ISSN 1341-710X

JIRCAS Working Report No.86

Soil Fertility Improvement with Indigenous Resources in Lowland Rice Ecologies in Ghana

Edited by
Satoshi Tobita
Satoshi Nakamura


March 2018
Japan International Research Center for Agricultural Sciences
Tsukuba, Ibaraki, Japan

Photographs on the cover page

(left)	(right)
Rainfed lowland rice field in the Northern Region	Irrigated rice field in the Ashanti Region

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Preface

Africa where food production has been stagnant and people do not have access to sufficient food for living and are at risk for their lives. The number of poverty in Africa is still increasing. The government of Japan announced an initiative in TICAD III held in May 2008 and launched the Coalition for African Rice Development initiative (CARD), which aims at doubling the African rice production within the next decade to meet the recent rapid-increase of rice demand.

CARD was jointly suggested by Japan International Cooperation Agency (JICA) and the Alliance for a Green Revolution in Africa (AGRA). In this situation, Japan International Research Center for Agricultural Sciences (JIRCAS) has come to carrying out the project "The Study of Improvement of Soil Fertility with Use of Indigenous Resources in Rice Systems of Sub-Saharan Africa" as commissioned by Ministry of Agriculture, Forestry and Fisheries (MAFF), Japan, during 2009-2013. This project had the objective as to develop and demonstrate technologies for sustainable soil fertility management with effective application of indigenous resources in Africa with the cooperation of the Soil Research Institute (SRI) and Crop Research Institute (CRI) under the CSIR , University for Development Studies (UDS), as well as Ministry of Food and Agriculture (MoFA), Ghana. This project has yield fruitful results which will contribute to increasing and sustaining the rice productivity in Ghana.

The workshop on this project was held 15-16 October 2013 at the UDS International Conference Center, Tamale, Ghana, to discuss the developed technologies for sustainable soil fertility with use of indigenous resources in the Equatorial forest and Guinea savanna agro-ecological zones of Ghana. We do hope that the proceedings of the workshop will provide useful practices and contribute to its wider use in Ghana and in many African countries. Those proceedings had been selected and peer-reviewed, aiming to present our findings and to disseminate those established technologies to a larger number of readers through this current JIRCAS Working Report.

Finally, we would like to express our gratitude and appreciation to MoFA and the project members of Ghanaian institutions, chiefly CSIR-SRI and UDS. We would appreciate to JICA, the Japanese Embassy in Ghana who gave us kind cooperation and meaningful advices in implementing of the project. To end, I would thank to all contributors of papers in this Working Report and cordially apologize this delayed publication.

Satoshi Tobita
Program Director, JIRCAS

Contents

Present status of soil fertility in lowland rice fields of Ghana and recommended management practices

Buri M.M. and Issaka R.N.
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INTRODUCTION

The Ministry of Food and Agriculture (NRDS of MoFA, 2009) has stated that the per capita consumption of rice in Ghana increased to 63.0 kg by 2015, and the country's rice requirements will be in the range of 1.4–1.6 million tons per annum by 2018. At present, rice is the second-most important staple cereal food, the consumption of which continues to increase because of the changes in consumer habits, population growth, and urbanization. Ghana produces less than 40 % of it rice requirements. Of the potential yield target of 6.5 $t \cdot ha^{-1}$, less than 2.0 $t \cdot ha^{-1}$ (about 31 % of the target yield) is the mean rice yield recorded across the country.

In Ghana, rice cultivation is achieved via three main production systems: rain-fed upland, rain-fed lowlands, and irrigation. The rain-fed lowland ecology (mainly inland valleys and river flood plains) is considered to be the dominant type, accounting for over 78 % of the total cropped area. Ghana is estimated to have over four million hectares of unexploited rainfed lowlands, which have been identified as the most profitable sites for rice production provided the water management and cultural practices are improved. In order to ensure food security, import substitution, and savings in foreign exchange, Ghana needs to ensure increased and sustained domestic production of good-quality rice. With greater emphasis and production concentration shifting to lowland ecologies, the major production constraints, especially with regard to soil fertility, need to be identified.

Low inherent soil fertility has been a major constraint in the tropics. With increased cropping intensity, the situation might further worsen unless sustainable and effective management practices are applied. Therefore, this study aimed to determine the soil fertility status of Ghana's lowlands in order to provide a basis to develop sustainable and effective management technologies.

MATERIALS AND METHODS

A review of studies on soil fertility (Abe *et al*., 2010; Buri *et al*., 2011; 2010; 2007; 2004; 2000; 1998; Issaka *et al*., 1996) of rice growing environments, particularly the lowlands of Ghana, the entire West Africa sub-region, and other similar areas, was conducted. Results obtained were then compared with those obtained in similar environments of tropical Asia (Kawaguchi and

Kyuma, 1977) and some major rice-growing sites worldwide. Recommendations for sustainable and effective utilization of these ecologies were provided for improved rice cultivation and increased productivity.

RESULTS AND DISCUSSION

The mean levels of selected fertility parameters of lowland soils in Ghana and West Africa were generally lower than those in tropical Asia (Table 1). Lowland soils of Ghana had low total carbon and basic cations (Ca and Mg) levels, thus reflecting lower levels of effective cation exchange capacity. In particular, soil phosphorus (P) was very limited across Ghana (mean, 3.2 $mg \cdot kg^{-1}$) and West Africa (8.4 $mg \cdot kg^{-1}$) compared to that in tropical Asia (17.6 $mg \cdot kg^{-1}$). In Ghana, the savanna zones (1.5 $mg \cdot kg^{-1}$) showed greater P deficiency than that in the forest zones (4.9 $mg \cdot kg^{-1}$) as shown in Tables 2a & 2b). The clay content of lowland soils across Ghana was also generally low. Furthermore, active clay minerals were less, leading to lower activity of these minerals.

Table 1 Soil nutrient levels of lowlands in Ghana compared with that in the lowlands of West Africa, tropical Asia, and Japan

	pH	TC	TN	Av. P	Ex. K	Ex. Ca	Ex. Mg	eCEC	Clay
Lowland site	H_2O	($g \cdot kg^{-1}$)		($mg \cdot kg^{-1}$)	($cmol_c \cdot kg^{-1}$)				($g \cdot kg^{-1}$)
Ghana	5.2	9.1	0.88	3.2	0.3	4.8	2.5	8.6	97
West Africa	5.3	12.3	1.08	8.4	0.3	2.8	1.3	5.8	230
Tropical Asia	6.0	14.1	1.30	17.6	0.4	10.4	5.5	17.8	280
Japan	-	33.0	2.90	57.0	0.4	9.3	2.8	12.9	210

Modified from Buri et al., 2010; Kawaguchi and Kyuma, 1977.

In Ghana, most lowlands within the Guinea savanna and semi-deciduous rainforests were mainly inland valleys and river flood plains. Rectilinear valleys occurred within the savanna agro-ecological zone, whereas convex valleys were common within the forest agro-ecological zone. However, concave valleys occurred in both the zones. The major soil types in these two zones were Gleysols and, to a lesser extent, Fluvisols. *Volta* and *Lima* series were prominent within the savanna, whereas *Oda, Kakum*, and *Temang* series were prominent in the forest zone (Buri *et al*., 2010).

Soil fertility levels for selected parameters were low across locations, particularly within the savanna zone (Buri *et al*., 2009). Available P was the most deficient nutrient in both the zones. Soils of the savanna were also considerably acidic (Table 2a).

Table 2a Mean soil fertility characteristics of lowlands within the Guinea savanna zone

Parameter	Mean	Range	SD
pH (water)	4.6	3.7–7.4	0.5
Total C ($g \cdot kg^{-1}$)	6.10	0.6–19	3.0
Total N ($g \cdot kg^{-1}$)	0.65	0.1–1.6	0.3
C:N ratio	9.3	5.0–14.3	1.4
Available P ($mg \cdot kg^{-1}$)	1.5	Tr–5.4	0.9
Exchangeable K ($cmolc \cdot kg^{-1}$)	0.22	0.04–1.1	0.17
Exchangeable Ca ($cmolc \cdot kg^{-1}$)	2.10	0.53–15	1.9
Exchangeable Mg ($cmolc \cdot kg^{-1}$)	1.00	0.27–5.87	0.27
Exchangeable Na ($cmolc \cdot kg^{-1}$)	0.12	0.1–0.72	0.11
Exchangeable acidity ($cmolc \cdot kg^{-1}$)	1.00	0.05–1.80	0.48
Clay content ($g \cdot kg^{-1}$)	66	40–241	39
Silt content ($g \cdot kg^{-1}$)	607	347–810	107

Number of samples: 90; Source: Buri *et al*., 2009; Topsoil, 0–20 cm

Table 2b Mean soil fertility characteristics of lowlands within the semi-deciduous rainforest

Parameter	Mean	Range	SD
pH (water)	5.7	4.1–7.6	0.89
Organic C ($g \cdot kg^{-1}$)	12	3.6–36.5	0.58
Total N ($g \cdot kg^{-1}$)	1.1	0.30–3.20	0.05
C: N ratio	11	4.9–14.2	1.26
Available P ($mg \cdot kg^{-1}$)	4.9	0.1–28.5	5.36
Exchangeable K ($cmol_c \cdot kg^{-1}$)	0.42	0.03–1.28	0.25
Exchangeable Ca ($cmol_c \cdot kg^{-1}$)	7.5	1.1–26.0	5.1
Exchangeable Mg ($cmol_c \cdot kg^{-1}$)	4.1	0.3–12.3	2.6
Exchangeable Na ($cmol_c \cdot kg^{-1}$)	0.32	0.04–1.74	0.26
Exchangeable acidity ($cmol_c \cdot kg^{-1}$)	0.31	0.04–1.15	0.29
Clay content ($g \cdot kg^{-1}$)	127	41–301	8.2
Silt content ($g \cdot kg^{-1}$)	502	187–770	45.8

Number of samples: 122; Source: Buri *et al*., 2009; Topsoil, 0–20 cm

Exchangeable cations (K, Ca, Mg, and Na levels) were considerably moderate levels across areas within the forest agro-ecology, but relatively low for the savanna, particularly Ca. Both total carbon and nitrogen levels, even though low, were comparatively higher in the forest than in the savanna zone. The yield levels can be increased under these conditions by improving the fertility levels of the soils (Tables 2a & 2b).

Introduction of the *Sawah* eco-technology might ensure increased and sustained rice production (Ofori *et al*., 2005). The *Sawah* technology is an integrated soil, nutrients, and water management that consists of bunding, ploughing, puddling, and leveling with inlets for irrigation and outlets for drainage. This technology ensures appropriate water control and, with the application of additional good agronomic practices, rice yields of above 4.0 $t \cdot ha^{-1}$ can be easily obtained (Issaka *et al*., 2009).

CONCLUSION

Rice-growing environments in Ghana include heterogeneous topographies with low inherent fertility and low clay content. For effective exploitation and utilization, careful site-specific development and management technologies (improved soil/water management), which need to be disseminated through intensive on-the-job training, are necessary. The *Sawah* technology for rice production is ideal for this situation and can play a significant role in increasing the productivity of these lowlands. While rice farmers should be encouraged to use mineral fertilizers, the development of low-input integrated nutrient (using local materials) management systems would be ideal for farmers with limited resources.

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Potential sources, application, and contribution of organic matter to soil fertility restoration for lowland rice production in Ghana

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INTRODUCTION

The Republic of Ghana is located on Latitude 4° 44′ N and 11°11′ N and Longitude 3° 11′ W and 1° 11′ E (MoFA, 2013). The country has the following seven agro-ecological zones: the Sudan savanna, Guinea savanna, Forest-Savanna transition, Equatorial forest, Moist-Evergreen, Wet-Evergreen, and Coastal savanna (Figure 1; JIRCAS, 2010).

Figure 1 Agro-ecological zones in Ghana

Rice is Ghana's most important cereal food crop after maize, and its total consumption is rapidly increasing (MoFA, 2009). In 2012, the planted area of lowland rice was 189,500 ha, and the average yield of rain-fed lowland rice was 2.5 $t \cdot ha^{-1}$. This level of yield accounted for 39 % of the achievable yields (MoFA, 2013). In addition, the self-sufficiency ratio of rice in Ghana was only 24 % in 2006 (MoFA, 2009), resulting in high annual rice imports and decreased foreign exchange saving. Therefore, promoting rice production to address food security and poverty has been a very important policy for many years.

Inherent low fertility of lowland soils has been considered as a major cause of low rice grain yields (Buri *et al*., 2012). Lowland soils in Ghana are infertile compared to those within the West Africa sub-region or tropical Asia, particularly with regard to total C, N, P, and clay content (Buri *et al*., 2012). Single or multiple applications of chemical fertilizers is a common practice for restoring soil fertility. However, the estimated rate of fertilizer consumption in Ghana was approximately 10 $kg \cdot ha^{-1}$ (Owusu-Bennoah, 1997) mainly because farmers are unable to afford mineral fertilizers. Therefore, maintaining optimum levels of rice yields with low fertilizer usage is difficult. Hence, alternative soil fertilizing materials that are locally available, easily accessible, and affordable by small-scale farmers should be explored. This study is aimed to investigate the abundance and availability of indigenous organic resources that can be used to restore and improve soil fertility for lowland rice production.

MATERIALS AND METHODS

The socioeconomic surveys were performed by the Crop Research Institute (CSIR-CRI) in Kumasi for central and southern parts of Ghana (Equatorial forest zone), and by the University for Development Studies (UDS) in Tamale for northern part of the country (Guinea savanna). A survey focused on rice farmer's view and concern of soil fertility, current local practices for soil fertility management and the related agricultural needs in Ghana. Indigenous resource in Ghana was survey based on literature to quantify, qualify, and localize the kinds of resources for soil fertility management.

RESULTS AND DISCUSSION

Locally available organic resources, particularly from plant and animal origins, occur abundantly throughout Ghana. Rice straw and husk are abundant in the Northern, Volta, Upper East, Western, and Eastern Regions. The total production of straw and husk has been estimated to be 430,000 tons (Figure 2). The estimated nutrient equivalents of total rice residues produced per annum for N, P_2O_5, and K_2O amounts to 2,500; 1,000; and 5,500 tons, respectively (Table 1).

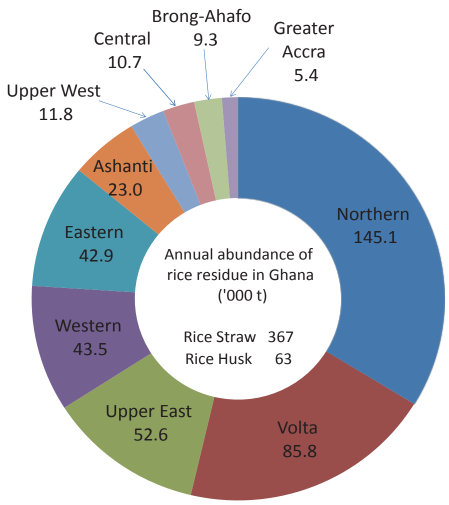

Figure 2 Annual abundance of rice residue in Ghana

Table 1 Nutrient equivalents of organic resources produced annually as nitrogen (N), phosphorus (P_2O_5), and potassium (K_2O) in ’000 ton

Sources		N	P_2O_5	K_2O
Rice (Straw+Husk)		2.5	1.0	5.5
Animal (Dung+Urine)	Cow	41.8	31.8	32.4
	Goat	16.4	4.1	11.4
	Sheep	13.4	3.3	9.3
	Chicken (dung only)	5.8	3.1	2.9
	Pig	3.1	2.3	3.2
	Toal	83.0	45.5	64.6

Estimated daily manure and urine excretions were 3.6 kg and 3.4 L for cow, 0.36 kg and 0.25 L for goat and sheep, and 0.66 kg and 0.6 L for pig, respectively; chicken produced 6.0 kg dry matter of manure per year. Nutrient contents (%) of N, P_2O_5, and K_2O in manure and urine were 1.12, 1.72. 0.48, and 1.21, 0.01, 1.38 for cow; 1.95, 0.70, 0.70, and 1.47, 0.05, 1.96 for goat and sheep; and 2.28, 1.82, 1.80, and 0.38, 0.01, 0.99 for pig; and 2.6, 1.4, and 1.31 for chicken manure, respectively (Adapted from Yagodin, 1984, Mahimairaja *et al*. 2008, and McCalla, 1975).

Livestock excreta (dung and urine) are also ample resources, particularly from cows. Estimated nutrient equivalent of livestock excreta for N, P_2O_5, and K_2O per annum amounts to 80,500; 44,500; and 59,200 tons, respectively (Table 1). However, the amount of excreta differed among regions. Cow and pig excreta were largely produced in Northern, Upper East, and Upper Western Regions. Poultry manure was plentiful in the Greater Accra, Ashanti, and in the major municipalities and cities (Figure 3).

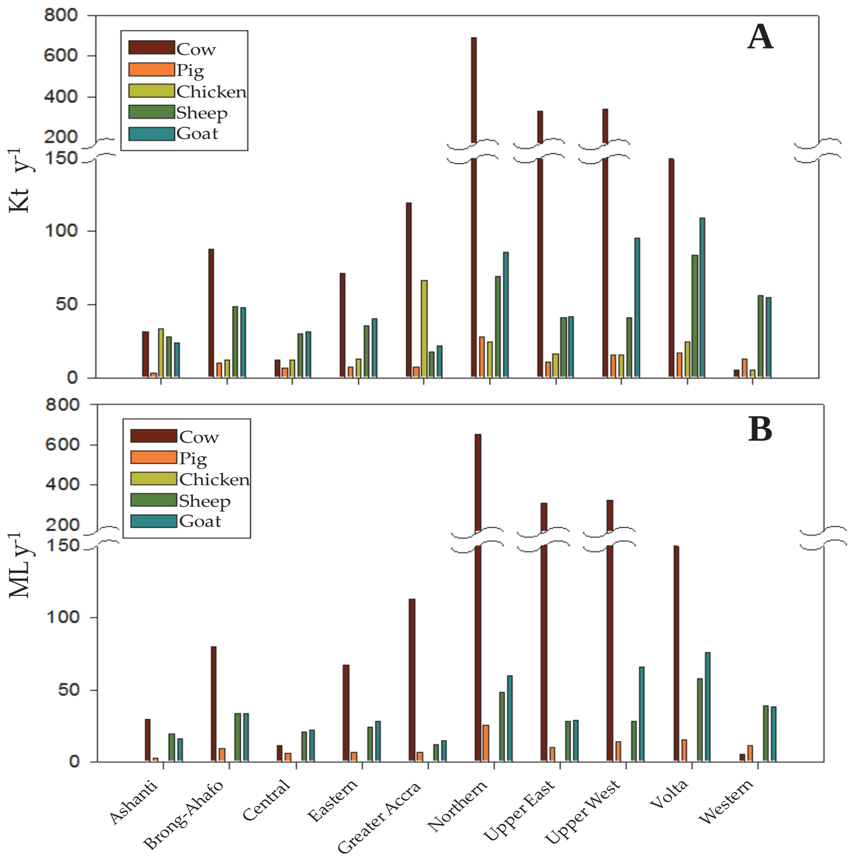

Figure 3 Quantities of dung (A) and urine (B) of the five most common livestock broken down by region in Ghana

In Ghana, most of the straw is burnt while some are removed from the rice fields. While, animal manures are accepted by most farmers either in small-scale house holder and commercial levels. There is an exception with pig manure due to religion belief.

Regarding various kinds and quantities of organic resources which are distributed across the regions. The utilization of these materials for soil fertility improvement is essential and should commence from a community in which they are found or in areas adjacent to such communities. This is a sustainable way for farmers to economically and effectively contribute to soil fertility restoration. For instance, in the Northern region where rice is the most dominant crop, an approach such as incorporating rice straw into the soil would compensate for approximately 20 % of N and P and most K requirements of the soil compared to that obtained by application of chemical fertilizers. In addition, some technical treatments to raw materials such as composting and bio-charring are also attractive options to enhance the effectiveness of rice residues on soil fertility improvement and rice production (Tobita *et al*., 2012; Issaka *et al*., 2012; JIRCAS, 2011).

In Ghana, if only 20 % of the estimated organic fertilizer resources from livestock can be utilized annually, this could substitute for the total requirement for chemical fertilizers for rice cultivation in the entire Northern regions (Tobita *et al*., 2012). Although collecting livestock (i.e., cow, sheep, and goat) excreta/droppings is slightly difficult, especially liquid waste, because of unrestricted animal movement; such collections could be made when the animals are housed during the night. Ensuring that farmers obtain good quality and amounts of animal excreta requires that livestock enclosures should be constructed near houses, or animals should be directly led to the fields so that they can excrete directly onto the target field.

Poultry manure is another very good material because it contains all the major nutrients. However, poultry manure is now in high demand and not available free of charge. Farmers have to purchase poultry manure (Issaka *et al*., 2012). This might be a constraint to most farmers since they cannot afford to pay for fertilizers. Composts derived from droppings of poultry or grazing livestock and plant residues are rich in plant nutrients and should be applied to the soil. Other organic resources such as human excreta, sawdust, and oil palm shells can also be used effectively as per recommended guidelines.

CONCLUSION

In Ghana, local organic resources are plentiful and available across the country. Such organic resources provide large quantities of plant nutrients. The effective utilization of these organic resources would overcome the need for chemical fertilizers, leading to the restoration of soil fertility and increase in grain yield of lowland rice. Organic resources available to farmers also play a major role in the gradual restoration of soil organic matter and macro- and micronutrients.

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Importance of various organic materials in lowland rice production systems in the forest zone of Ghana

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INTRODUCTION

Low inherent soil fertility has been identified as a major cause for low rice yield in Ghana (Buri *et al*., 2009; Issaka *et al*., 1997). The problem is compounded by the fact that farmers are not able to control water and purchase sufficient mineral fertilizer owing to the high cost. Therefore, farmers mostly rely on natural soil fertility, which is not only low, but also declining, resulting in poor rice yields. Large amounts of organic materials that can be used either solely or in combination with mineral fertilizers in rice production are plentiful in the forest zone of Ghana (Issaka *et al*., 2011). These materials have shown to be effective in increasing rice yield, especially when combined with mineral fertilizer. Improving soil fertility necessitates that such cheaper alternative organic materials are identified. In this study, both on-station and on-farm investigations were conducted using such organic materials, and some of the results are presented herein.

MATERIALS AND METHODS

A survey was conducted in 2008 to determine the sources, types, and quantity of organic materials available in Ghana. A series of on-station and on-farm trials were also conducted between 2010 and 2012 at several sites by using various locally available organic materials listed in Table 1.

Table 1 Availability and sources of organic materials in Ashanti region

Organic material	Sources	Estimated quantities (t)
Poultry manure	Poultry farms	20,000
Rice straw	Rice fields	32,000
Rice husk	Rice mills	5,000
Saw dust	Saw mills, Carpentry shops	NA

Source: Issaka *et al*. (2011). NA: not available

Saw dust is abundant in Ashanti, Brong Ahafo, and the Western and Eastern regions of Ghana and is generally concentrated around saw mills. It is commonly disposed off through burning.

RESULTS AND DISCUSSION

Sources and availability of organic materials

Large amounts of organic materials (rice straw/husk, poultry manure (PM), and saw dust) are available in Ghana (Table 1). At present, poultry manure is widely used by both maize and vegetable farmers, but not by rice farmers. Rice straw is abundantly present on rice fields and is usually burnt or left to decompose around the edges of rice fields. Farmers do not attempt to incorporate it into their rice fields, but rather prefer mineral fertilizers. Because mineral fertilizers are very expensive, many farmers cannot afford them, leading to very low application rates.

Effect of organic material application on lowland rice yield

The effect of PM, saw dust char, and rice straw ash on rice yield is shown in Table 2. Application of rice straw ash (RS-Ash) or saw dust char (CHSD) significantly improved panicles·plant^{-1} and panicles·m^{-2}. Grain yield was significantly higher when organic material was applied. PM performed better than both CHSD and RS-Ash, which are cheaper alternatives to chemical fertilizer, because they are waste and generally burnt or allowed to decompose. Raw saw dust is not effective probably because it is very high in C/N and might require high rates of N to avoid poor plant growth.

Various organic resources showed significant positive effects (Tables 2 and 3). PM showed the highest effectiveness on lowland rice. RS and SD at appropriate levels also showed positive effect on improving lowland rice production.

Table 2 Effect of poultry manure, saw dust char, and rice straw ash on yield parameters.

On-station trial

Organic matter (OM)	Plant height (cm)	No. of stand·m^{-2}	Number of panicles·$plant^{-1}$	No. of panicles·m^{-2}	Stover yield (t·ha^{-1})	Grain yield (t·ha^{-1})
No-OM	129.6a	24.6a	2.0c	148c	4.5c	3.4c
CHSD	128.9a	24.7a	2.4b	167b	5.3b	4.3b
RS-ash	129.0a	24.7a	2.3b	161b	5.3b	4.3b
PM	130.1a	24.6a	2.9a	194a	6.6a	5.7a

No-OM: no organic matter applied; CHSD: charred saw dust; RS-ash: rice straw ash; PM: poultry manure. Within a column, values followed by the same letters are not significantly different by a margin of the standard error.

Table 3 Yield parameters affected by rice straw and charred saw dust.

On-farm trial

Organic material	Plant height (cm)	No. of stand ·m^{-2}	Number of panicles ·$plant^{-1}$	No. of panicles ·m^{-2}	Stover yield (t·ha^{-1})	Grain yield (t·ha^{-1})
Control	123b	28.0a	2.0b	198a	5.2c	3.4c
2 t·ha^{-1} RS	126a	27.0a	3.0a	216a	6.6b	5.8b
2 t·ha^{-1} CHSD	126a	27.0a	3.5a	241a	6.4b	5.4b
2 t·ha^{-1} PM	123b	26.0a	3.5a	200a	7.3a	6.3a

RS: rice straw; CHSD: char saw dust; PM: poultry manure. Within a column, values followed by the same letters are not significantly different by a margin of the standard error.

Application of rice straw and its derivatives (at 2 t·ha^{-1} + 30 kg N·ha^{-1}) showed comparable grain yield as that for mineral fertilizer (Figure 1), indicating that these organic materials can be used as alternative to mineral fertilizer.

The effect of integrating PM and sole application of poultry or mineral fertilizer on rice grain yield is shown in Figure 2. The application of 4 t·ha^{-1} PM + 30 kg N·ha^{-1}, 2 t·ha^{-1} PM + 22.5:15:15 kg N-P_2O_5-K_2O·ha^{-1}, and 90-60-60 kg N-P_2O_5-K_2O·ha^{-1} showed similar grain yield, which was significantly higher than that obtained in the other treatments. Application of PM (4.0 $t \cdot ha^{-1}$ and above) showed strong residual effect, resulting in significantly higher yield than that after the application of sole mineral fertilizer. In contrast, 90-60-60 kg $N\text{-}P_2O_5\text{-}K_2O \cdot ha^{-1}$ showed definitely weak residual effect compared with that after the application of PM.

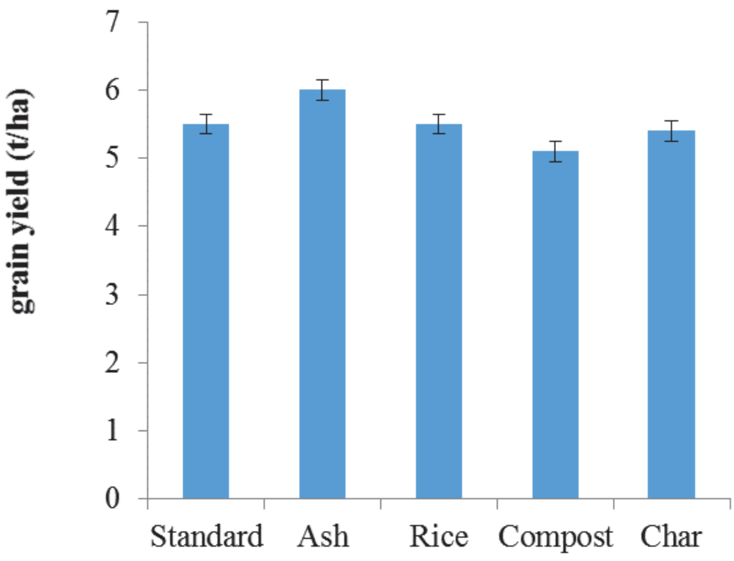

Figure 1 Effect of organic materials and mineral fertilizer on rice grain yield.
Standard: 90-60-60 kg N: P_2O_5: K_2O; Rice straw, Ash, Rice straw compost, and Saw dust char

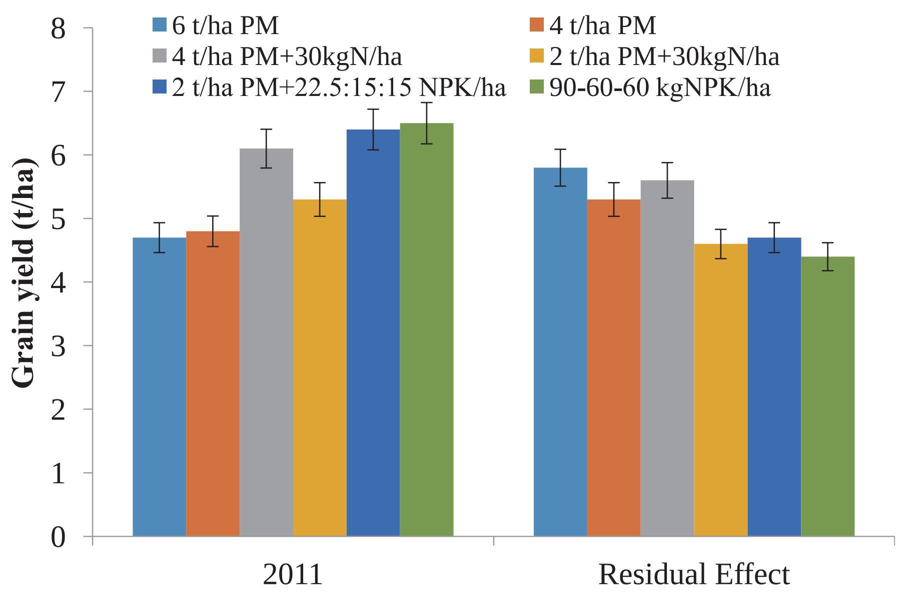

Figure 2 Effect of integrating mineral fertilizer and poultry manure on rice grain yield

CONCLUSION

Plant resources such as rice straw and saw dust were found to be useful as effective alternatives to mineral fertilizer for lowland rice cultivation in the forest zone. PM showed the highest effectiveness, followed by RS and SD; SD needs to be charred before application. Further investigations need to be performed to determine the appropriate rates for the application of these organic material combinations.

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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.

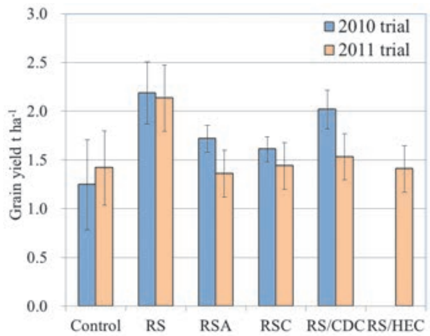

Figure 1 The effect of the application of various pretreated RS with basal CF

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.

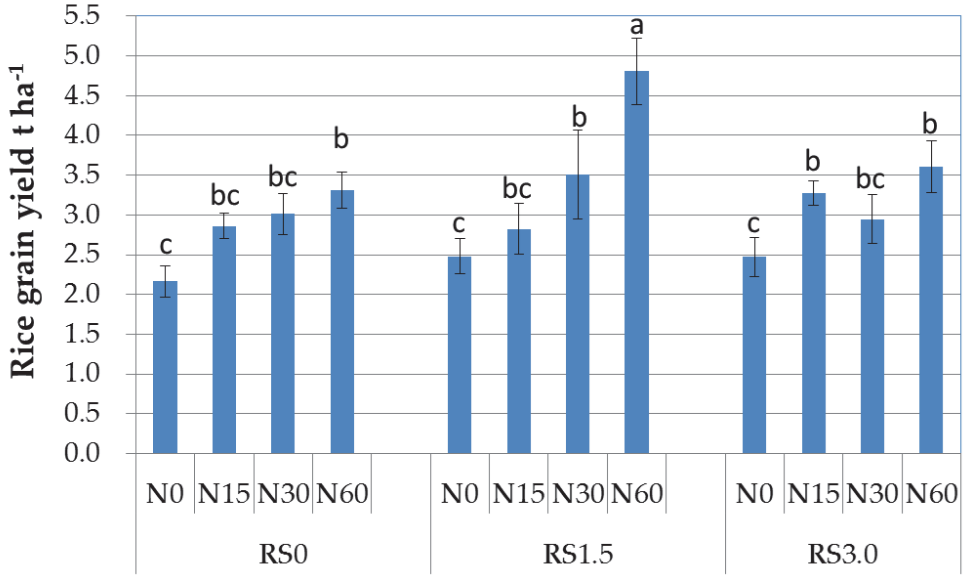

Figure 2 Effect of RS application with the combination of four levels of N application on rice grain yield

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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Poultry manure-based composting with rice straw and saw dust for lowland rice production in the forest zone of Ghana

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INTRODUCTION

Rice consumption in Ghana has outnumbered production, triggering large importation of the commodity to satisfy demand (MoFA, 2009). Because of poor soil fertility, rice yields are generally low (Buri *et al*., 2009; Issaka *et al*., 1997). Increasing rice production requires the implementation of improved agronomic and structural practices. While improved rice varieties are presently cultivated, appropriate water/soil management and fertilizer affordability are required to ensure high yields. The availability of large amounts of rice straw, saw dust, and poultry manure (Issaka *et al*., 2011) in the Ashanti Region provides an opportunity to improve the productive capacities of soil in this region. These materials have been shown to be effective in increasing rice yield, especially when combined with mineral fertilizer (Buri *et al*., 2004). Improving soil fertility necessitates the identification of cheaper alternatives that can be used solely or in combination with mineral fertilizer. In this study, both on-station and on-farm studies were conducted using these organic materials, and the findings are reported herein.

MATERIALS AND METHODS

In 2012, compost was prepared from poultry manure (PM) mixed with either rice straw (RS) or saw dust (SD) at a ratio of 1:1. An on-station trial was conducted to compare the effect of these materials with that of the application of PM alone. Another on-farm trial was conducted in 2011 where RS, PM, and char from SD (2 $t \cdot ha^{-1}$) were used as sole organic materials. In addition, these materials were combined with PM (1:1) and mineral fertilizer.

RESULTS AND DISCUSSION

Effects of the application rate of organic matter on grain yield and yield components are shown in Table 1. Application of 2.0 $t \cdot ha^{-1}$ organic matter significantly improved $panicles \cdot plant^{-1}$ and $panicles \cdot m^{-2}$, resulting in significantly higher grain yield than that when 1.0 $t \cdot ha^{-1}$ organic matter was applied. Availability of more nutrients when organic matter is applied at 2.0 t·ha^{-1} largely explains the observed results. Generally, the application of organic matter (1.0 or 2.0 t·ha^{-1}) provided significantly higher grain yield than that when organic matter was not applied.

Table 1 Effect of the rate of application of organic matter on yield components and grain yield

Organic matter (t·ha^{-1})	Plant height (cm)	No. of stand ·m^{-2}	No. of panicles ·plant^{-1}	No. of panicles ·m^{-2}	Stover yield (t·ha^{-1})	Grain yield (t·ha^{-1})
0.0	129.6a	24.6a	2.0c	148c	4.5c	3.4c
1.0	129.6a	24.6a	2.4b	168b	5.4b	4.5b
2.0	129.2a	24.6a	2.8a	188a	6.2a	5.3a

Organic materials: poultry manure, rice straw compost and saw dust compost
Within a column, values followed by the same letters are not significantly different by a margin of the standard error.

Table 2 Effect of sources of organic materials on yield components and grain yield

Organic matter (OM)	Plant height (cm)	No. of stand ·m^{-2}	No. of panicles ·plant^{-1}	No. of panicles ·m^{-2}	Stover yield (t·ha^{-1})	Grain yield (t·ha^{-1})
No-OM	129.6a	24.6a	2.0c	148c	4.5c	3.4c
PM + RScomp	129.3a	24.5a	3.1a	200a	6.6a	5.8a
PM + SDcomp	129.5a	24.6a	3.1a	199a	6.6a	5.7a
PM	130.1a	24.6a	2.9a	194a	6.6a	5.7a

Materials applied at 2.0 t/ha
No-OM: no organic matter was applied; PM + RScomp: poultry manure + rice straw compost; PM + SDcomp: poultry manure + saw dust compost; and PM: poultry manure. Within a column, values followed by the same letters are not significantly different by a margin of the standard error.

PM alone and in combination with RS compost or SD compost showed similar grain yield (Table 2). Composting RS or SD with PM improved the quality of the compost, and hence supplied similar amounts of nutrients. Since RS and SD are relatively cheaper sources of organic materials, more of these materials can be used to cultivate larger areas.

Interaction of sources and rates of organic materials

When organic materials were applied at a higher rate (2 t·ha-1), rice grain yield increased significantly (Figure 1). Increasing the rate of application refers to the increase in the amount of nutrients, especially N, available to plants. All the three organic materials with fertilizer showed similar grain yields ranging from 4.2 t·ha-1 to more than 7.0 t·ha-1. Application of 30 kg N·ha-1 resulted in significantly increased grain yield for all the treatments (Figure 1). This finding indicates the need to integrate organic materials with mineral fertilizer for better performance. At 1.0 t·ha-1 and without fertilizer application, all the organic materials provided comparable grain yield as that of fertilizer application of 30 kg N·ha-1.

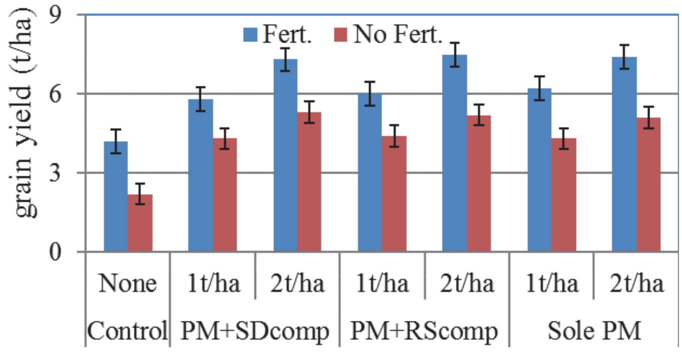

Figure 1 Effect of sources and rates of organic materials on rice grain yield. Fert: Fertilizer applied a 30 kg N·ha-1

Effect of source of organic materials and their combinations

PM alone (2 t·ha-1) and in combination with either RS or char from SD showed similar grain yields that were significantly higher than those obtained when RS or char from SD were applied alone (Figure 2). PM has better quality than RS or char from SD; this could be the reason for the differences in their effectiveness.

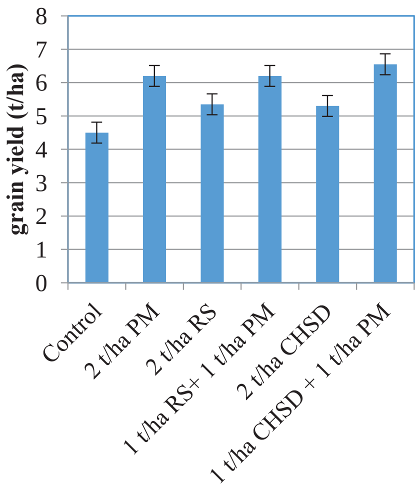

Figure 2 Effect of sources and combinations of organic materials on grain yield

CONCLUSIONS

Integrating organic materials with mineral fertilizer yields better results than those when organic minerals are applied alone. Composting PM with either RS of SD yielded similar results as those after the application of PM alone. Combing relatively rich PM with RS or charred SD enhances rice yield. Compost applied at 2.0 t·ha-1 also improves rice yield.

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Implication of the direct application and residual effects of phosphate rock in the lowland rice system of Ghana

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INTRODUCTION

Phosphate rock (PR) is a promising resource that can be used as an attractive alternative to water-soluble phosphorus fertilizers such as triple super phosphate (TSP) for crops (Chien *et al*., 2010). PR deposits are known to exist in African countries, e.g., Togo and Morocco (Appleton, 2002). Thus, proposing an appropriate PR application method by using local PRs is necessary.

Although direct application of PR is a cost-saving option that involves no processing, in general, PR produced in sub-Saharan Africa has been considered to be less effective because of its low solubility. During the direct application to field, PR solubility was found to be affected by soil and climate conditions. On the other hand, PR direct application on field would have a positive effect on rice production if used as a delayed-release fertilizer. Therefore, this study aimed to elucidate the effect of the direct application of PR on rice yield in Ghana.

MATERIALS AND METHODS

Study sites

Investigations were performed in paddy fields in the Northern Region which is in Guinea savanna zone and Ashanti regions which locates in Equatorial forest zone, of Ghana. Two fields in each region were selected for this trial, and three replication plots were established at each site.

Treatments

Experimental plots of 25 m^2 were established in 2010 with six and four treatment replications in Guinea savanna zone and Equatorial forest zone, respectively, to elucidate the effects of Burkina Faso phosphate rock (BPR) direct application on lowland rice cultivation in Ghana. Plots were partitioned at the beginning of the 2010 and 2011 growing seasons after amendment with PR or TSP in order to create successive application subplots and residual effect subplots. The 1-year residual effect was investigated in subplots in 2011 and 2012. The 2-year residual effect was investigated from 2010-2012. In the trial for elucidation of the 2-year residual effect, there were two treatments. The first treatment was successive application; the plot received consecutive P application in 2010 and 2011, but was not amended with P in 2012. The residual effect treatment received just a single P application in 2010; therefore, Res in 2011 showed the 1-year residual effect, and Res in 2012 showed the 2-year residual effect. A schematic of these experiments is shown in Figure 1.

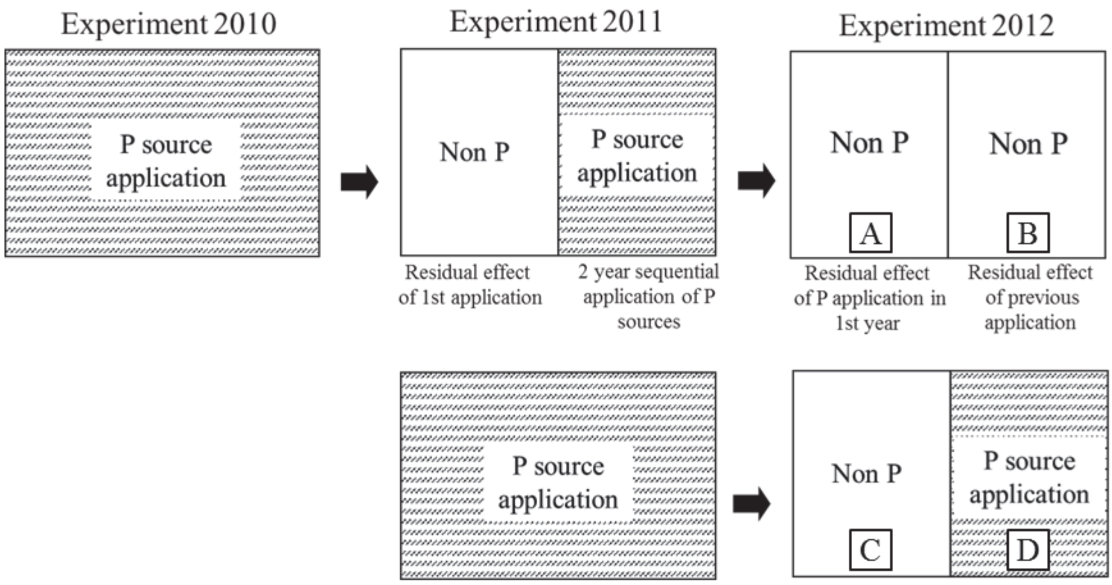


Figure 1 Outline of conducted experiments. The P sources are Burkina Faso phosphate rock (BPR) or triple super phosphate (TSP). All plots received N and K fertilisers at recommended levels for each study site. ABCD are indications of treatments shown in Figure 3 and 4.

In the successive application plots, P sources were applied at the same level in the subsequent cultivation season as in the initial season, while the residual plot did not receive additional P. PRs were initially applied at 67 kg P_2O_5 ha^{-1} (PR-L), 135 kg P_2O_5 ha^{-1} (PR-M), and 270 kg P_2O_5 ha^{-1} (PR-H), respectively. TSP had been applied at 270 kg P_2O_5 ha^{-1} (TSP) in each agro-ecological zone, and, in addition, the recommended level for the Equatorial forest zone was applied to the plot of TSP-rec (60 kg P_2O_5 ha^{-1}). Recommended levels of nitrogen (N) as ammonium sulphate and potassium (K) as potassium chloride were applied annually to all plots. Recommended levels of N were 60 kg N ha^{-1} and 90 kg N ha^{-1}, and recommended levels of K were 30 kg K_2O ha^{-1} and 60 kg K_2O ha^{-1} for Guinea savanna and Equatorial forest zones, respectively. TSP and BPR were applied one week after transplanting. All treatments except control plot received 60 kg N·ha^{-1} and 30 kg K_2O·ha^{-1} in the Guinea savanna zone and 90 kg N·ha^{-1} and 60 kg K_2O·ha^{-1} in the Equatorial forest zone. All K and half of N were applied one week after planting. The other half of N was applied five weeks after transplanting. K and N fertilizers are applied as potassium chloride and ammonium sulfate and the general descriptions of application rates are shown in Table 1.

The rice cultivars used in these trials were GR18 in Guinea savanna zone, and Jasmine 85 in Equatorial forest zone. Rice cultivar GR18 is one of the most cultivated varieties in regions of northern Ghana (Ghana Seed Company 1988). Jasmine 85 was selected and distributed as the ideal variety by the Crop Research Institute (CSIR-CRI, Kumasi, Ghana), and is an improved variety for rain-fed rice cultivation, as demonstrated in the 1990s by the Ghana Rice Project.

Table 1 Fertilizer application rates in PR direct application trial conducted in the Guinea savanna zone and Equatorial forest zone (kg·ha^{-1})

Trearment	P source	Guinea savanna zone			Equatorial forest zone		
		P_2O_5	N	K_2O	P_2O_5	N	K_2O
Zero	None	0	0	0	-	-	-
NK	None	0	60	30	0	90	60
PR-L	BPR*	67	60	30	67	90	60
PR-M	BPR*	135	60	30	135	90	60
PR-H	BPR*	270	60	30	270	90	60
TSP	TSP**	270	60	30	270	90	60
TSP-rec†	TSP**	-	-	-	60	90	60

*BPR: Burkina Faso phosphate rock

**TSP: Triple Super Phosphate

†TSP-rec is the treatment which is recommended application rate for lowland rice in Equatorial forest zone.

Soil analysis

Soil samples were obtained before fertilizer application and at harvest from each site from 0–20 cm depth. They were air-dried and sieved at 2 mm diameter. Chemical analysis was performed for the air-dried soil samples.

The soil pH was measured at 1:2.5 (soil:water) of extraction ratio by using the glass electrode method. The total C and N were determined through the dry combustion method using an NC analyzer (Sumigraph NC-220; Sumika Chemical Analysis Service, Ltd.). Available-P was determined according to Bray-1 method (Bray and Kurtz, 1945); P concentration was determined using the ascorbic acid-molybdenum blue method. Exchangeable bases were extracted using the 1.0 M ammonium acetate solution. The concentrations of cations were determined through the inductively coupled plasma (ICP) method by using ICPE-9000 (Shimadzu Inc.).

RESULTS AND DISCUSSION

Effect of PR application on rice yield

The results of the 2010 trail regarding the effect of PR direct application on rice yield in Guinea savanna and Equatorial forest zones are shown in Figure 1. The rice grain yields indicated increasing tendency with PR application except Site 2, and in the case of the same application level, the yield was comparable with that for the application of TSP. Therefore, PR direct application was considered to be effective to improve rice yield in Ghana. However, in comparison among two agro-ecological zones, Equatorial forest zone showed higher positive effect than those in Guinea savanna zone. It means that effect of PR direct application was affected by meteorological and soil conditions. Rajan *et al*. (1996) suggested that enhancement of PR dissolution with increasing soil moisture is expected due to diffusion of the dissolved P away from the PR particles. Therefore, the reproducibility of the positive effect of PR direct application needs to be evaluated.

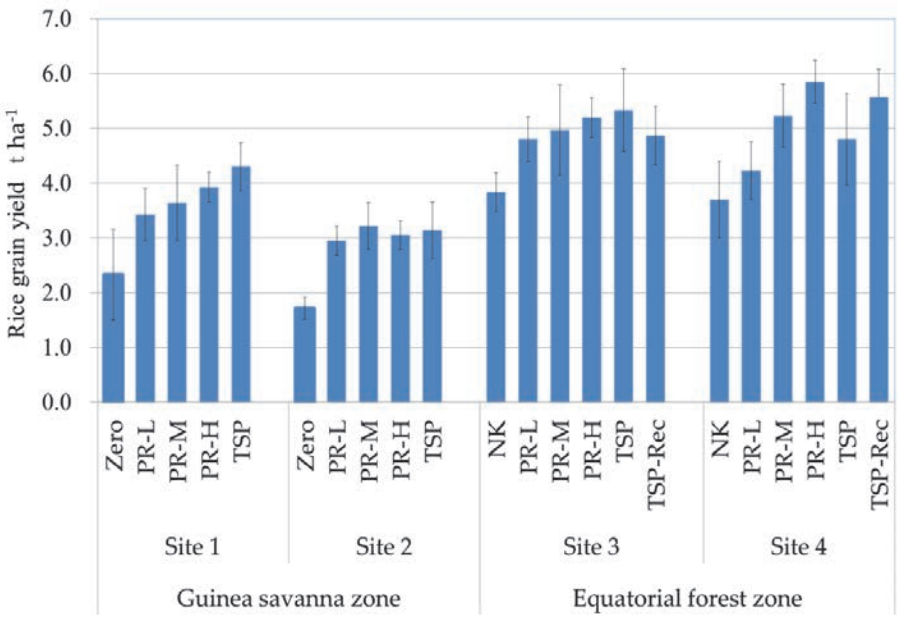


Figure 2 The effect of BPR direct application on rice yield in the Guinea savanna and Equatorial forest zones. Error bars indicate standard error (n = 3).

The residual effect of PR direct application on rice yield in the Guinea savanna zone

PR direct application seemed to have a high residual effect regardless of regional differences. In the Guinea savanna zone, two research sites were used for the elucidation of PR residual effect. The results in two site showed similar tendency, so the results at site 2 of PR residual effect experiments conducted in 2011 and 2012 are shown in Figure 3.

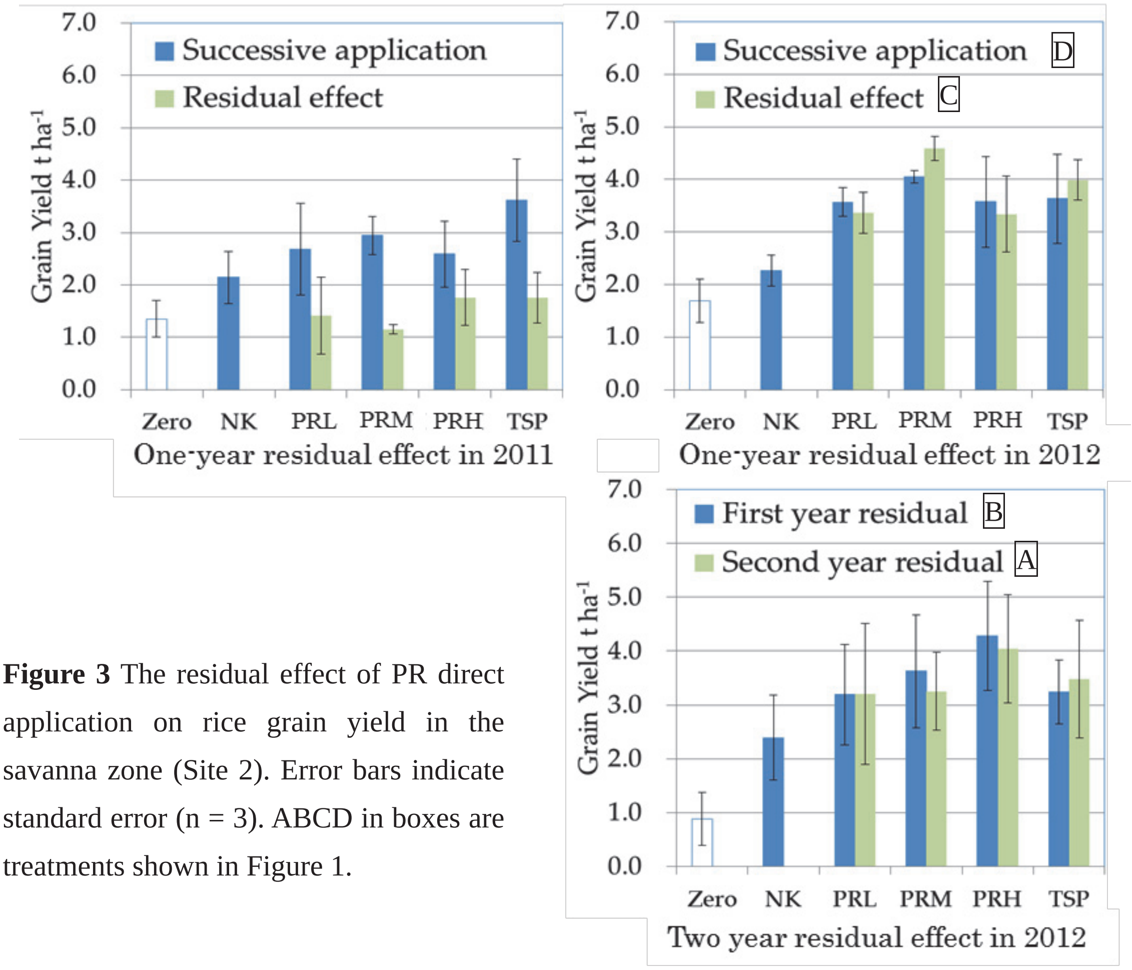
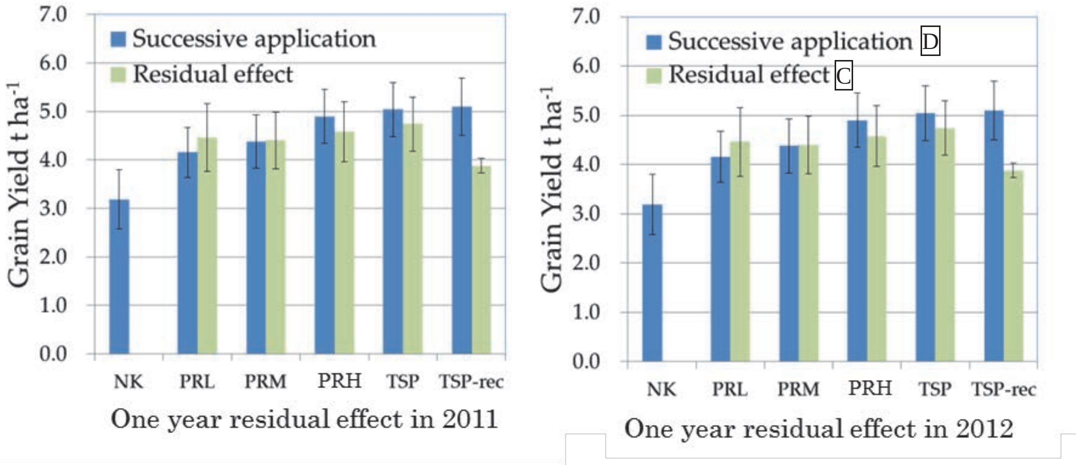


Figure 3 The residual effect of PR direct application on rice grain yield in the savanna zone (Site 2). Error bars indicate standard error (n = 3). ABCD in boxes are treatments shown in Figure 1.

At site 2 located in the Guinea savanna zone, the PR residual effect was lower in the 2011 trial. The yield obtained in the residual effect plots was 52.5 % higher than those noted in the continuous plot in PR-L, PR-M (39.1 %), and PR-H (67.9 %). Yields in the PR residual effect plot were lower than those in NK. However, in the 2012 trial, all treatments indicated high residual effects against successive application. Moreover, the two-year residual effect plot showed residual effect, although no residual effect was noted in 2011. The severe drought affected rice growth in 2011; thus, the dissolution of remaining PR in soil might be limited. Thus, PRs applied alone might have been partly dissolved, and residual effect was not found owing to the retarded or limited re-mobilization of the PR remaining in the soil. Phosphorus originating from the remaining solubilized PR could mobilize when the soil was submerged. These results suggested that PR residual effects showed yearly variation owing to the influence of meteorological conditions, especially precipitation.

The residual effect of PR direct application on rice yields in the Equatorial forest zone

The results of 2011 and 2012 trials suggested markedly high residual effect on rice yield after PR direct application in the Equatorial forest zone (Figure 4). In the one-year residual effect trial conducted in 2011, rice yields in the residual effect showed the same level as that after successive application and were higher than those in NK. Even the minimum PR application plot (PR-L) showed 1.4-times higher yield than that in NK as that in the control. Conversely, in the TSP plot applied with 270 kg $P_2O_5 \cdot ha^{-1}$, the yield was the same as that noted in the successive application plot, but TSP-rec showed definitely lower yield than that noted after successive application and showed little difference from that of NK.



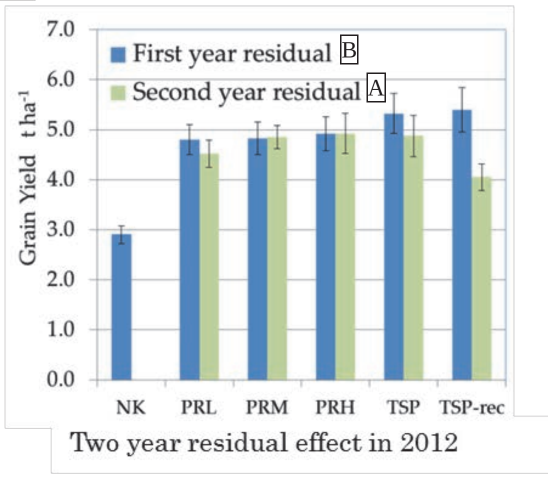


Figure 4 The residual effect of PR direct application on rice grain yield in the Equatorial forest zone (Site 3). Error bars indicate standard error (n = 3). ABCD in boxes are treatments shown in Figure 1.

In the 2012 trial, the same tendency was noted. In the one-year residual effect trial, high residual effect of PR application was noted, unlike that in TSP-rec, indicating low residual effect. Therefore, PR direct application could be considered effective over the subsequent cultivation, and its reproducibility was also obvious in the equatorial forest zone.

Moreover, the two-year residual effect trial showed the same tendency as that of the one-year residual effect trial. In the TSP-rec plot for the two-year residual application effect trial, one-year residual effect showed relatively high yield of approximately 5 $t \cdot ha^{-1}$. This result seemed to suggest that phosphorus accumulated in the soil. The successive application plot in 2011 received 60 kg $P_2O_5 \cdot ha^{-1}$ in addition to the previously applied 60 kg $P_2O_5 \cdot ha^{-1}$ in 2010. For the one-year residual effect plot, only 60 kg $P_2O_5 \cdot ha^{-1}$ was applied in 2010. In contrast, compared to the two-year residual effect trial conducted in 2012, the one-year residual effect plot had received total 120 kg $P_2O_5 \cdot ha^{-1}$ owing to accumulation during the 2010 and 2011 application.

CONCLUSIONS

The increase in rice yields reflect that PR direct application could be applied in both the agro-ecological zones. Therefore, PR direct application was effective in Ghanaian rice cultivation. However, PR direct application effect showed annual and environmental variation, owing to differences in meteorological conditions such as precipitation and soil water conditions, especially in the Guinea savanna zone.

In addition, the one-year or two-year residual effect of PR direct application on lowland rice was indicated in both the agro-ecological zones. The results of two-year investigation showed definite PR residual effect, and hence residual effect of PR direct application can be noted in this region. The presence of residual effect continued for two years; thus, single PR application can be used for three croppings. Although TSP application also showed residual effect at the rate of 270 kg $P_2O_5 \cdot ha^{-1}$, in the case 60 kg $P_2O_5 \cdot ha^{-1}$ (TSP-rec) as the recommended level, low residual effect was noted.

These results indicate that, in rain-fed rice cultivation, although PR direct application was effective, its direct or residual effect possibly varied owing to soil and/or meteorological conditions.

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Combination and timing of application of phosphate rock and organic amendments in the lowland rice field of Ghana

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INTRODUCTION

Grounded phosphate rock (PR) is used to ameliorate soil P deficiency and maintain crop productivity. A significant effectiveness of PR on rice production has been also observed in our previous studies (Nakamura *et al*., 2013, 2016, Fukuda *et al*., 2012a) conducted under some specific soil conditions. Not only direct application of PR, but also co-application with organic matter such cattle manure (CM) was found to be effective (Fukuda *et al*., 2012a). Since CM and rice straw (RS) are important organic resources that are available on-farm and easily accessible to farmers, utilization of these materials might play a major role in the improvement of soil fertility, crop productivity, and self-sufficient economics in Ghana. This study aimed to elucidate the suitable agricultural practices for utilizing PR and organic matter in the rice cultivation system.

MATERIALS AND METHODS

Experiment 1: our previous pot experiment regarding Fukuda *et al*. (2013a, 2012b), acidic-low P soil of Ishigaki island containing 0, 21.8, and 87.3 mg P·kg^{-1} soil as BPR (Burkina Faso phosphate rock) or MCP (calcium dihydrogen phosphate) under flooded and upland conditions were used to grow rice (*Oryza sativa* L. cv. IR74) for 68 days with 4 replicates. Plant dry matter was determined and the dissolution of BPR was calculated from the difference in available P levels obtained from BPR-amended and unamended treatments.

$$\%\ \text{BPR dissolution} = 100 \times \frac{[\text{Extractable P (BPR treated)} - \text{Extractable P (control)}]}{\text{BPR} - \text{P added}}$$

Experiment 2: Incubation experiment-effects on pre-incubating soil with BPR on the growth of rice seedling regarding Fukuda *et al*. (2012a); Treatments pledged with pre-incubation (hereafter as Pre), soils (200 g) (Ghanaian soils sampled at Gbrimah and Nabogu experimental sites with acidic (pH 4.9-5.0), P deficit (1.8-2.6 mg P kg^{-1}; , Bray 1-P), 0.04 % nitrogen; N, and 0.37-0.41%

total carbon; C) were mixed with BPR and added water to 50% field capacity, and incubated for two weeks in the incubator (30 °C and 65 % humidity) to allow P sources reacted with soils. Water was added to compensate water loss. While, treatments without pre-incubation (hereafter as Non) were exempt from this step. After pre-incubation, a rice seedling was transplanted and grown on Pre- and Non-soils for 28 days under flooded and upland (water at 50% field capacity) conditions. Rice shoot dry matter was determined.

Experiment 3: Incubation experiment to evaluate the effects of BPR incorporated with organic amendments on rice growth; Gbrimah soil was used and treatments were triplicated of 1) soil control without amendments, 2) +RS (1% of dried soil or equivalent to 9 ton ha^{-1} or 7 kg P ha^{-1}), 3) +CM (1.34 ton ha^{-1} or 9.8 kg P ha^{-1}), 4) +BPR120 (120 kg P ha^{-1}), 5) +BPR+RS, 6) +BPR+CM, 7) +BPR+RS+CM, and 8) +KH_2PO_4 (120 kg P ha^{-1}) under flooded condition. All mixtures were pre-incubated for two weeks and then were conducted flooded and upland conditions for 28 days as same as the procedure described earlier. A 3 leaf-age rice (IR74) seedling was transplanted into glass beaker at 28 days after incubation (DAI), and grown for another 28 days in greenhouse (averaged temperature 30 °C). In summary, the timeline of the incubation included 0-14 days for Pre- (or Non-) incubation, followed by 28 days of flooding or conducting upland condition, and a final 28 days of growing rice plant (or 28-day-cultivation). Finally, rice shoot dry matter was determined. Soil samples were taken at time interval, Bray 1-P was determined and then the dissolution of BPR was calculated using Bray 1-P values. Percentage of BPR dissolution was calculated as follows;

Experiment 4: Incubation experiment-effects of BPR, rice straw compost (RC), and their combinations on rice growth; Gbrimah soils were mixed with 120 mg P kg^{-1} BPR and its combination with RCs (1, 4, and 8 week-composted RCs as RC1, RC4, and RC8, respectively) at the rate of 0.2% of dried soil, and potassium dihydrogen phosphate; KH_2PO_4 (as KP, 120 mg P kg^{-1}). All mixtures were pre-incubated for two weeks and then were conducted flooded and upland conditions for 28 days as same as the procedure described earlier. Soil samples were taken at time interval. A rice seedling was transplanted, grown, and maintained for 28 days as the same procedure given in Exp. 3.

RESULTS AND DISCUSSION

Direct application of BPR

Our previous pot experiment, it was found that directly applied BPR had not effective on rice biomass production. A high rate of BPR application was required for high P retention soil. An ideal BPR application rate should have compensated the P that is fixed in soil as well as that which is utilized by plants. Adding BPR to soil increases the P content that slowly dissolves available P over years (Fukuda *et al*., 2013a). On the other hand, BPR was effective on rice shoot production in flooded and moist conditions under the incubation experiments (Fukuda *et al*. 2012a, 2013b).

The incubation experiment 2 showed that pre-incubating BPR did not improve shoot biomass regardless of water conditions and soils compared without pre-incubation (Fig.1), indicating that applying BPR at the time of planting was preferable. Adversely, early application of BPR to flooded soils significantly retarded the growth of rice.

Co-application of BPR with organic amendments

Directly application of BPR had positive effect for rice growth compared with the control (Table 1). BPR+CM and CM could increase the biomass of plant up to 144 and 204 %, respectively because they are P-enriched sources. A fast-P-release CM and slow-P-release BPR can supply P to meet the P requirements by rice plants for the entire growing period. In contrast, BPR + RS retarded plant growth (Table 1). Available P released from BPR might be fixed in soil by soil microorganisms that compete for soil P with growing plants (Fukuda *et al*., 2011). Moreover, it is possible that increasing soil pH after RS application and adding raw organic materials (high C/N ratio) temporarily reduced the BPR dissolution (Fig. 2).

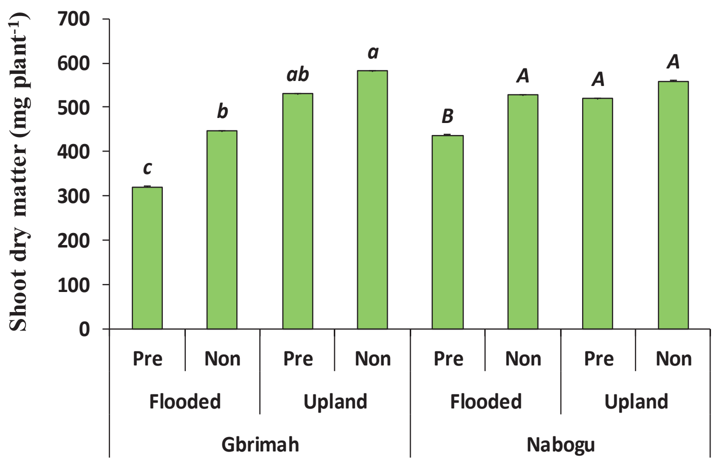

Figure 1 Shoot dry matter of rice (IR74) affected by pre-incubating (Pre) and non-incubating (Non) the soils (Gbrimah and Nabogu) with BPR before transplanting plants under flooded and upland conditions (*n* = 3) in the incubation study.

Table 1 Shoot dry matter of rice (IR74) under 28-day-cultivation as affected by soil fertilizer materials

Treatments	Shoot DM (mg)			
	Mean SE (n =3)			
Control	48	±	9	*bc*
+ RS	20	±	5	*c*
+ CM	69	±	17	*abc*
+ BPR	118	±	27	*a*
+ BPR+RS	37	±	9	*bc*
+ BPR+CM	98	±	19	*ab*
+ BPR+RS+CM	28	±	1	*c*
+ KH_2PO_4	102	±	26	*ab*

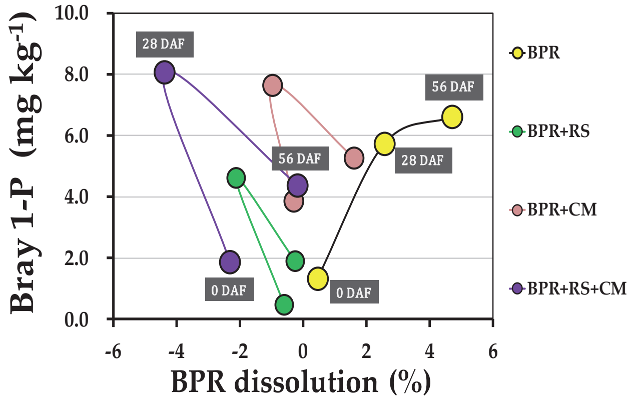

Figure 2 Trends of BPR dissolution and available P in incubated soil affected by directly applied BPR and co-applied BPR with RS and/or CM during 0, 28, and 56 days after flooding (DAF) the soil.

Fig. 2 indicates that applying BPR + CM + RS potentially increased available P in soil, but adding large quantity of organic materials that contain high carbon contents (high C/N and C/P) possibly reduced the dissolution of BPR because of the increasing soil P fixation and rising soil pH. PR is sparingly dissolved P fertilizer and its dissolution depends on the inherent chemical components, soil properties, and water conditions (Rajan *et al*., 1996; Simpson, 1998; FAO, 2004). PR will be continuously dissolved if products of dissolution (c.a. dissolved P from BPR) is diffused away from PR particles and soil acidity or H^+ supply is increasing (Simpson, 1998).

Amending large amount of P into soil through organic materials can reduce the dissolution of BPR following a simple Law of diffusion and the associations of organic matter-P as a sink of P fixation. In Fig. 2, BPR was not dissolved (negative values) during 28 days after flooding when it was co-applied with CM and RS. Later, dissolution of BPR tended to be improved (become more positive values) after growing the rice plant, particularly in BPR+CM. Plant P removal should have facilitated the diffusion of dissolved P products out from soil matrix, made diluted P in soil solution, and acidified the soils by root exudates. BPR dissolution was much improved in BPR+CM rather than BPR+RS+CM treatments because plant could firstly utilize P from highly water-soluble P from CM rather than those from low-P containing RS. RS had much adverse effect on BPR dissolution due to its high C/P ratio and increasing pH during decomposition.

On the other hand, the growth of rice plants was improved when BPR was co-applied with composed RS (RC) in flooded and upland soils (Fig. 3) in comparison with the control. This suggested that RS should be applied to the field before planting and then allowed to decompose to release essential nutrients to the soils. The conventional method to incorporate rice straw to the field is by plowing or mixing the straw to soils after harvest.

Continuous application of inorganic fertilizer and organic materials to soil is expected to accumulate soil capital P, improve soil physical properties, and consequently overcome soil fertility constraints, and benefit rice production. Moreover, the effectiveness of co-applied BPR with organic materials on rice production are expected to increase with time along with the decomposition of organic materials.

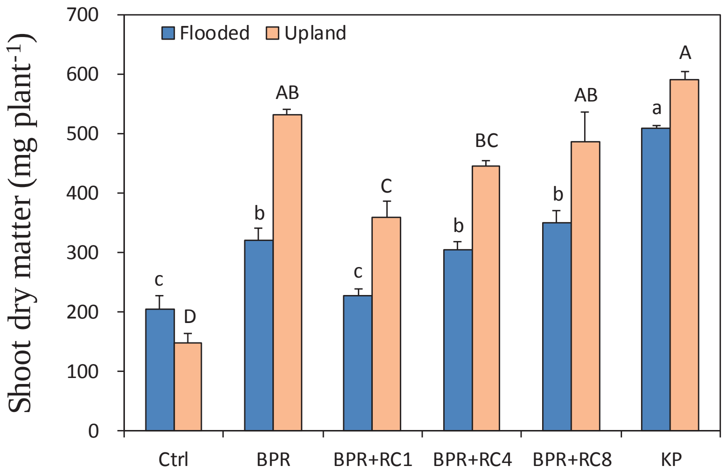

Figure 3 Shoot dry matter of rice (IR74) affected by directly applied BPR and co-applied BPR with rice straw composts (1, 4, and 8 week-composted RCs as RC1, RC4, and RC8, respectively) and chemical P fertilizer potassium dihydrogen phosphate; KH_2PO_4 (KP)

CONCLUSION

Co-application of BPR and organic amendments (i.e., CM and RS) could be used to improve rice growth and soil fertility in lowland rice systems, including areas having acidic soils, low P content, and varying soil water contents from upland to flooded conditions. The effectiveness of these materials on rice growth has been influenced by the types and chemical properties of P sources, rates of application, methods of application, and management of total P fertilizer. Promising levels of rice yield and soil productivity in short and long terms are expected to reach when some of the suitable practices are applied by farmers.

Applying soil fertilizing materials, both inorganic and organic resources, is recommended to increase rice production and soil fertility. Inorganic P sources such as BPR showed high potential to supply P for rice cultivated soil. A suitable rate of BPR application would supply sufficient amount of P for the entire plant growth season. Organic amendments such as CM and RS are P fertilizing resources for small-scale farmers. Both direct and co-application of inorganic and organic materials are preferable. A fast-P-release CM and high-P-content PR can also be applied at the planting time. RS with high C/N ratio and low P contents should be well composed before applying to the field. Agricultural practices such as plowing RS with soils after harvest or making RS compost are excellent options to reduce some adverse effects related to P fixation in soil.

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Technology for the solubilization of phosphate rock and its advantages—Phosphate rock solubilization by low-temperature calcination

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INTRODUCTION

The effect of phosphate rock (PR) direct application is inferior to that of water-soluble P fertilizer; several biological, chemical, and physical means can be used to enhance the availability of PR to plants (FAO, 2004; Nakamura *et al*., 2013). Among presented technologies for PR solubilization, chemical and physical methods will be processed in fertilizer plants, while the biological one such as PR added-composting can be carried out by farmers by themselves. And therefore, it seemed not applicable technologies for small-scale agronomies.

PR elution characteristics are known to be substantially improved by high-temperature calcination (Bolan *et al*., 1993; Ando, 1987). The high-heat processed phosphorus (P) fertilizer is widely used and is called “calcinated phosphate fertilizer” and/or “fused phosphate fertilizer.”

Calcinated phosphate fertilizer is the P fertilizer that has improved citric acid solubility by the defluorination process with high-heat processing at 1300 °C and addition of Na_2O, leading to the production of α-tricalcium phosphate and, partially, rhenanites ($CaNaPO_4$). Fused phosphate fertilizer is obtained by melting some of the components in addition to PR (Bolan *et al*., 1993). In Japan, fused magnesium phosphate fertilizer is widely used.

However, these calcination and fusion treatments need costly facilities and advanced techniques like for some chemical procedures for PR solubilization. They cannot be applicable to farmers in the developing countries. However, several studies have suggested low-temperature calcination enhanced low-grade PR solubility, which might allow the development of farmer-applicable technology for Burkina Faso PR (BPR) solubilization.

Therefore, this study investigated the effect of low-temperature calcination on the improvement of BPR solubility. The applicability of low-temperature calcination technology by using Kun-tan (biochar) prepared using indigenous saw dust and rice husk was also evaluated.

METHODS

Material and Calcination procedure

In our study, PR produced in Kodjari, Burkina Faso (BPR), was investigated. BPR mainly consists of Fluorapatite ($Ca_5(PO_4)_3F$) and Quartz(SiO_2), and the P_2O_5 contents in BPR was 34.1% (Nakamura *et al*, 2015).

The BPRs were calcinated using Muffle furnace for 1, 2, 4, and 8 h at 6 levels of temperature from 100 °C to 600 °C at 100 °C intervals. After calcination, BPR was placed in a desiccator for cooling. Then, the calcinated BPR was analyzed as low-temperature calcinated PR sample (LTC-BPR).

Chemical analysis

The solubility of BPR and LTC-BPR was analyzed by water extraction and 2 % citric acid extraction. About 25 mL of the two solvents were added to 0.25 g of samples. After 16 h of shaking, the samples were centrifuged for 5 min at 3000 rpm. The P contents in the supernatant were determined using the molybdenum blue method by adding ascorbic acid. The absorbance was detected at 710 nm by using UV visible spectrophotometry (Shimadzu, UV2400PC). The ignition loss after calcination was determined as the difference of sample weight before and after calcination; 2.5 g of BPR was ignited at 100 °C to 800 °C.

Kun-tan generation and temperature changes during the charring process

We focused on the biochar making process, which was available as one of pretreatments for organic materials, as a farmer-affordable heat production technology. Low-temperature calcination of BPR has possibility to improve solubility using the heat produced by the charring of organic materials.

In the Equatorial forest zone, saw dust charring by using Kun-tan charring was preliminarily carried out. Saw dust is one of the abundant unused organic wastes produced from timber processing. The saw dust was collected from a timber mill located in Kumasi. In the Guinea savanna zone, rice husk charring was attempted. Rice husk can be used in every rice field. Rice husk was collected from a rice mill.

In this study, the equipment for Kun-tan charring was used (Figure 1; Honma Factory Co. Ltd.) as an alternative heat source. The Kun-tan was charred as follows: (1) A few wood pieces were placed inside the Kun-tan maker as ignition woods. (2) After wood pieces were ignited, the fire wood was covered by the Kun-tan maker. (3) The mixture of saw dust and BPR was set around the Kun-tan maker. (4) After white smoke was generated, a black spot would appear on the surface. (5) When the surface was charred, the samples were mixed. 6) When completely charred, the fire was

Figure 1 Kun-tan maker (Honma Factory Co. Ltd. Nigata, Japan)

extinguished by water. The charred saw dust was then dried.

The temperature changes during charring were monitored using a thermometer (CT-05SD; CUSTOM) with a high temperature sensor (LK-1200i). The sensor was placed at the center of saw dust and/or rice husk char (length, 5 cm from the Kun-tan maker; height, 5 cm from the ground surface).

RESULTS AND DISCUSSION

Ignition losses of BPR

Ignition losses of BPR with low-temperature calcination are shown in Figure 2. The ignition loses increased with temperature increase. Doak *et al.* (1965) reported that low-temperature calcination of PR, produced in New Zealand, increased the ignition losses, which reached the maximum at about 500 °C. During BPR calcination, ignition losses continued to increase up to 800 °C in this experiment. Doak *et al.* (1965) indicated that the ignition loss maximum in New Zealand PR was about 18 % at 500 °C, whereas BPR showed relatively lower ignition loss (4.5 %) even at 800 °C calcination.

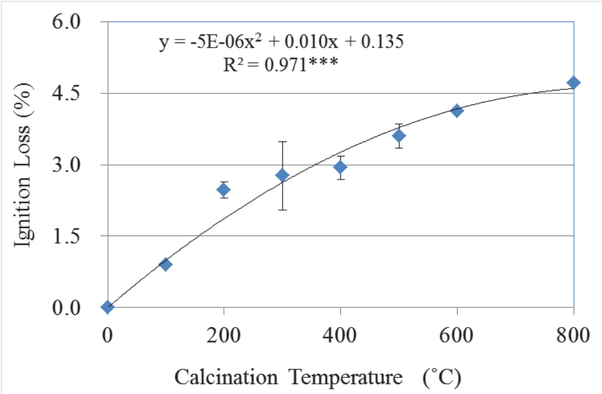

Figure 2 Ignition losses of BPRs with low-temperature calcination
Error bars indicate the standard error (n = 3)

The difference in ignition losses in two PRs seemed to suggest that various PRs have different thermal properties, reflecting the chemical and/or mineralogical composition of the PRs. New Zealand PR is guano-origin phosphate hydrate minerals which has crystallization water, such as Crandallite ($CaAl_3(PO_4)_2(OH)_5{\bullet}H_2O$) and Millisite ($(Na,K)CaAl_6(PO_4)4(OH)_9 {\bullet}3(H_2O)$). But BPR consists of Fluorapatite without crystallization water. Thus, the effect of low-temperature calcination on PR solubilization might be different depending on the occurrence of PR, because of its chemical composition.

PR solubilization by using low-temperature calcination

Water-extractable P indicated the lowest value at 400 °C calcination (Figure 3). The LTC-BPR at 400 °C showed definite decrease in water solubility, i.e., 0.21 to 0.27 g P·kg^{-1} of water-extractable P, whereas BPR at room temperature contained 0.86 g P·kg^{-1} of water-extractable P.

Kimiwada *et al*. (2010) reported that the decrease of water-extractable P in poultry manure ash up to 800 °C because of low-temperature calcination. However, the increasing trend was observed over 400 °C calcination (Figure 3). The increase of water-extractable P might be attributed to the vitrification of some phosphate. However, detailed investigation will be required to determine whether vitrification occurs during low-temperature calcination.

Citric acid-extractable P showed the highest value around 300 °C to 400 °C calcination, unlike water-extractable P (Figure 4). BPR at room temperature contains 34.1 $g \cdot kg^{-1}$ of citric acid-extractable P, and it markedly increased to 46.1 $g \cdot kg^{-1}$ at 300 °C and 45.8 $g \cdot kg^{-1}$ at 400 °C calcination. The ratio of citric acid-extractable P against total P in BPR was 22.86 % at room temperature, but LTC-BPR at 300 °C has 30.95 % and LTC-BPR at 400 °C contained 30.73 % of citric acid-extractable P against total P in BPR. In addition, citric acid-extractable P was considered as the fraction indicating the plant available P.

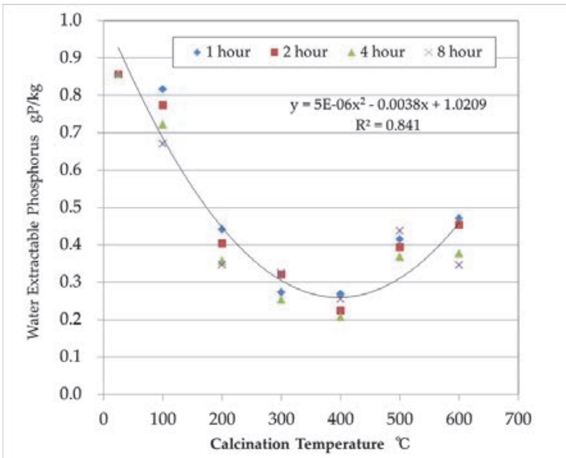

Figure 3 Changes in the water solubility of BPR after low-temperature calcination.

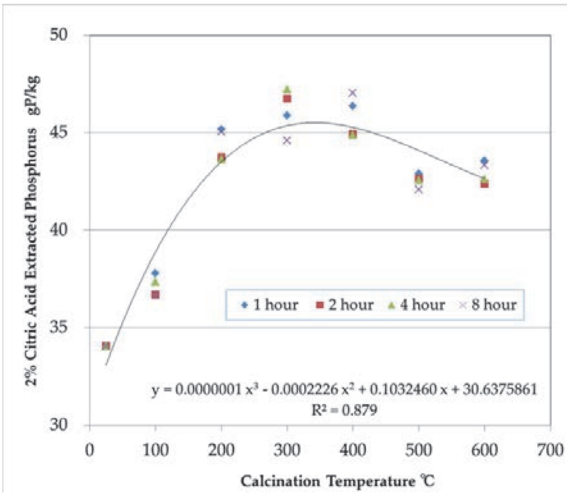

Figure 4 Changes in solubility of 2 % citric acid of the BPR by low-temperature calcination.

The largest decrease of water-extractable P was 0.59 $g \cdot kg^{-1}$ from un-calcined BPR, whereas the largest increase of citric acid-extractable P was 12.0 $g \cdot kg^{-1}$. These results suggested that calcination around 300 °C to 400 °C can enhance the BPR solubility, especially of the citric acid-extractable fraction, whereas water solubility was slightly reduced.

The time for calcination did not affect BPR solubility in both water and citric acid, suggesting that 1 h of calcination is sufficient to enhance the solubility of BPR.

The development of a farmer-applicable procedure for low-temperature calcination

As described above, if maintaining the temperature of about 350 °C for 1 h is feasible without high cost equipment, BPR could be calcinated, remarkably improving its citric acid solubility. The time-sequential temperature changes during the process of Kun-tan making with sawdust (A) and rice husk (B) are shown in Figure 5. The temperature during saw dust charring rapidly increased at 15 min after ignition and reached 300 °C in almost 30 min (Figure 5A). The saw dust temperature was maintained 300-360 °C for about 120 min.

As can be seen from Figure 5A, saw dust charring by using the Kun-tan method can produce sufficient heat for low-temperature calcination of PR.

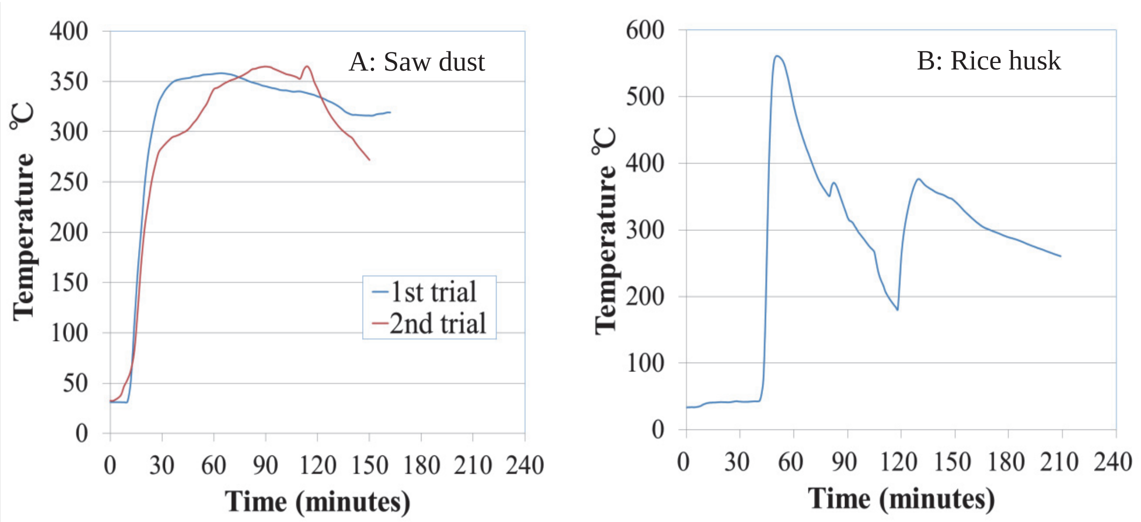

Figure 5 Temperature changes during the Kun-tan making process by using sawdust (A) and rice husk (B)

The time-sequential temperature changes during the rice husk charring are shown in Figure 5B. The temperature during rice husk charring rapidly increased in about 40 min after ignition and reached the maximum temperature of 560 °C. Subsequently, the temperature was maintained at about 400 °C for approximately 30 min. Then, the temperature decreased gradually until the end of charring. Unlike in the case of saw dust charring, rice husk charring did not keep the constant temperature. However, the mean temperature during rice husk charring was about 330 °C.

Low-temperature calcination with saw dust or rice husk charring are estimated to solubilize 9 to 10 % of the total P in BPR, as expected using the equation calculated from Figures 2 and 3.

Although the amount of solubilized P was extremely small for agricultural effectiveness, this technology might be improved by calcination with carbonate addition. Akiyama *et al*. (1992) showed that calcination with sodium carbonate remarkably improved the solubility of low-grade PR. Moreover, Nakamura *et al*. (2015) indicated that BPR solubility for 2 % citric acid solution can be strongly enhanced by calcination with sodium carbonate.

CONCLUSIONS

Our results suggested that improving BPR solubility by low-temperature calcination can be a potential technical option, through charring of saw dust or rice husk which are readily available organic resources for farmers in the Equatorial Forest and Guinea savanna zones. The Kun-tan method can be applied in various regions by using various crop husks or powdered organic compounds. Although low-temperature calcination enhanced the citric acid solubility of PR by 10 g $P \cdot kg^{-1}$, further investigation would be required to determine the effect of low-temperature calcination with various types of carbonates on BPR solubility.

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Technology for the solubilization of phosphate rock and its advantages—Phosphate rock solubilization via rice straw composting

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INTRODUCTION

The effect of phosphate rock (PR) direct application is inferior to that of water-soluble P fertilizer; however, the availability of PR to plants can be enhanced using many biological, chemical, and physical methods (FAO, 2004; Nakamura *et al*., 2013). Among the suggested technologies for PR solubilization, chemical and physical methods involve the use of fertilizers factories, whereas biological methods can be implemented by farmers. Chemical and physical methods cannot be afforded by small-scale farmers.

Biological methods promote the dissolution of minerals via the interaction between microbes and plants (Nakamura *et al*., 2013). Organic matter composting enriched with PR has been widely reported to accelerate the dissolution of PR with organic acid production during microorganism proliferation during the composting process. Recently, the inoculation of particular phosphate-solubilizing microorganisms has been investigated for preparing PR-enriched compost (Zayed and Abdel-Motaal, 2005).

In this study, the effectiveness of PR-enriched rice straw composting that can be possibly applicable for farmers was elucidated as a biological PR dissolution technology.

MATERIALS AND METHODS

Research site

The experiment was conducted at the Tropical Agriculture Research Front (TARF) of the Japan International Research Center for Agricultural Sciences (JIRCAS) at Ishigaki Island of Okinawa Prefecture.

Treatments

The experiment was conducted for rice straw (RS) composting with PR yielded in Kodjari deposit in Burkina Faso. The RS were inoculated with Aspergillus niger at the initial (+ANi) and delayed timing (+ANd) of those composting process, and one treatment included no inoculation (Non-AN). A. niger which has been previously evaluated as the PR-solubilizing fungus by Hellal *et al* (2013), was selected and inoculated. The composts received 0 % (PR0), 5 % (PR5), and 10 %

(PR10) of PR against dry matter weight.

A. niger was pre-incubated on potato dextrose agar medium for 3 days. Next, the suspended culture was added to the medium consisting of 10 kg sea sand (Wako sea sand; 425–850 μm) and 1 kg wheat flour. The medium culture was incubated for 5 days in 30 °C. The inoculated medium was applied to RS at a rate of 25 g medium against 1 kg DM. Further, 150 g of ammonium sulfate was added to the compost for the acceleration of microbial activity. The treatments are listed in Table 1.

The water contents were maintained to approximately 60 % during composting. The composting trial was conducted for 56 days in the green-house of the Japan International Research Center for Agricultural Sciences (JIRCAS) at the Tropical Agricultural Research Front (TARF), at Ishigaki Island (24˚N, 129˚E). The composts were turned, and samples were collected once per week.

Table 1 Treatments of rice straw composting experiment

ID	Treatment	Rice Straw	*A.Niger* medium	Inoculation timing	PR	Ammonium sulfate	Initial P contents
		g DM			g		$mgP\ kg^{-1}$
1	Non-AN PR0	7500	0	None	0	150	686
2	Non-AN PR5	7500	0	None	375	150	7617
3	Non-AN PR10	7500	0	None	750	150	13929
4	ANi PR0	7500	187.5	DAT 0	0	150	670
5	ANi PR5	7500	187.5	DAT 0	375	150	7443
6	ANi PR10	7500	187.5	DAT 0	750	150	13624
7	ANd PR0	7500	187.5	DAT 28	0	150	670
8	ANd PR5	7500	187.5	DAT 28	375	150	7443
9	ANd PR10	7500	187.5	DAT 28	750	150	13624

Procedure on monitoring and chemical analysis

The compost temperature was monitored using a thermocouple with a three-point averaging circuit placed at the center of the samples. Data were collected every 30 min. And the soil temperature were monitored as the reference. The compost samples for chemical analysis were sampled from three points of the container. Collected samples were oven-dried at 80 °C for 48 h and crushed (dried sample), or were stored at 4 °C and shredded to obtain approximately 5 to 10 mm long pieces by using hand scissors (fresh sample).

The total nitrogen and carbon were determined by using the dry combustion method by using Sumigraph NC-220 (Sumika Chemical Analysis Service, Ltd.).

Sequential P extraction was conducted as reported by Hedley *et al*. (1982) and Frossard *et al*. (1994). This sequential extraction can fractionate P into four fractions. The first step involved the extraction of the inorganic and organic forms of P with water. Next, $NaHCO_3$ (0.5 M at pH 8.5) was used to extract other labile forms of P (inorganic and organic); 0.1 M NaOH extracted the inorganic P absorbed on mineral and organic colloids and the organic P present in humic and fulvic compounds; and 1.0 M HCl solubilized the calcium phosphates. After each extraction, 2.5 M sulfuric acid was added to the extract, and inorganic P content was determined colorimetrically at 710 nm (Murphy and Riley, 1962). The precipitation was re-fused and diluted, and then P concentration in this solution was determined using inductively coupled plasma emission spectrometer (ICPE-9000; Shimadzu). In this study, precipitated P was defined as organic P form. And among the four fractions in sequential fractionation, authors defined sum of water soluble inorganic P and $NaHCO_3$ extractable inorganic P as plant available P. Water-soluble inorganic P concentration was measured for both dried and fresh samples.

RESULTS AND DISCUSSION

General information about composting process

The changes in C/N ratio are shown in Figure 1a. The C/N ratio of rice straw, which is the main material of compost, was 58.3 at the beginning of this study. But at 56 days after treatment (DAT), most of the composts showed decreased values around 15 to 17. It suggest that the samples in each treatment were successfully composted. Decreasing C/N ratio is one of the indices for composting stage of organic materials.

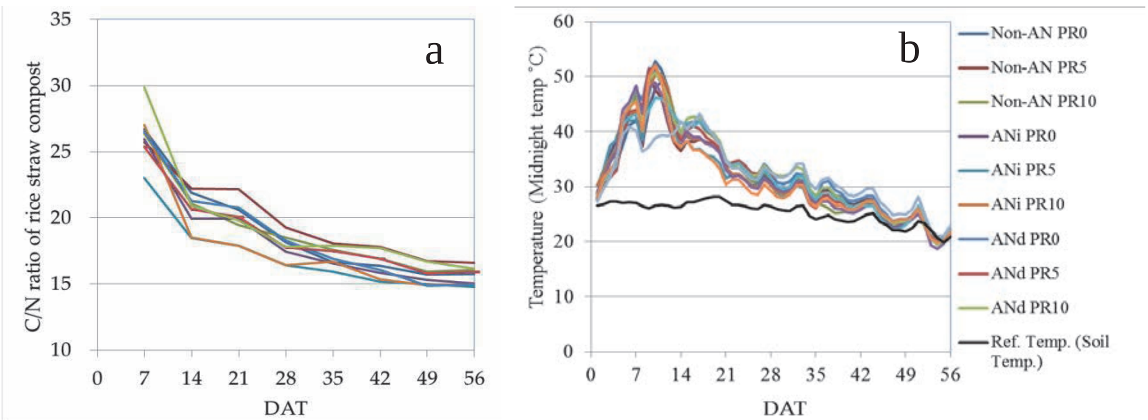

Figure 1 Changes in C/N ratio (a) and compost temperature (b) during rice straw composting. Legends are common to a and b.

The temperature changes in compost samples during the composting period are shown in Figure 1b. Observed midnight temperature showed the highest value of over 50 °C at DAT 9 to DAT 11 and gradually decreased after DAT 30. Difference between sample and soil temperatures also gradually reduced after DAT 30. From these of C/N ratio and temperature, the composting process was thought to reach the peak of primary fermentation at almost 2 weeks after treatment, and the second fermentation was started almost after DAT 30. Therefore, days from initial to DAT 30 were defined as primary fermentation period, and days from DAT 30 to the end of composting were defined as second fermentation period in this trial.

Effect of rice straw composting on PR solubilization

Results of P fractionation in the compost of DAT56 were shown in Table 2. Total P content and HCl extractable P content increased with PR addition rate. It means most of PRs remained as mineral form at DAT56, although available P content increased with PR application. On the other hand, available P content, which is sum of inorganic forms of water soluble P and $NaHCO_3$ soluble P were higher in PR5 and PR10 than those in PR0. PR was partly solubilized and became plant-available form through composting process. Furthermore, inorganic P in NaOH extractable fraction indicated clear increasing with PR addition. NaOH extractable fraction was not defined as plant available, because P in this fraction seemed complexed with mineral and/or organic colloids. But it also suggest that mineral form of PR was solubilized and complexed with colloids. Therefore, it can be considered that results suggested PR can be solubilized via rice straw composting.

Table 2 P concentrations (mg P kg^{-1}) at DAT 56 in each fraction determined by Hedley's sequential fractionation method.

Treatment		Water		$NaHCO_3$		NaOH		HCL	Total P	Ava-P	
		Inorg	Org	Inorg	Org	Inorg	Org	Inorg		Ave.	S.E.
		mg P $kgDM^{-1}$									
Non AN	PR0	115.1	118.6	64.6	73.7	79.9	121.9	101	675	179.7	9.9
	PR5	161.6	87.1	100.4	63.7	141.5	108.4	5762	6425	262.0	17.2
	PR10	171.1	88.1	101.3	97.9	233.5	71.1	12493	13256	272.4	25.2
ANi	PR0	97.9	117.0	69.2	79.3	83.5	102.6	146	696	167.1	22.0
	PR5	129.7	118.5	99.0	49.7	193.0	133.9	6473	7197	228.7	23.0
	PR10	164.2	126.2	102.7	98.7	258.3	105.1	9650	10505	266.9	14.1
ANd	PR0	85.8	94.8	74.3	164.7	74.3	105.4	87	686	160.1	18.0
	PR5	179.7	79.7	84.8	35.6	101.9	108.8	5177	5767	264.5	42.0
	PR10	239.1	80.1	97.6	75.5	175.5	93.3	9984	10745	336.7	15.1

PR5 showed 1.46- and 1.37-times higher available P value than that at PR0, and PR10 showed 1.52 and 1.60 times higher available P values than those of PR0 (Figure 2). And the effect of initially inoculated A. niger was not observed. Conversely, for ANd, delayed inoculation with A. niger, relatively higher P was noted than that for other treatments, i.e., 1.66 times at PR5 and 2.10 times at PR10 higher than that at PR0 (Figure 2).

ANi did not affect PR solubility of the rice straw compost. It is well known that *Aspergillus spp*. becomes extinct around 60 °C (e.g. Fujikawa 2002), therefore *A. niger* applied in this trial might have been destroyed at 60 °C, and primary fermentation developed fever over 60 °C in this trial at daytime. Therefore, most of the applied microorganisms might have become extinct by high temperature during the primary fermentation, or by the reproduction of contaminated microorganisms. The spores of fungi can survive under this condition, but whether the growth stage of *A. niger* in compost already reaches the sporulation phase or abjection phase at DAT 9 to 11 when the maximum temperature was recorded is not known. The effect of *A. niger* application on PR dissolution needs to be determined. For example, the application timing might have to be changed to later such as that for the second fermentation period, for avoiding high temperature of primary fermentation.

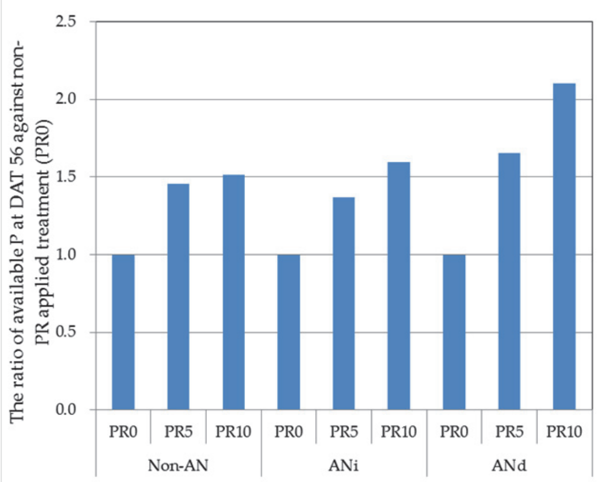

Figure 2 The effectiveness of rice straw composting for PR solubilization at DAT 56
The ratio of available P at DAT 56 against non-PR applied treatment (PR0)

Inoculation of A. niger, as a microorganism producing organic acid, can contribute to the enhancement of PR solubilization in the case of delayed inoculation. The available P content of non-AN and ANi showed almost the same values, but ANd indicated higher available P than those in non-AN and Ani.

CONCLUSION

In general, composting can be considered as an effective technology for Ghanaian rice production because of several reasons, such as mineral nutrient concentration, decreasing C/N ratio, and avoiding pest and disease risk. Furthermore in this study, authors suggested that the phosphate rock solubilization technology by using composting process is effective to dissolve phosphate rock even without the addition of microorganisms such as *Aspergillus niger*, but the inoculation of *A. niger* seemed to enhance PR solubilization. And we suppose that *A. niger* inoculation should be done after primary fermentation, to avoid extinction by high heat. In the rice straw compost, the final available P was increased with the PR application rate. The rice straw composting process might be considered to be useful as a PR solubilizing technology.

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Effects of pre-seed and seedling treatment by phosphorus fertilizer on growth and grain yield of lowland rice

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INTRODUCTION

Rapidly increasing costs of fertilizers and lack of purchasing credit for farmers have led to the inability to access sufficient quantity of fertilizers, particularly in developing countries, resulting in low crop production. In addition, the loss and low use efficiency of fertilizers can be noted in common fertilizer application methods such as spreading fertilizer over the field. Hence, reducing the loss of fertilizer per planting area and increasing fertilizer use efficiency are necessary. Fertilizer seed coating and seedling soaking methods have long been considered as the options to reduce the quantity of fertilizer use in agriculture; however, the information regarding these methods is still lacking. This study aimed to investigate the potential of using small quantity of chemical fertilizer to improve the early growth of rice seedlings in a lowland system.

MATERIALS AND METHODS

In a pot experiment, the shoot dry matter (DM) of *indica* rice (*Oryza sativa* L. cv. IR74) after seedling soaking and seed coating with small quantity of P fertilizers was determined on acidic low P soil for three replications. For seedling soaking trial, a 6–7 leaf seedling was soaked in 1 % and 5 % (w/v) NPK (14-14-14) or potassium dihydrogen phosphate (KH_2PO_4-KP) for 30 and 60 min, transplanted, and grown for 75 days on zero basal P fertilizer applied- and applied- soils (331.4 mg $Ca(H_2PO_4)_2$ / 3 kg soil). Other basal fertilizers were applied regarding Ros *et al*. (2000). For seed coating trial, rice seeds were coated with ground Burkina Faso phosphate rock (BPR), NPK, and KP at the rate 1.2 and 2.4 mg fertilizer per seed, directly sowed, and grown for 40 days in a pot experiment. Both studies were conducted at the Tropical Agriculture Research Front (TARF) in Ishigaki, Japan.

Another seed coating experiment was conducted at the on-station field of the University for Development Studies, Tamale, Ghana. For this, triple superphosphate (TSP)-coated seeds were prepared by mixing the seeds (GR18), soil, and TSP at a ratio of 10:10:1 with some water and air-dried before use (Photo 1). The coated seeds were cultivated on low P soil and fertilized with three rates of P fertilizers (0 P, 135 kg $P_2O_5 \cdot ha^{-1}$ as BPR and as TSP, respectively), and three rates of organic residues: control without organic residue application (NoR); 2 $t \cdot ha^{-1}$ rice straw, RS; and 1.5 $t \cdot ha^{-1}$ cattle manure, CM, for 6 replications. The experimental design was randomized complete block design. The grain yield was observed after cultivation.

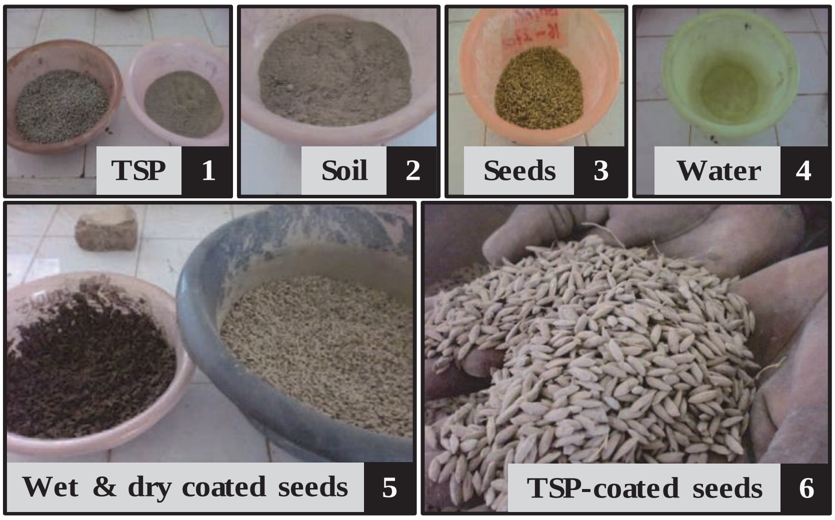

Photo 1 Materials used for fertilizer seed coating conducted in the field trial; (1) Ground TSP, (2) Soil, (3) Rice seeds, (4) Water, (5) Coated seeds during wet and air-dried conditions, and (6) TSP-coated seeds ready for use.

RESULTS AND DISCUSSION

In the pot experiment, coating seeds with KP and 30-min soaking the seedlings in KP significantly increased DM (Figures 1 and 2). From Tables 1 and 2, agronomic efficiency of P of KP-coating and soaking were higher than those of P fertilizers used for seed and seedling pre-treatment. By using KP-coating and soaking could reduce amount of P fertilizers for rice growth. Estimated P fertilizer saving rate of the seedling soaking technique was 40 % relative to that of chemical fertilizer (Fukuda *et al*., 2013). Both methods improved the early growth of rice seedlings and were expected to reduce the loss of fertilizer per planting area and to save farmers' credit for fertilizer purchasing at the early cropping season (Fukuda *et al*., 2012).

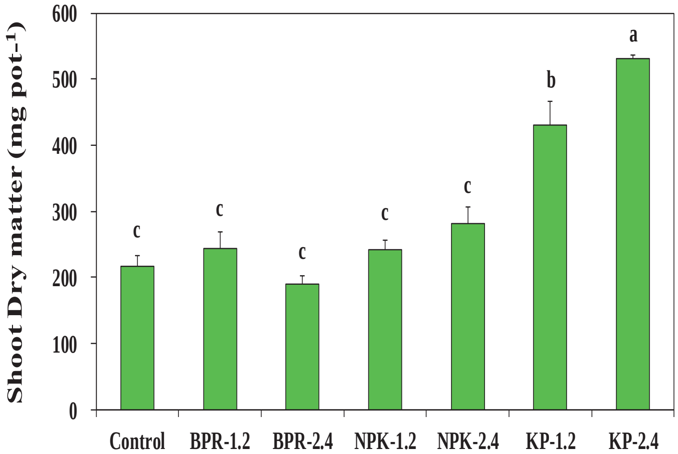

Figure 1 Shoot dry matter or rice plant (IR74) as affected by fertilizer seed coating at 40 days after sowing. Fertilizer application rates were 1.2 and 2.4 mg fertilizer seed^{-1})

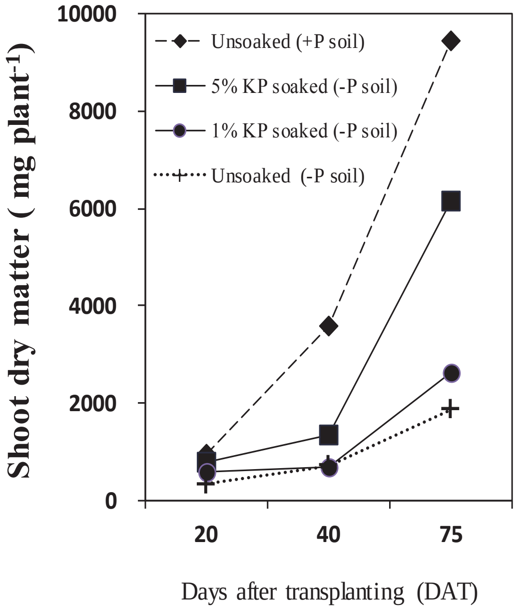

Figure 2 Shoot dry matter of rice (IR74) after soaking seedlings in 1 % and 5 % KH_2PO_4 (KP) for 30 min before transplanting compared with un-soaked seedlings grown on non P (-P) and P (+P) applied soils obtained at 20, 40, and 75 days after transplanting (DAT).

Table 1 Agronomic efficiency of P of the rice plants obtained at 20 and 40 days after sowing as affected by fertilizer seed coating (Pot experiment)

Coating fertilizer	Applied P	Agronomic efficiency of P (AEP) †	
		Days after sowing (DAS)	
	(mg/seed)	20	40
BPR-1	0.18	32	151
BPR-2	0.36	(nil)	(nil)
NPK-1	0.07	(nil)	349
NPK-2	0.15	(nil)	434
KP-1	0.27	64	781
KP-2	0.55	24	575

†Agronomic efficiency of P = ($DM_{amended}$ - $DM_{control}$)/(Total P added)

Table 2 Agronomic efficiency of P of rice plants obtained at 75 days after transplanting as affected by seedling soaking for 30 min before transplanting (Pot experiment)

Soaking solution	Applied P/seedling† (mg)	Shoot DM (mg)	Agronomic efficiency of P (AEP)††
Non-soaked (-P soil)	0.0	1,854	-
1% KP	452	2,622	1.71
5% KP	2261	6,142	1.90
1% NPK	122	1,602	-2.10
5% NPK	612	1,759	-0.16
Non-soaked (+P soil)	17.5	9,442	433

†Fertilizer solution 3 L per 15 seedlings, ††Agronomic efficiency of P = (DM amended - DM control)/(Total P added)

In the on-station trial, TSP-coated seeds showed increased rice grain yield, particularly in BPR and RS co-applied soils (Figure 3). The increased grain yields were 449 and 481 kg·ha^{-1} in BPR and TSP fertilized soils without OR application, respectively. Under RS application, increased yields were 657 and 797 kg·ha^{-1} in P0 and BPR application, respectively. Under CM application, the increased grain yield was 263 kg·ha^{-1} in non-P treatment (Table 3). This implied the positive results of using the seed coating technique to improve the rice grain yield. Moreover, the seed coating could be used either when inorganic and organic fertilizers are being solely- or co-supplied to the soils.

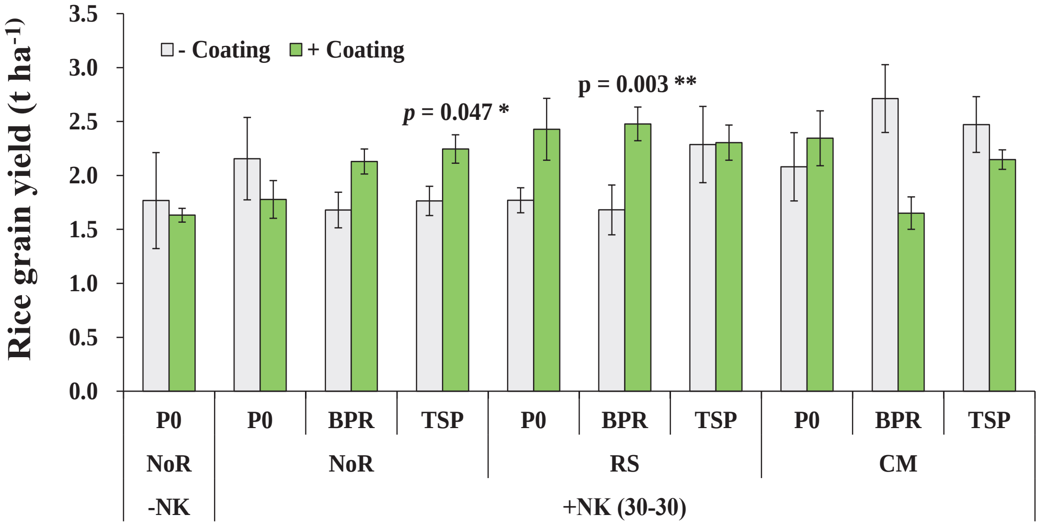

Figure 3 Grain yield of rice (GR18) as affected by seed coating under various co-applications of inorganic fertilizer and organic residue at the on-station experiment. Bars indicate SE (n = 4).

Table 3 Increased rice (GR18) grain yield as affected by triple superphosphate (TSP) seed coating compared to that of uncoated seeds at the on-station experiment

Basal fertilizer	Organic residue	P Fertilizer	Increased grain yield ($kg\ ha^{-1}$)	Significance
-NK	NoR	P0	-	
+NK	NoR	P0	-	
		BPR	449	*
		TSP	481	*n.s*
	RS	P0	657	*n.s*
		BPR	797	**
		TSP	19	*n.s*
	CM	P0	263	*n.s*
		BPR	-	
		TSP	-	

*, ** Significance at $p < 0.05$ and 0.01, respectively and *n.s.* = non-significance (Student's t-test)

According to our on-station experiments, coating rice seeds with small amount of TSP increased rice grain yield. Other benefits of the method, such as reducing the amount of used fertilizer and labor, saving money for purchasing fertilizer, easy handling, and adding P elements and other nutrient compounds to soil, have been also expected.

The fertilizer seedling soaking method has been tested only in a pot experiment. The results indicated positive effects on the early growth of plants and improved the agronomic efficiency of P; however, further investigations conducted in fields are necessary. Similarly, the beneficial effects of soaking method are expected through the returning of fertilizer-soaking solution to the field and strengthening young rice seedlings to cope with low P in soils. From our calculation, 3 L of 5% KP could be used for 500 seedlings of rice plant.

In Ghana, very low rate of P fertilizer application and zero-fertilization are common and become typical constraints of rice production under the ordinary rice cultivation system. Although, the utilization of locally available organic resources has been well documented for improving soil and crop productivity (Issaka *et al*., 2012; FAO 2006; Buri *et al*., 2005). In Guinea Savanna agro-ecological zone, where seed direct sowing is a major system of rice cultivation, the fertilizer seed coating technique should be useful. Conversely, seedling soaking can be adopted under the transplanting system that is practiced in the lowlands of the equatorial forest zones.

The advantages of utilizing small amount of chemical fertilizer in lowland rice cultivation system included facilitation of small-scale farmers to maintain desired crop production in a short term when fertilizer sources and labor are limited and helping farmers in delayed fertilizer application until they can obtain all the fertilizers needed for the crops. Moreover, the costs for handling of seed coating and seedling soaking techniques are relatively lower than those for the complete doses of chemical fertilizer for crops. Therefore, appropriate selection of the types or forms of accessible fertilizers and addition of seed and seedling treatment options such as soaking or coating might facilitate farmers to obtain more yield production while lowering the expenditure for rice production.

CONCLUSIONS

The utilization of small quantity of fertilizer could increase the early growth of plant and crop productivity, reduce losses, and increase the efficiency of fertilizer P. Applying small quantity of fertilizer directly to the seeds or seedlings might benefit farmers in managing fertilizer sources and the time of application when sufficient amount of fertilizers are not easily available.

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Blending science with indigenous knowledge: An Assessment of rice farmers' views on soil improvement technologies in Northern Ghana

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INTRODUCTION

Rice is a staple food for more than half of the world's population (Amissah *et al*., 2003). Since 2009, rice has achieved the status of the second most important staple crop after maize in Ghana (Ministry of Food and Agriculture, 2009). This indicates the important role of rice in ensuring household food security in the country. One major constraint that affects Ghana's domestic rice production is the declining soil fertility which results in very low yields. Despite the poor soil fertility conditions which negatively affect food crop production(Rhodes 1995), most subsistence farmers in northern Ghana cannot afford chemical fertilizers owing to their high price (Yiridoe, *et al*., 2006). Consequently there is an imbalance in the demand and domestic supply of rice, forcing reliance on huge imports of rice to fill the gap. Agricultural soil management performed using adapted local resources and knowledge systems are known to have a potential for improving production for subsistence farmers (Yiridoe, *et al*. 2006). The present study assessed farmers' accessibility, acceptability, and the affordability of local resources for soil fertility improvement in the savanna lowlands of northern Ghana. The benefits derived from the use of local resources for improving soil fertility were estimated. Our findings could contribute to a better understanding of the resources available to mitigate the production constraints of subsistence rice farmers in Ghana.

MATERIALS AND METHODS

Participatory rural appraisal

This study used both socio-economic and agronomic data collected from sampled rice farmers in northern Ghana. The socio-economic data was collected through the application of participatory rural appraisal techniques as well as in-depth interviews using a checklist and questionnaires. Participatory methodologies have become popular for assessing development and technological interventions (Dietz *et al*. 2009). The agronomic data was generated from on-farm rice production trials conducted by the UDS in collaboration with JIRCAS at sites located in the northern region of Ghana.

Profitability analysis

The socio-economic data was analyzed descriptively by using statistical measures such as means and percentage distribution. The profitability of soil improving technologies was determined by partial budgeting. The main cost components included those for land preparation, planting, weeding, harvesting and threshing, rice seed and fertilization (eight technologies), and transportation. Farmers' conditions were determined using prevailing market prices for inputs and outputs. A similar approach was adopted by Langyintuo and Dogbe (2005). Benefits to farmers were estimated using the benefit–cost analytical technique (Gittinger, 1984). Generally, the profit equation is given as follows:

Gross margin (profit) = PQ - TC

Where PQ = Gross income and TC = Total variable cost.

The types of soil improvement technologies (Fertilizers) are defined in Table 1.

Table1 Soil improvement technologie

Treatment Type	**Definition**
Zero	No treatment
NK	Nitrogen/Potassium (Non-Phosphorus)
NK + PR	Nitrogen/Potassium + Phosphate Rock (PR)
CD/RS + NK + PR	Cow dung/Rice straw compost + Nitrogen/Potassium + PR
HE/RS + NK + PR	Human excreta/Rice straw compost + PR
TSP + NK	Triple superphosphate + Nitrogen/Potassium
RS	Rice Straw Only
RS + NK	Rice Straw + Nitrogen/Potassium

RESULTS AND DISCUSSION

According to the farmers, cow dung (dropping from cattle), compost, ashes (prepared from rice straw), and charred rice straw were readily available in their communities. However, the farmers were concerned about how to obtain the recommended quantities of these materials for their rice fields (Figure 1). A majority of respondents (73.3 %) believed that using human excreta for agriculture purposes is inappropriate. Some respondents indicated that they might not consume food produced using human excreta as fertilizer. Religious, cultural, and social believes other than health reasons are the cause of the strong objections to the use of human excreta for soil improvements in the area. Charred rice straw (Kun-tan) is the most promising technology since it completely meets the triplicate criteria of accessibility (Figure 1), acceptability (Figure 2) and affordability (Figure 3). Compost, which is produced mainly from animal droppings and crop residues is accessible in the communities but the farmers feel that it is not a suitable soil improvement technology (fertilizer) for rice fields. The farmers opined that they would rather use compost for their upland maize farms, instead of the rice fields.

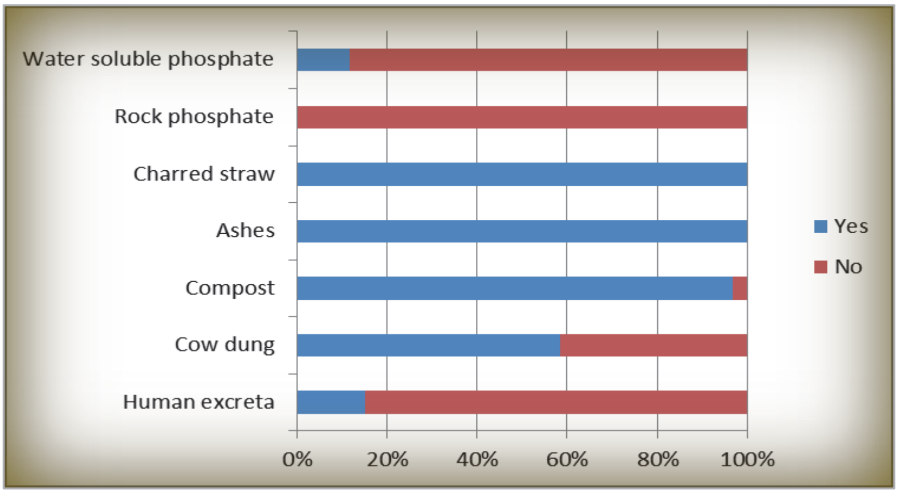

Figure 1 Accessibility in percentage of respondents

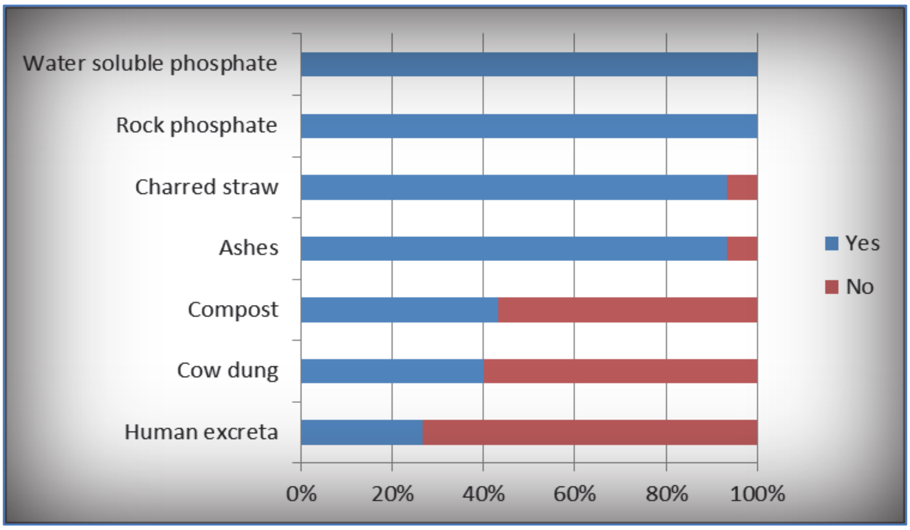

Figure 2 Acceptability in percentage of respondents

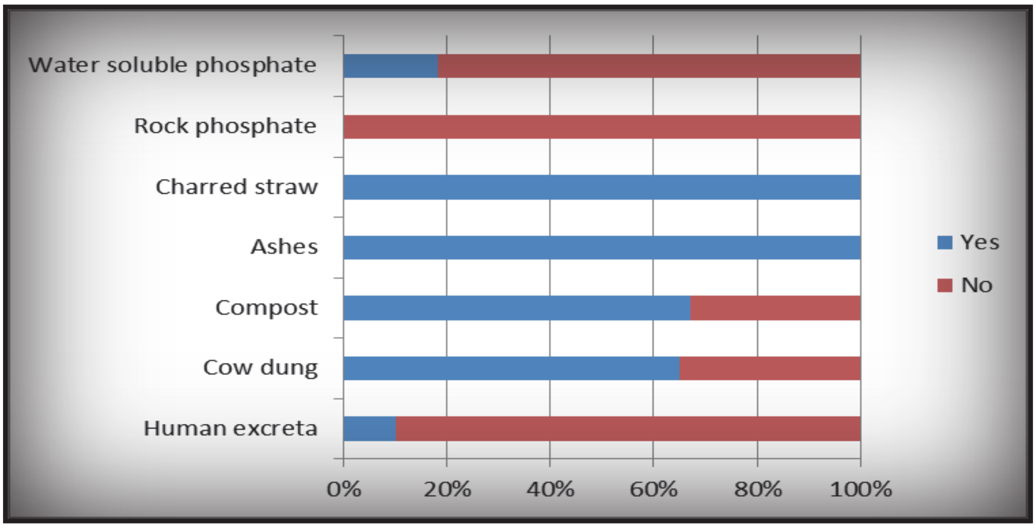

Figure 3 Affordability in percentage of respondents

Results of Profitability Analysis

The HE/RS + NK + PR treatment yielded the highest gross margin of GHS 1,681.28, followed by NK + TSP and CD/RS + NK + PR (compost) with gross margins of GHS 1582.88 and 1528.62, respectively (Table 2). Zero treatment and RS produced the lowest and second lowest gross margins of GHS 815.84 and GHS 1,008.89 respectively. However, in terms cost of production, the HE/RS + NK + PR treatment posted the highest cost of GHS 530.8/hectare. With the second and third highest cost of production going to the RS +NK and CD/RS + NK + PR (compost) respectively. The lowest and second lowest cost of production was realized from the zero treatment (GHS 290.2) and RS (GHS 345.3). In terms of yield, the HE/RS + NK + PR treatment produced he highest paddy of 3.12 tons/ha, followed by NK + TSP and CD/RS + NK + PR (compost) with average yields of 2.92 tons/ha and 2.88 tons/ha respectively (Table 2). Zero treatment and RS produced the lowest and second lowest paddy yield of 1.56 tons/ha and 1.91 tons/ha respectively. Such results, clearly indicates that farmers in the area need to add fertilizes in order to obtain higher yields.

Table 2: Results of profitability analysis of soil improving technologies

Treatment Type	number of samples	Rice Yield ton/ha	price per/ton GHS)	Gross income (GHS)	Total variable cost* (GHS)	Gross margin (GHS)
Zero	7	1.56	709	1,106.04	290.2	815.84
NK	7	2.42	709	1,715.78	453.6	1,262.18
NK+PR	7	2.56	709	1,815.04	493.5	1,321.54
CD/RS+NK+PR	7	2.88	709	2,041.92	513.3	1,528.62
HE/RS+NK+PR	7	3.12	709	2,212.08	530.8	1,681.28
NK+TSP	7	2.92	709	2,070.28	487.4	1,582.88
RS	7	1.91	709	1,354.19	345.3	1,008.89
RS+NK	7	2.30	709	1,630.7	519.1	1,111.6

* excluding cost of family labor (opportunity cost of family labor assumed to be zero)

CONCLUSIONS

Failure to apply any form of fertilization results in very poor economic returns to rice farmers in the area, but chemical fertilizers are relatively expensive, as a result most farmers cannot afford them. There are some local resources that have the potential for improving soil fertility at a lower cost. These resources need to be developed and used to improve production.

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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.

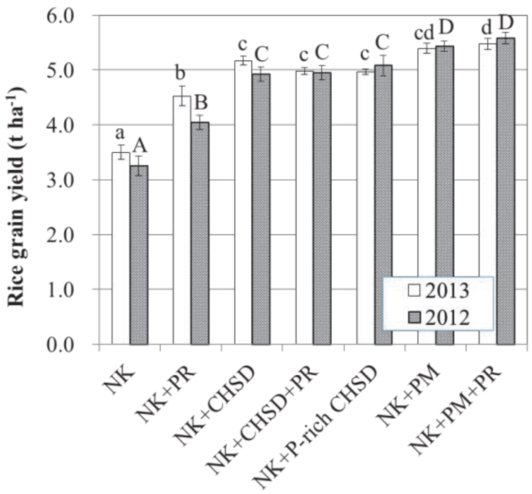

Figure 2 Effect of charred saw dust or poultry manure application on lowland rice cultivation in Ghana.
Error bars are standard error; n = 9 in 2013, and n = 6 in 2012. Different alphabets indicate significant difference ($p < 0.05$) by Tukey’s multiple comparison.

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).

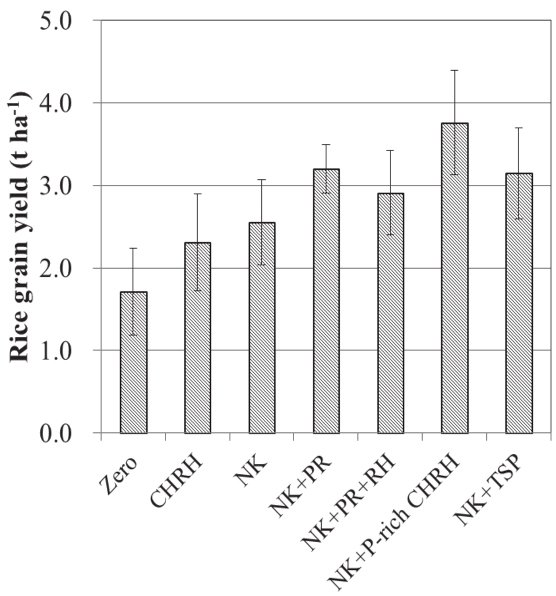

Figure 3 Evaluation of the effect of charred rice husk application and combination with phosphate rock direct application for lowland rice cultivation in the Guinea savanna zone, Ghana. Error bars indicate standard error (n = 4)

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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Plant nutrient content of some animal manure types in the Guinea savanna (GS) agro-ecological zone of Ghana

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INTRODUCTION

Organic manure is a natural fertilizer mainly consisting of waste and residues from plant and animal life (Cooke, 1972); it is also a rich source of nutrients and includes various microorganisms (Taylor and Taylor, 1993). The only naturally occurring sources of major nutrients are the various forms of organic manure (Kauwenbergh, 2006).

The major types of animal manure in the Guinea savanna zone of Ghana are cattle, sheep/goat, and chicken manure. Cattle manure is beneficial in compost preparation and serves as a worm food. Pelletized cow manure is available commercially, and only water is added to reconstitute the manure for application. Sheep/goat manure differs considerably from other ruminant manure; it is dropped as pellets and dehydrated; it is a concentrated product with relatively high potassium content. Various biochemical compounds are also present, including amino acids and enzymes. Chicken manure contains a good balance of the major macro nutrients (NPK) because all bird excreta is highly concentrated with nitrogen rich urea (Taylor and Taylor, 1993).

Due to low inherent soil fertility in the Guinea savanna (GS) agroecological zone of Ghana, farmers continue to rely on fertilizers to improve crop yield. However, for many resource-poor farmers in the GS zone of Ghana, the cost of inorganic fertilizers is prohibitive. Many of these farmers therefore rely on locally available organic soil amendments such as animal manure to improve soil fertility. About 90 % of households in the GS are estimated to use animal manure to fertilize their lands (Anane, 1993), without considerable knowledge on its nutrient composition.

Animal manure is not homogeneous, and the nutrient composition and quality depends on the animal species, feed type, collection method, and storage length (Laegried *et al*. 1999). Therefore, this study which is aimed at determining the nutrient composition of the major animal manure types from the GS zone of Ghana could be a valuable contribution to knowledge that could support extension agents make the right recommendations to meet crop requirements.

MATERIALS AND METHODS

The GS agroecological zone of Ghana is located in the northern part of the country. The GS zone experiences unimodal rainfall pattern with an average of 1034 mm per annum. Temperature distribution is moderately uniform with monthly mean minimum and maximum values of 23 °C and 38 °C, respectively. The vegetation consist predominantly of grassland interspersed with drought-resistant trees (MoFA, 1998).

Local farmers in Ghana practice extensive system of animal husbandry commonly known as free range. Animals are left to feed on anything during the day and they return to their pens and kraals during the night. Generally, no supplementary feeding is done.

Four samples each of Cattle, sheep/goat and chicken manure were collected from four randomly selected communities (Nyankpala, Cheyohi, Kpalsawgu, and Changnaayili) near Tamale the Northern Region of Ghana. The samples of cattle, sheep/goat, and chicken manure were collected from kraals and pens from the four selected communities. The samples were air-dried and ground to fine particles for laboratory analysis. Kjedahl digestion, ammonium molybdate and flame photometry, and atomic absorption spectrophotometry were used to determine Nitrogen (N), Phosphorous (P), Potassium (K), Magnesium (Mg), Calcium (Ca), and Sulphur (S) contents in the manure types. The results from the laboratory analysis were subjected to Analysis of variance (ANOVA) using Genstat software. Mean separation was done using the Least Significance Difference (LSD). The error bars shown on charts represent standard error.

RESULTS AND DISCUSSION

Nitrogen

The N content of the three manure types across the four communities was similar (Table 1). The highest N content value of 2.51 % for cattle manure was recorded in Kpalsawgu, followed by that for Cheyohi manure with 2.26 %. The lowest value of 1.99 % was recorded in Changnalili and Nyankpala (Table 1). Tisdale *et al*. (1993) reported that the normal plant N composition is between 1 and 5 % . The N content of the manure samples could have been attributed to the mainly vegetarian/plant diet of animals in the study area in particular and northern Ghana in general. The range for N content was found to be lower than that of Tisdale *et al*. (1993) probably due to the homogenous feed source of these animals. Animals in northern Ghana rely on natural vegetation as food source because of the extensive system of animal husbandry.

Table 1 Plant nutrient content of manure from four (4) selected

Manure Types	N (%)	P (%)	Mg (%)	S (mg/kg)
Nyankpala				
Cattle	1.99	0.03	1.24	0.35
Sheep/Goat	2.12	0.02	0.90	0.30
Chicken	1.89	0.05	1.30	0.70
Cheyohi				
Cattle	2.26	0.03	0.65	0.65
Sheep/Goat	2.10	0.03	0.72	0.35
Chicken	2.01	0.03	0.38	0.40
Kpalsawgu				
Cattle	2.51	0.04	0.82	0.75
Sheep/Goat	2.45	0.04	0.66	0.65
Chicken	2.45	0.04	0.24	0.55
Changnalili				
Cattle	1.99	0.03	0.76	0.70
Sheep/Goat	1.95	0.05	1.08	0.65
Chicken	2.05	0.04	0.58	0.70

Phosphorous

The results showed that animal manure might not be a good source of phosphorus (P). The P content ranged from 0.02 to 0.05 % (Table 1). These P values were not significantly different among manure types and among communities. The low P content of animal diets (plants) in the study area might account for the low P in their remains. The P content is significantly lower than those reported for similar studies (Nicholson *et al*. 1996). According to Olaitan *et al*. (1988), P is the most limiting nutrient in plants and agricultural soils. These results suggest that famers who rely entirely on animal manure as their preferred method of soil amendment might have to apply supplementary P from inorganic sources.

Magnesium

Similarly, Mg content was also very similar among the different manure types (Table 1). The highest Mg content was 1.3 % and the least was 0.24 %. (Tables 1). The results showed that Mg was relatively high compared to the standard Mg concentration of 0.1 % and 0.4 % suggested by Beaton *et al*. (1993). The relatively high content of Mg could be because Mg is more prevalent in critical plant pigments involved in photosynthesis which in turn is consumed by animals in the study area.

Potassium

Significant difference ($p < 0.001$) was noted in the potassium (K) levels among the manure types (Figure 1). Although the K content of manure studied ranged between 0.24 $mg \cdot kg^{-1}$ and 0.53 $mg \cdot kg^{-1}$, revealing a considerably low K concentration in the manure types, chicken manure appears to be significantly richer in K than cattle and sheep/goat manure.

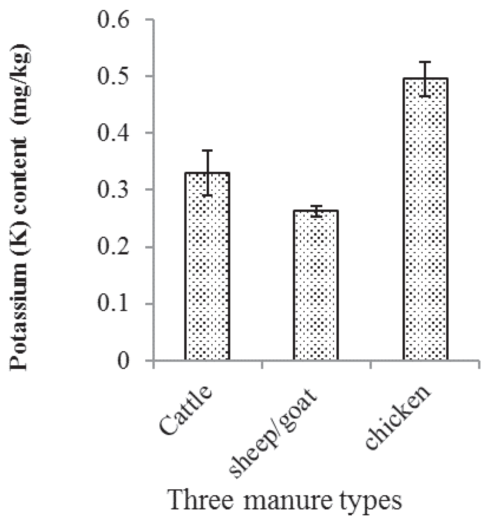

Figure 1 K content of the three manure types in the Guinea savanna agroecology of Ghana

Sulphur

S concentration in the different manure types was very similar (Table 1). The S concentration was highest (0.75 $mg \cdot kg^{-1}$) in Kpalsawgu cattle manure. The least sulfate concentration of 0.4 $mg \cdot kg^{-1}$ was found in sheep/goat manure from Nyankpala (Table 1).

Calcium

There was significant difference ($p < 0.001$) in Ca levels among the manure types (Figure 2). The sheep/goat manure contained significantly higher amount of Ca compared to that in cattle and chicken manure. Plants growing with adequate Ca in their natural habitats have shoot Ca concentrations between 0·1 and 5 % (Marschner, 1995). The values obtained in this study are within the range reported for plant shoot Ca. The significantly higher Ca concentration in sheep/goat manure could be explained by their feeding pattern. According to Tiessen *et al*. (1991), the annual deposition of dust into northern Ghana by the Harmattan weather system has resulted in top soils that contain moderate levels of Ca. The high content of Ca in sheep/goat

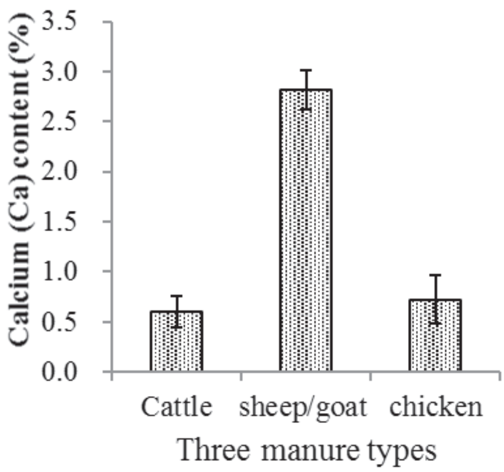

Figure 2 Ca content of three manure types in the Guinea savanna agroecology of Ghana

manure relative to cattle and chicken manure might be because goats have prehensile tongues by which they can graze up to the root levels of plants close to the surface soil that contains appreciable amounts of Ca.

CONCLUSION

This study revealed that the nutrient content of animal manure in the Guinea savanna is low and varied. Nitrogen content is around 2 %, whereas phosphorous content is around 0.05 %. The potassium content is significantly higher in chicken manure, whereas calcium concentration is the highest in sheep/goat manure.

In terms of lowland rice fertilization, no manure type presents any specific advantage. The low nutrient content of the manure types in the Guinea savanna implies that large quantities will have to be applied to meet crop nutrient requirements.

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The Outlines of the Workshop

The Workshop on "Improvement of Soil Fertility with Use of Indigenous Resources in Rice Systems in Ghana" was held on October 15, 2013 at the International Conference Center, University for Development Studies (UDS), Tamale, Ghana, jointly organized by JIRCAS, UDS, and Soil Research Institute (SRI), Ghana.

1. The Opening Ceremony

With around 50 participants in the venue, the Workshop has been commenced at 09:30 AM by the words of Mr. Boakey-Acheampong, Regional Director, MoFA-NR (Northern Region), the MC, followed by opening remarks by Dr. Israel Dzomeku of UDS, the chairman of the WS.

Dr. George Nyarko, Dean of the Faculty of Agriculture, UDS, was then called for his welcome address, where he expressed great pleasure of the faculty to collaborate with Japan International Research Center for Agricultural Sciences (JIRCAS) and the other partners toward the improvement of soil fertility and the use of indigenous resources in rice cultivating systems in Ghana. He stated that the project has already implemented field experiments in the northern areas of Ghana with indigenous resources available in the Savanna zone. It had examined the effects of direct application of organic matter and their processed materials on soil chemical properties and rice growth. He emphasized the fact that the presentation titles outlined in the program of the workshop testify to the great achievement of this project so far. He restated that this year, the project is repeating some of these important experiments for confirmation as well as undertaking socio-economic analysis on affordability of the new technologies developed so far under the project. He said the faculty welcomes these initiatives and promised that UDS shall perform diligently because they are aware that rice is a food security crop in Ghana as well as being very important staple food for all tribes in the country. He concluded by saying on behalf of the Vice-Chancellor of UDS, all welcome all participants to UDS for the very important workshop and wish all well in their presentations and deliberations.

As a representative of the sponsor of this project, Mr. Hiroaki Kinoshita, chief executive officer of MAFF, Japan, provided his speech with a lot of appreciation to all the players of this project, especially to partners in Ghana. He also conveyed his expectations to the project for the contribution to the CARD goal, to double the rice production in Sub-Saharan Africa (SSA).

2. Introductory speech

Dr. Satoshi Tobita, JIRCAS leader to this project, clearly showed the purposes of the workshop as well as the project outlines. They are, 1) to summarize the achievements of the "UDS/CSIR-

SRI/MoFA (Ghana-Japan) JIRCAS/MAFF" project and 2) to discuss new technologies and to brain storm on ways of disseminating the technologies. The project is centered in studies on soil fertility improvement with focus on rice cultivation using indigenous materials in West Africa. The target area is SSA especially West Africa where its soil fertility is the most threatened and in Ghana is due to reasons spanning from environment, political and academic among others.

The constitution of the WS sessions (I, II and III) was then introduced by Dr. Tobita.

I. Indigenous resource / Technologies on soil organic matter, all presented by Ghanaian counterpart researchers from UDS and CSIR-SRI, chaired by Dr. N. Fujimoto, Project Leader to the African Rice Promotion Project, JIRCAS,

II. Technologies on phosphate rocks (PR), Coating/soaking technologies, and Socio-economic studies, all presented by JIRCAS researchers, chaired by Mr. H. Dan, Representative of the JIRCAS Liaison Office, Accra, Ghana, and

III. General Discussions, chaired by Mr. E. Adjei, Agroforestry Specialist, CSIR-Soil Research Institute.

3. Discussion points of the sessions

In the session I, the Ghanaian scientists (UDS and SRI) had presentations on indigenous organic resources and technologies for soil fertility and rice production improvement with the resources. Discussions were chiefly pointed on the locality and effectiveness of materials especially when applied with chemical fertilizers. In the session II, the potentiality of phosphate rocks from the neighboring Burkina Faso has been recognized, but it might be challenging unless technologies to enhance the effectiveness would be developed and appropriate policies would be planned and executed by the government. In the session III, the adaptability of technologies was discussed. It was learned that the ex-ante socio-economic analysis would be important to fine-tune the technologies for effective transfer to local societies. There was also general brain storming on how to disseminate the technologies and the research project has recommended and suggestion was made to write proposals for funding from MoFA of Ghana, MAFF of Japan and other development partners. The Northern Regional Director of MoFA said the research unit of the Ministry at their Real Committee Meeting, if farmers demand for the technologies MoFA would definitely disseminate to them. Others cautioned that farmers learn from successful farmers not researchers even though the idea that technology is from research.

4. Comments from the guests

Mr. Theo Osei Owusu, Department of Agricultural Extension Services (DAES), MoFA-Ghana had comments about the present situation of rice in Ghana, one of the major staple foods and blessed with many natural resources to enable it to be self-sufficient in rice cultivation. And he explained that the extension unit of MoFA disseminates information to farmers and this project is timely for the purpose.

Dr. Satoshi Yoshinaga, a member of the advisory committee of the Project, gave the comments that the site specific technology as the combination of organic matter and fertilizer should be developed to increase and stabilized rice production in Ghana. He recommended, for examination, current information should be modified based on climate conditions, water status and social situation. Knowledge on the use of phosphate rocks to improve soil fertility has greater impact on basic soil science and agronomy. The use of rice straw, rice husk and the bio-char (or *Kun-tan* in Japanese) are very useful and practical for farmers to increase the fertility of their cultivable fields. He expressed hope that the information manual would be available and with ease of accessible to farmers to improve upon rice productivity in Ghana. He challenged the researchers to further evaluate their research and disseminate the information to the extension unit of MoFA.

Mr. Minoru Yoshino, an expert of the JICA Project, expressed interest to incorporate, adopt the results and ideas of research work into his project activities, and requested to publish the results of research work on the project web site. He also suggested that technical and scientific reports should be modified and simplified to aid reading and understanding by extension officers and farmers.

5. Concluding remarks

The MC, Mr. Boakey-Acheampong, expressed appreciation on the use of indigenous plants to improve soil fertility. He added that the Government of Ghana since 2009 has been spending huge sums of money to subsidize fertilizer and last year Government spent over 117 million of Ghanaian Cedis to subsidize fertilizer. This year, 2013, Government subsidy on fertilizer is projected around 70 million Cedis. He thanked the Japanese Government for the support it has been giving to Ghana and promised that MoFA would readily disseminate the information the workshop would generate to the farmers.

6. Excursion tour to visit on-farm experiments

The Workshop participants attended the excursion tour on the next day (16, Oct), to visit two villages (Ziong and Sanga) where on-farm experiments in the Savanna zone have been implemented. Thanks to tremendous efforts of Mr. Al-Hassan, a field technician of UDS, the tour was very much successful for visitors to clearly understand the effectiveness, as well as problems, of technologies to improve rice production through soil fertility enhancement in the paddy fields. A lot of questions and comments were raised, especially from the MAFF delegation from Japan, Mr. H. Kinoshita and Mr. T. Hattori.

Picture 1. A group photo of the Workshop

Picture 2. Students of UDS actively participated in the session

Picture 3. A field technician explaining about the on-farm trial in front of the signboard (at Ziong)

Picture 4. A group photo of excursion tour (at Sanga)

(Reported by S. Tobita)

JIRCAS Working Report No.86 **ISSN 1341-710X**

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Published by

Japan International Research Center for Agricultural Sciences

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Tel. +81-29-838-6313
https://www.jircas.go.jp/

JIRCAS Working Report No.86
平成30年3月16日発行

発行者：国立研究開発法人　国際農林水産業研究センター
理事長　岩永　勝
〒305-8686　茨城県つくば市大わし1-1
TEL　029(838)6313（代表）

印刷：株式会社デジタル印刷

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JAPAN