Effect of rice straw application on lowland rice cultivation in the Guinea savanna zone, Ghana

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INTRODUCTION

Low inherent soil fertility has been identified as a major cause for low rice yield (Abe *et al*., 2010; Buri *et al*., 2004; Issaka *et al*., 2009; Senayah, *et al*., 2008). The problem is compounded because farmers are unable to purchase fertilizer (relatively high cost) and rely mostly on natural soil fertility, which is low and declining.

However, various organic materials (OM) are available that have the potential of effective agronomical use in Ghana (Issaka *et al*., 2011). The best promising OM for agricultural use in the Northern region has been judged as rice straw (RS). RS application is a cost-effective approach since labor cost for gathering and transportation is less. Moreover, the effects of RS application on rice yields were comparable to those of cow dung and/or human excreta application. Thus, establishing procedures for obtaining RS-based OM management for improving rice cultivation in the Guinea savanna zone is necessary.

Part. I *Potential of RS utilization in soil fertility management for lowland rice cultivation in Ghana*

Rice residues such as RS, the common material in rice farms, are one of the most accessible materials for farmers. Because RS is produced in rice fields itself, no transportation cost is involved. Therefore, the development of proper management of this material is essential for Ghanaian rice production.

As reported previously (Fukuda *et al*., 2016b), especially in the Northern region, RS is abundant because of the large cultivation area of rice in this region. However, it is often combusted by wild fire. Therefore, an experiment was conducted to compare the effect of various types of pretreated RS application in order to suggest appropriate RS management in the Guinea savanna zone of Ghana.

MATERIALS AND METHODS

Site Description

The experiment was conducted at the University for Development Studies (UDS), Nyankpala, in the Guinea savanna zone. The site is located on altitude 183 m a.s.l. ; latitude, 09º 25′ 41″N; and longitude, 0º 58′ 42″W of the equator. It has a unimodal rainfall pattern, with mean annual rainfall of 1000–1200 mm, which is fairly distributed from April to November. The area has mean monthly minimum temperature of 23.4 ºC and maximum of 34.5 ºC. The site has a minimum and maximum relative humidity of 46 % and 76.8 %, respectively.

Experimental design

The experiment was a 4 × 6 factorial laid in a randomized complete block design. It included six OM treatments: rice straw (RS), rice straw ash (RSA), rice straw charred (RSC), rice straw-cow dung compost (RS/CDC) which is RS composted with cow dung for four months, rice straw-human excreta compost (RS/HEC), and without OM (Control). Treatments were administered at four levels (A, B, C, and D) and replicated five times. The treatments were as follows: (A): single level of OM application with basal application of N and K; (B) single level of OM application without inorganic fertilizer; (C) twice the level of OM application of that in (A); (D) twice the level of OM application of that in (B). Each plots were designed as 5 m × 5m.

The selected OMs were amended as follows: RS: 3 $t{\cdot}ha^{-1}$, RS/CDC: 4.16 $t{\cdot}ha^{-1}$, RSC: 2.12 $t{\cdot}ha^{-1}$, RS/HEC: 4.16 $t{\cdot}ha^{-1}$, RSA: 1.20 $t{\cdot}ha^{-1}$, and Control. The OM application was maintained at 3.2 kg $P_2O_5{\cdot}ha^{-1}$. As a basal chemical fertilizer (CF), ammonium sulfate as a source of nitrogen (N) and potassium chloride as a source of potassium (K) at 30 $kg{\cdot}ha^{-1}$ were applied.

The GR18 rice variety, which is one of the most cultivated varieties in Northern Ghana (Ghana Seed Company 1988), was used. The results of our site reconnaissance also indicated that GR18 is a popular rice cultivar in the northern part of Ghana. The density of rice plants was established at the recommended dose of 20 cm × 20 cm at each site.

Procedure for yield survey

The total number of hills on each plot was counted two weeks after planting. Hills on each experimental unit contained five to seven stands. Five hills were randomly selected along the two diagonals of each plot and tagged. Plant height was measured at three weekly intervals. Yield survey was conducted by quadrat sampling from 16 m^2 of internal subplot settled in each plot. Quadrant (1m^2) was placed twice on each plot during panicle initiation to determine the number of effective tillers. The effective tillers during panicle initiation were counted. Visual observation and monitoring were used to record 50 % flowering on each plot. The number of panicles was counted at the maturity stage.

Rice grain yield and RS yield per plot were determined using the abovementioned quadrant method. The grain weight was determined after threshing and winnowing. The thousand paddy grain weight was measured in grams by using an electronic balance.

RESULTS AND DISCUSSION

The effect of pretreated RS application on rice yield

Application effects of several pretreated RS with basal chemical fertilizers observed in 2010 and 2011 trials are shown in Figure 1. In general, observed rice yields were very low. Rice grain yield without organic matter application showed about 1.3 t ha^{-1} which is almost same as mean values of farmer's rice yields in this region. Abe *et al* (2010) suggests that lowland rice yields in Ghana has been limited by low soil fertility especially in soil phosphorus deficiency. In Northern region, rice yields would be limited by unstable rainfall pattern in addition to soil fertility, because most of lowland rice in this region were cultivated in rain-fed lowlands (Nakamura *et al* 2016). The direct application of RS showed the highest yield among the various types of pretreated RS applications.

All pretreated RS applications led to apparent increases in rice grain yields in the 2010 trial, although RSA and RSC did not show the significant differences against Control. However, in 2011, all treatments except RS treatment showed little benefit. Only RS showed definite enhancement in rice grain yield; the yield in other RS treatment did not differ significantly from that of Control in 2011. Further investigations are needed to understand the effect of these OMs; nonetheless, the direct application of RS was effective in improving rice yield in the Northern region.

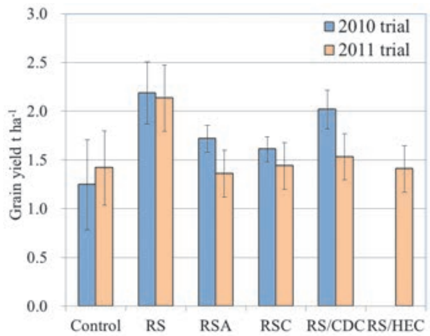

Figure 1 The effect of the application of various pretreated RS with basal CF

Error bars indicate standard errors (n=3 in 2010 trial and n=5 in 2011 trial)

The mean values and least significant difference (LSD) of rice grain yield observed in the pretreated RS applications at the four patterns of application rates are shown in Table 1. CF application significantly improved rice yield. However, the rice yield after single and twice the levels of OM application was not significantly different. Thus, it can be considered that single OM application with basal CF application is sufficient to enhance the rice yield in Ghana. In conclusion, we suggest that RS direct application with basal CF application is recommended as first option. But it should be noted that RS direct application without CF application also indicated relatively high effect on lowland rice yield although it has not significant difference compared with Control, in the mean values of two year experiments.

Table 1 The mean values of rice grain yields ($t{\cdot}ha^{-1}$) under several pretreated RS amended cultivation with four levels of application rates

Amended Organic Materials			Application Rate		
RS	1.71	a	CF+OM	1.48	ab
RS/CDC	1.42	a	OM	1.16	b
RS/HEC	1.41	a	CF+Doubled OM	1.67	a
RSA	1.32	a	Doubled OM	1.31	b
RSC	1.29	a			
Control	1.29	a			
LSD (5%)	0.438		LSD(5%)	0.358	

LSD computed as Fisher's Least Significant Difference.

Results are calculated from 2011 trial.

Part II. ***Elucidation of the appropriate N application rate after the direct application of RS***

As shown in Part I, the co-application of RS and CF was markedly effective in improving rice yields and soil fertility. However, CFs are expensive and cannot be afforded by most farmers in Ghana. Therefore, this study aimed to determine the appropriate rate of CF application for co-application with RS.

MATERIALS AND METHODS

Site description and procedure for yield survey

This experiment was also conducted at UDS, Nyankpala, in the Guinea savanna zone. The yield survey was conducted in the same manner as mentioned before.

Experimental design

RS was applied at three levels of application rate, i.e., 0, 1.5, and 3.0 $t{\cdot}ha^{-1}$. The plots receiving the three doses of RS were applied ammonium sulfate as N fertilizer at four rates, i.e., 0, 15, 30, and 60 kg $N{\cdot}ha^{-1}$. Burkina Faso phosphate rock (PR) was applied at the rate of 135 kg $P_2O_5{\cdot}ha^{-1}$ to all plots as a P source. The rice variety used was GR18.

RESULTS AND DISCUSSION

Rice grain yields of each treatment are shown in Figure 2. Regardless of RS application rate, 60 kg N·ha^{-1} treatment (N60) showed the highest yield value. The rice yield increased linearly with an increase in N application rate. This result suggested that N should be applied to maximize farmer's income, although RS application is effective on lowland rice yield improvement. However, RS3.0N15 and RS1.5N30 showed comparable yield to that for RS0N60. Thus, RS application can reduce the N application rate.

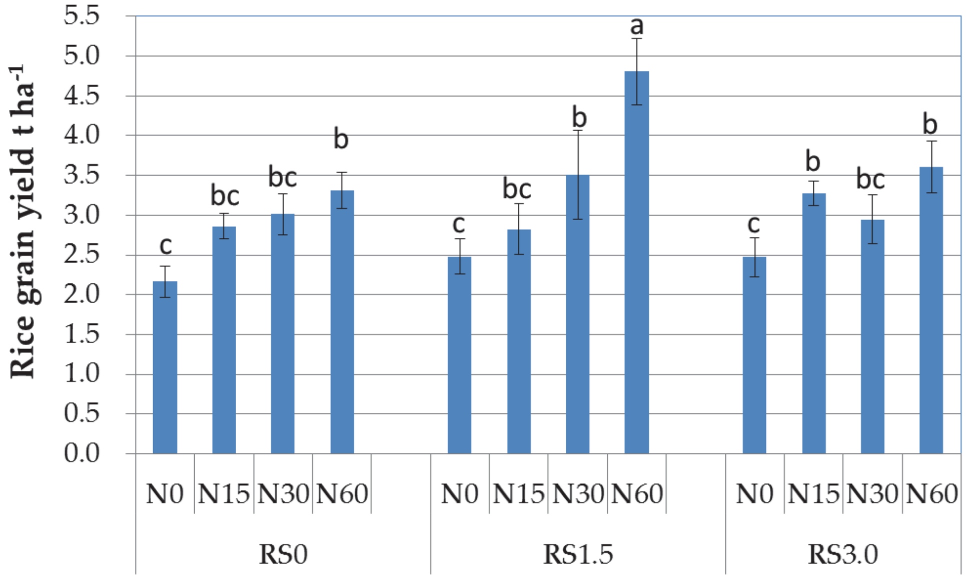

Figure 2 Effect of RS application with the combination of four levels of N application on rice grain yield

Error bars indicate standard errors (n = 6), different alphabets indicates significant difference ($p<0.05$) by Tukey's HSD method

In the case of N0 application, RS application increased rice grain yield: the yield was 2.16 t·ha^{-1} for RS0N0, whereas it was 1.15 times higher (2.48 t·ha^{-1}) for RS1.5N0 and 1.14 times higher (2.47 t·ha^{-1}) for RS3.0 compared with that for RS0N0. Twice the RS application (RS3.0) did not show significant difference in rice yield compared with that for RS1.5. This result is consistent with those of our previous experiments, and these results indicated the positive effect of RS application.

CONCLUSIONS

Our study aimed to investigate the effects of indigenous organic resources in the Guinea savanna zone, which is one of the typical agro-ecological zones for African rice cultivation. RS was found to be an effective indigenous organic resource in the Guinea savanna zone.

RS, an effective organic resource in the Guinea savanna zone, showed beneficial effect on rice yield, in particular after the co-application with CF.

Even in the non-CF application (N0), RS showed a positive effect on lowland rice yield for both application rates of 1.5 $t \cdot ha^{-1}$ and 3.0 $t \cdot ha^{-1}$. However, in the case of CF application, regardless of RS application rate, 60 kg $N \cdot ha^{-1}$ treatment showed the highest yield value. The rice yield tended to increase with an increase in N application rate. This result suggests that N should be applied to maximize farmer's income considering the relationship between fertilizer price and rice yield. However, RS3.0N15 and RS1.5N30 showed comparable yield to that of RS0N60. Thus, RS application could reduce the N application rate.

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