Assessment of biochar application for lowland rice cultivation through locally available feedstocks in Ghana

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INTRODUCTION

Soil fertility in sub-Saharan Africa is known to be extremely low. Soil organic matter (SOM) plays an important role in crop productivity in this region. Therefore, the application of various organic resources such as crop residue and/or manure has been recommended to maintain SOM and to supply nutrients to the crop land (Nakamura *et al*., 2012b). However, the effect of these amendments can only be expected for the long-term, but not for the short-term, especially in the tropics, because of the high decomposition rate of SOM (Nakamura *et al*., 2012a; Jenkinson and Ayanaba, 1977).

Recently, management of biochar (incompletely combusted charcoal) has been considered as promising soil amendment in the tropics (Lehamann and Rondon, 2006). Soil fertility improvement by using biochar application has been described as that increasing of soil pH in acid soil (Van Zwieten *et al*. 2010), stimulating of soil microbial activity (Lehamann *et al*., 2011), increasing in the availability of major cations and phosphorus as well as the total nitrogen concentration (Glaser *et al*., 2002).

In Ghana, various valuable organic resources are available for agricultural use (Issaka *et al*., 2012). Some of these materials such as rice husk and saw dust that are common waste in Ghana seemed unsuitable for direct application because of their persistent characteristics and high C/N ratio. Therefore, this study aimed to generate biochar from saw dust and rice husk, which are regionally abundant in Guinea Savanna (GS) and Equatorial forest (EF) zones, respectively. Furthermore, carbonization process was considered to possibly contribute to solubility enhancement in indigenous phosphate rock (PR).

Therefore, the effects of application of biochar alone and in combination with PR were evaluated as a soil amendment for lowland rice cultivation in Ghana.

MATERIALS AND METHODS

Biochar was produced using the Kun-tan method by using a Kun-tan maker (E-460S; Honma Co. Ltd., Niigata, Japan). The Kun-tan method can make biochar through low-temperature carbonization (see JIRCAS, 2014). The process involves five basic steps: (1) Fire is set. (2) The fire is covered with a kuntan maker. (3) Rice husk and/or saw dust are poured around the Kuntan maker. (4) The material is churned occasionally after charring commences. (5) The material changes color from brown to black, indicating completion of charring. The matured biochar is spread on a hard surface and watered to cool. The material can be applied to the field immediately or stored for application later. Powdered or granular organic materials need to be selected for the Kun-tan method.

Figure 1 Biochar making using a Kun-tan maker.

Experiment 1. Effect of charred saw dust application on lowland rice in Ghana

In the EF zone, effects of charred saw dust (CHSD) application were evaluated by comparing poultry manure (PM) application, in addition to the direct application of PR. Experimental design is shown in Table 1. All treatments received chemical fertilizers (nitrogen and potassium) as basal application. Basal chemical fertilizer application without organic resources was set as control (NK). “NK + PR” was NK application with PR direct application. “NK + CHSD” was CHSD application at the rate of 2 $t{\cdot}ha^{-1}$ in addition to basal chemical fertilizer. “NK + CHSD + PR” plot was also set to show the effect of CHSD application with PR application. Moreover, P-rich CHSD was applied to investigate the effect of low-temperature calcination on PR solubility enhancement after saw dust charring. “NK + CHSD + PR” and “NK + P-rich CHSD” contain the same amounts of PR and SD, at the rate of 1:1 (w/w). The “NK + PM” plot was PM application at the rate of 2 $t{\cdot}ha^{-1}$ in addition to basal application of NK. The “NK + PM + PR” plot was also set to reveal the effect of PM application with PR application.

The test plant was Jasmine 85 in the equatorial forest zone; it was transplanted at 20 × 20 cm. The experiment was conducted at 6 sites in 2012 and at 9 sites in 2013.

Table 1 Treatments on the effect of charred saw dust application on lowland rice cultivation in the Equatorial forest zone.

Plot ID	Chemical Fertilizer (kg ha^{-1})			Organic Materials
	N	K_2O	P_2O_5	
NK	90	60	0	0
NK+PR	90	60	135	0
NK+CHSD	90	60	0	Charred Saw Dust 2t ha^{-1}
NK+CHSD+PR	90	60	135	Charred Saw Dust 2t ha^{-1}
NK+P-rich CHSD	90	60	0	Charred Saw Dust with PR calcination 2t ha^{-1}
NK+PM	90	60	0	Poultry Manure 2t ha^{-1}
NK+PM+PR	90	60	135	Poultry Manure 2t ha^{-1}

Experiment 2. Effect of charred rice husk application on lowland rice in Ghana

In the GS zone, biochar prepared using rice husk was evaluated on lowland rice cultivation. Charred rice husk (CHRH) was prepared using the same process as that described for CHSD.

The experiment was conducted in an on-station field of the University for Development Studies (UDS), near Tamale, Guinea savanna zone. Treatments are listed in Table 2. “Zero” is the absolute control without any application; “NK” received nitrogen and potassium at the recommended rate for Guinea savanna zone (60 kg N·ha^{-1} and 30 kg K_2O·ha^{-1} respectively). “NK + PR” and “NK + TSP” plots received 135 kg P_2O_5·ha^{-1} as PR or TSP, respectively, in addition to NK application. “NK + PR + RH” and “NK + P-rich CHRH” contained the same amounts of PR and RH, at the rate of 1:1 (w/w). Only in the case of P-rich CHRH, the mixture of PR and RH was subjected to the charring process.

GR18, which is one of the most popular varieties in the Guinea savanna zone in Ghana, was used for this experiment. Planting density was 20 cm × 20 cm. All treatments were replicated four times.

Table 2 Treatments on the effect of charred rice husk application on lowland rice cultivation in the Guinea savanna zone

Plot ID	Chemical Fertilizer (kg ha^{-1})			Organic Materials
	N	K_2O	P_2O_5	
Zero	0	0	0	
CHRH	0	0	0	Charred Rice Husk 0.5t ha^{-1}
NK	60	30	0	
NK+PR	60	30	135	
NK+PR+RH	60	30	135	Rice Husk 1t ha^{-1}
NK+P-rich CHRH	60	30	135	Charred Rice Husk with PR calcination 1t ha^{-1}
NK+TSP	60	30	135	

RESULTS AND DISCUSSION

EXP.1 Effect of charred saw dust application on lowland rice in the equatorial forest zone

The effect of CHSD application on lowland rice production is shown in Figure 2. NK + CHSD showed significantly higher yield than that of NK. Thus, CHSD application led to P fertilization effect on lowland rice. Moreover, NK + CHSD showed significantly higher yield than NK + PR. PR was included as P fertilizer; PR application is known to have a comparable effect on lowland rice yield to that of triple super phosphate (TSP) application. Although NK + PR indicated significantly higher yield than NK, no significant difference was noted between NK + CHSD and NK + CHSD + PR. This result indicated that CHSD application becomes completely effective on lowland rice yield as P fertilizer.

Temperature during the charring of saw dust reached 300 °C. Most of the nitrogen in the saw dust was likely lost during the carbonization process.

Treatments with PM application, NK + PM and NK + PM + PR, showed the highest yield among the treatments. This result showed that PM acted as a nitrogen source, not just as a phosphorus source. PM can be one of the most effective organic resource for lowland rice cultivation in the equatorial forest zone. Furthermore, PM can be applied without any pretreatment.

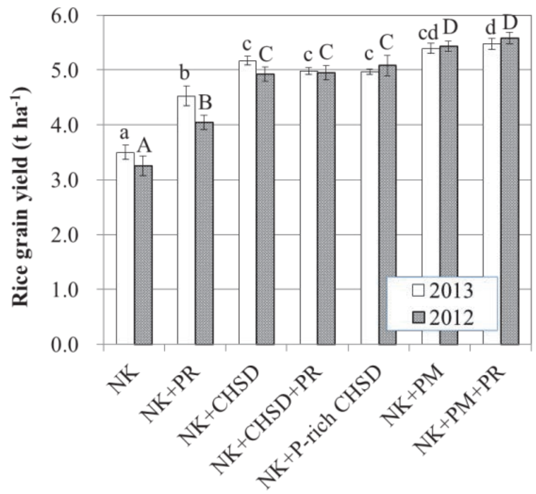

Figure 2 Effect of charred saw dust or poultry manure application on lowland rice cultivation in Ghana.
Error bars are standard error; n = 9 in 2013, and n = 6 in 2012. Different alphabets indicate significant difference ($p < 0.05$) by Tukey's multiple comparison.

As mentioned above, CHSD did not indicate comparable effect to that of PM on lowland rice yield. However, saw dust seemed to be a more considerable organic resource compared with PM, because, SD in the timber industry is considered as an industrial waste and difficult to dispose owing to environmental issues. However, Kun-tan method can transform this waste to effective soil amendment. Furthermore, CHSD application might have a long-term effect on soil fertility enhancement by improving soil physical and/or biological characteristics.

EXP.2 Effect of charred rice husk application on lowland rice in the Guinea savanna zone

Similar to CHSD, temperature during the charring process of RH was considered to be the cause of nitrogen sublimation. This is because the temperature reached 550 °C at the maximum level. However, CHRH application showed comparable effect to that of the NK treatment, although no significant difference was noted among the treatments (Figure 3).

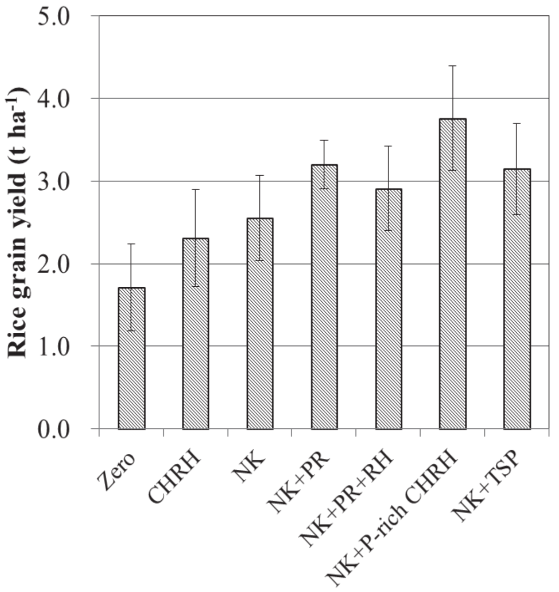

Figure 3 Evaluation of the effect of charred rice husk application and combination with phosphate rock direct application for lowland rice cultivation in the Guinea savanna zone, Ghana. Error bars indicate standard error (n = 4)

P-rich CHRH showed the highest yield. The quantity of applied resource for NK + PR + RH and for NK + P-rich CHRH was the same. The difference in these two treatments was the presence or absence of charring process. Calcination has been reported to enhance low grade PR solubility (Doak *et al*, 1964) However, the higher application effect in P-rich CHRH was not explained by phosphorus solubilization in PR, considering the obviously highest solubility in TSP. Relatively limited rice yield in NK + PR + RH can be considered to be caused by nitrogen starvation or generation of toxic organic acid such as aromatic carboxylic acid (Tanaka *et al*, 1990), because of the high C/N ratio of RH. Although CHRH shows extremely high C/N ratio because of carbonization, CHRH is thought to perform like undecomposable organic or inorganic material in the soil, contributing as microbial habitat, and/or as negatively and positively charged surface (Lehmann *et al*., 2011). Further investigation would be required for confirming this result.

CONCLUSIONS

Biochar application was effective on improving lowland rice yield when it was combined with NK. Furthermore, charring process showed a clear effect of PR in GY for the case of rice husk, but not for the saw dust. However, using saw dust seemed to be more considerable organic resource compared with PM because this is considered as an industrial waste. Hence this study indicated that Kun-tan method can utilize a locally available agricultural or industrial waste in efficient way to improve lowland rice production in Ghana.

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