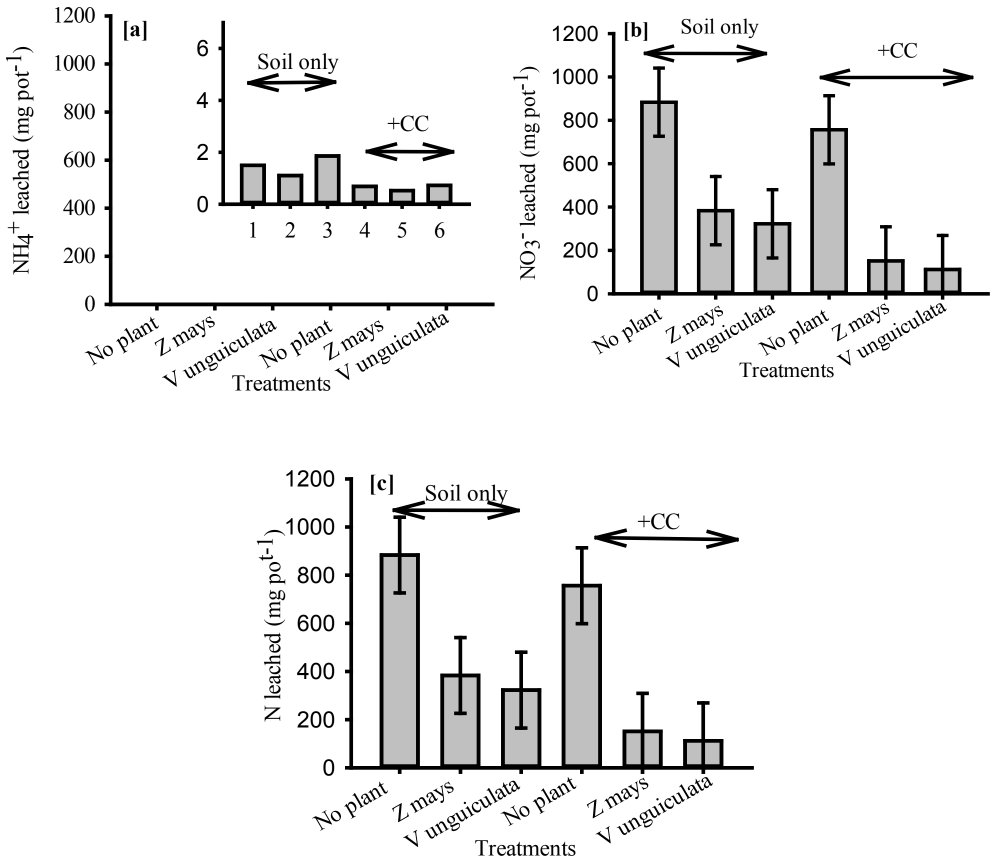

Figure 4. The effects of CC addition and plants on the leaching of [a] NH_4^+, [b] NO_3^- and [c] N at 4 weeks after emergence

Plant growth

Figure 4 shows the effects of CC addition on plant top dry matter. It was observed that CC increased the plant top biomass of maize, but, did not have the same effect on cowpea. Since cowpeas is a legume, the addition of N from CC did not provide any yield advantage to cowpea. Using oat (*Avena sativa* L.), Schulz et al. (2013) demonstrated that composted biochar improved soil properties and plant growth better just using biochar only.

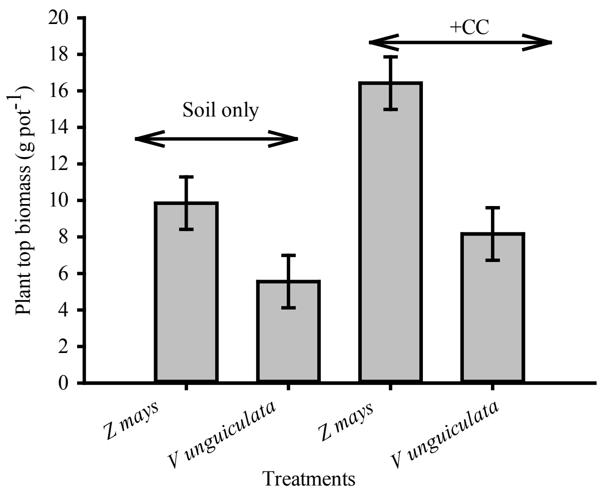

Figure 5. The effects of CC addition on plant top dry matter

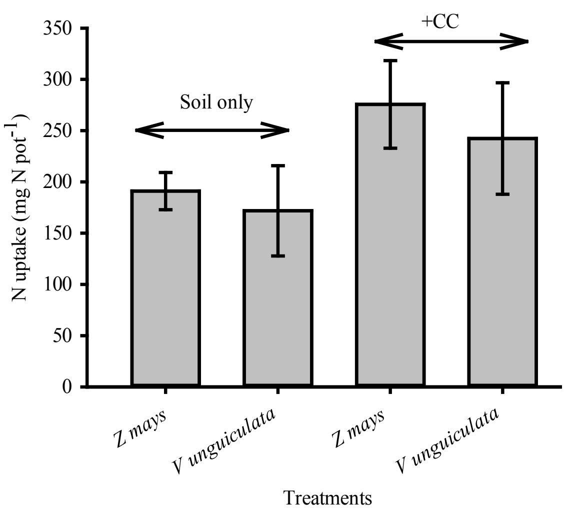

Figure 6. The effects of CC addition on N uptake

N uptake

The effect of CC on N uptake (Figure 6) was similar to plant biomass pattern. The significant effect of CC application on N uptake was only observed in maize. This confirms that the need for N in cowpea was due to the fixation process.

Net N balance

The balance of N in the plant-soil system is estimated by taking into account leaching of N and N uptake. Figure 6 shows the effects of CC addition and plants on the net N balance in plant-soil system. The presence of CC decreased the net N balance both in soil only and soil+plant. It maybe that the higher water held by the soil caused by CC application (Figures 2 and 3) after leaching may enhance the denitrification process. To avoid N loss due to denitrification watering management for crops would be crucial, when, charcoal is applied. Further investigation is need to estimate the amount of water applied, if, the charcoal presence in the soil.

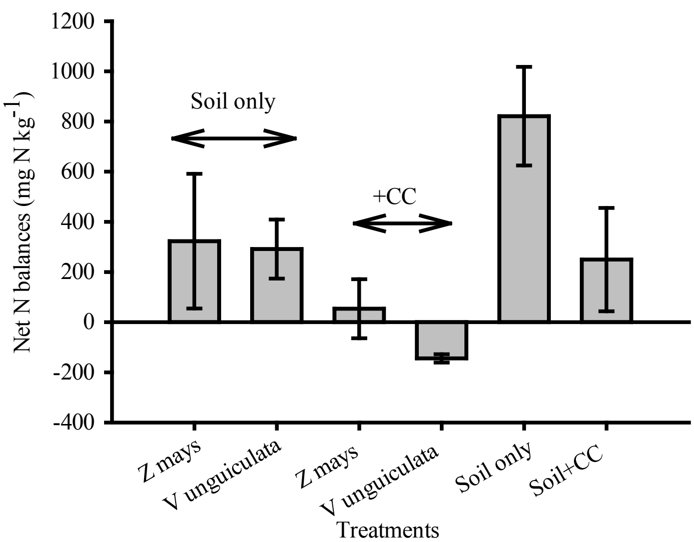

Figure 7. The effects of CC addition and plants on the net N balance in plant-soil system

CONCLUSION

The results showed that the use of CC decreased the net N balance in plant-soil system. This may be associated with the ability of CC in holding more water in soil to result in reductive condition that may enhance the loss of N via the denitrification process. The N loss may be minimised by managing the watering system when charcoal is present in the soil. It was also found that CC application only significantly increased the dry matter yield and N uptake of maize, but, it did not produce the same results with cowpea.

The use of CC significantly decreased the leaching of N during the early growth of maize and cowpea.

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