

Full Length Research Paper

Effect of Burkina Faso phosphate rock direct application on Ghanaian rice cultivation

Satoshi Nakamura^{1*}, Roland Nuhu Issaka², Israel K. Dzomeku³, Monrawee Fukuda¹, Moro Mohammed Buri², Vincent Avornyo³, Eric Owusu Adjei², Joseph Awuni³ and Satoshi Tobita¹

¹Japan International Research Center for Agricultural Sciences (JIRCAS), Tsukuba, Ibaraki 305-8686, Japan.

²Soil Research Institute (CSIR-SRI), Academy Post Office, Kwadaso, Kumasi, Ghana.

³University for Development Studies (UDS), P. O. Box TL 1350, Tamale, Ghana.

Accepted 29 April, 2013

Phosphorus is a critical nutrient for crop production. The soil phosphorus deficit in sub-Saharan Africa is one of the most important constraints on crop productions. Resulting from the high phosphorus fixation capacities of highly weathered acidic soil coupled with the relatively low total phosphorus, the impact of this deficit is particularly pronounced in the case of rice cultivation. Phosphate rock is a promising alternative to water-soluble phosphorus fertilizers, but its low solubility has so far prevented its widespread adoption in the region. This study examined the results of a direct application effect of phosphate rock produced in Burkina Faso phosphate rock (BPR) on rice yields in on-farm trials conducted in the Guinea savannah and Equatorial forest zones, and on a phosphate rock decision support system (PRDSS) model. We initially hypothesized that BPR direct application will show little effect on rice yield due to its low solubility as same as previous studies. However, our study found that direct application of BPR has an effect on rice grain yield comparable to that of chemical water-soluble phosphate fertilizer, although according to PRDSS simulations, direct application of BPR had little effect compared to the effect of water-soluble phosphate fertilizers. The recognition of BPR effect on rice yield can enhance rice cultivation along with the aspect of usage of indigenous phosphorus resource in sub Saharan Africa (SSA).

Key words: Phosphate rock, direct application, phosphate rock decision support system (PRDSS), lowland rice, Ghana.

INTRODUCTION

Phosphorus (P) is a critical nutrient for crop production all over the world. In sub-Saharan Africa (SSA), deficit of soil phosphorus is one of the most serious constraints on crop production. This shortfall has resulted from the high phosphorus fixation capacities of highly weathered acidic soils (Bationo et al., 1990; Bationo and Mokwunye, 1991). The lack of soil phosphorus impacts on a range of

agricultural lands, including paddy soils for rice cultivation (Abe et al., 2010). Few farmers in SSA can use commercial water-soluble phosphorus (WSP) fertilizers to cope with this phosphorus deficiency. Resource-poor farmers can especially find it difficult to apply these chemical fertilizers because of very limited accessibility and affordability (Bationo and Mokwunye, 1991).

*Corresponding author. E-mail: nsatoshi@affrc.go.jp. Tel: +81-29-838-6353. Fax: +81-29-838-6355.

Geological phosphate rock (PR) deposits are found throughout the world, and are plentiful enough in parts of the African continent that some countries, such as Togo and Morocco for example, actually are exporters of PR. However, most PR deposits located in the tropics and subtropics have not been well developed (McClellan and Notholt, 1986). Manufacturers have rejected the region's deposits because of its low P quality and/or low reactivity, which do not match their standard requirements (FAO, 2004). PR produced in SSA can be considered a potential source of accessible, but not fully utilized potential phosphorus resource.

Therefore, it is imperative to consider proper PR application management for agricultural environments in Africa. Especially, elucidation of the effect of PR direct application will be fundamental information for PR management in SSA. PR direct application could be considered as a labor, energy, and time-saving technical option. Authors focused on the direct application of Burkina Faso PR (BPR) to improve rice yield in SSA because BPR is more easily accessible than other PRs produced in SSA.

It is well known that the agricultural impact of PR direct application depends on the origin locality of PR, as chemical properties and solubility vary a great deal depending on the phosphate's origin and its petrogenetic process (Hammond et al., 1989; FAO, 2004). PR produced in SSA has been evaluated to have less positive effect on rice yield compared with WSP because of its low solubility. Truong et al. (1978) compared the solubility of several varieties of PR, and concluded that most PR produced in SSA is not suitable for direct application. Bationo and Mokwunye (1991) classified BPR as low reactive PR according to Diamond's classification (Diamond, 1979). Recently, Fukuda et al. (2010) reported on the low solubility of BPR through direct application in pot trial that was conducted in Japan with lowland rice (IR74) under low-P soil, especially in submerged conditions. Research hints that, in actual direct application in the field condition, that PR solubility could be affected by variation of soil and climate conditions. On the other hands, there are reports that introduce the positive effect of low-grade PR direct application in lowland rice cultivation (FAO, 2004; Somado et al., 2003). Moreover, Vincent (1991) showed a definite positive effect of BPR direct application on the irrigated rice cultivation trial conducted in Burkina Faso. Therefore, it could be hypothesized that BPR direct application in paddy field conditions will show a positive effect on rice production. If such a positive effect can be observed, then BPR can be considered as a potential indigenous P resource available to local farmers in SSA as an attractive alternative to WSP fertilizers such as triple super phosphate (TSP) (Chien et al., 2010).

Rice demand has been rapidly increasing in SSA recently (WARDA, 2008). Aggregated rice consumption is projected to rise from 19.8 million ton (Mt) in 2010 to 35.0 Mt by 2020 under the scenario that is using each

country's rice consumption growth rate for the period 1980 to 2010. Thus, SSA would import roughly 14.0 Mt of milled rice in 2020 to fill the gap between consumption and production (Africa Rice Center, 2011). Therefore, improvement of rice production is highly required in SSA. This study focuses on the direct application effect of Burkina Faso PR (BPR) to improve the yield of lowland rice in SSA. We examined the effect of BPR direct application upon rice yields from fields located in the Guinea savannah and Equatorial forest zones as these comprised two common agro-ecological zones in SSA. The investigations were conducted in Ghana, where the government has tried many approaches to enhance rice yields (MOFA, 2009).

MATERIALS AND METHODS

Location of study sites

The investigations were carried out in Tamale and Kumasi, capitals towns of Northern and Ashanti regions respectively, in Ghana. Northern region is located in the Guinea savannah zone whilst the Ashanti region is situated in the Equatorial forest zone (Figure 1). Monthly mean precipitations and temperatures for both Northern and Ashanti regions were shown in Figure 2. Annual precipitations are 1100 mm with a unimodal pattern in the Northern region, and 1370 mm with a bimodal pattern in Ashanti.

Two communities in each region were selected as study sites. Gbrimah and Fuu were the study sites selected in the Northern region. Gbrimah is located 10 km northeast of Tamale, while Fuu is about 40 km southeast of Tamale. In the Ashanti region, two locations, namely site B and C, were set-up in Baniékrom, which is located about 50 km northwest of Kumasi. The selected rice cultivars used in these trials were GR18 (Northern region) and Jasmin 85 (Ashanti region). The GR18 is reported as the one of the most cultivated varieties in Northern Ghana by Ghana Seed Company (1988). And Sikamo was selected out by Crop Research Institute (CRI), and was improved variety for rain-fed rice cultivation, demonstrated in 1990s Ghana rice project.

Plot design and treatments

Phosphate rock (BPR) produced in Kodjari, Burkina Faso, was used. The P_2O_5 content of this BPR was 34.1 and 2% citric acid soluble P content was 6.1%. Previously, Vincent (1991) introduced relative agronomic efficiency (RAE) calculated from the results of BPR direct application trial conducted in Burkina Faso. This experiment showed 97% of RAE against WSP on the irrigated rice cultivation.

25 m² plots were designed for each treatment. The plant density of rice plants was set-upped at recommendation rate of 20 × 20 cm in each site. And rice was grown for four months in each sites.

At the investigation sites, three rates of BPR; PR-L (67 kg P_2O_5 ha⁻¹), PR-M (135 kg P_2O_5 ha⁻¹), PR-H (270 kg P_2O_5 ha⁻¹), TSP (270 kg P_2O_5 ha⁻¹), and Control (non P application). As shown in Table 2, control in equatorial forest zone successfully received basal chemical fertilizer, but control in savanna zone did not fertilized by basal chemical fertilizer, so the control in savanna zone needs to be considered as absolute control or zero application. All treatments were settled with three replications. All BPR was broadcasted and incorporated into the soil a week before planting, whilst TSP was applied one week after planting. Basal fertilizer, ammonium sulfate as nitrogen (N) fertilizer and potassium chloride

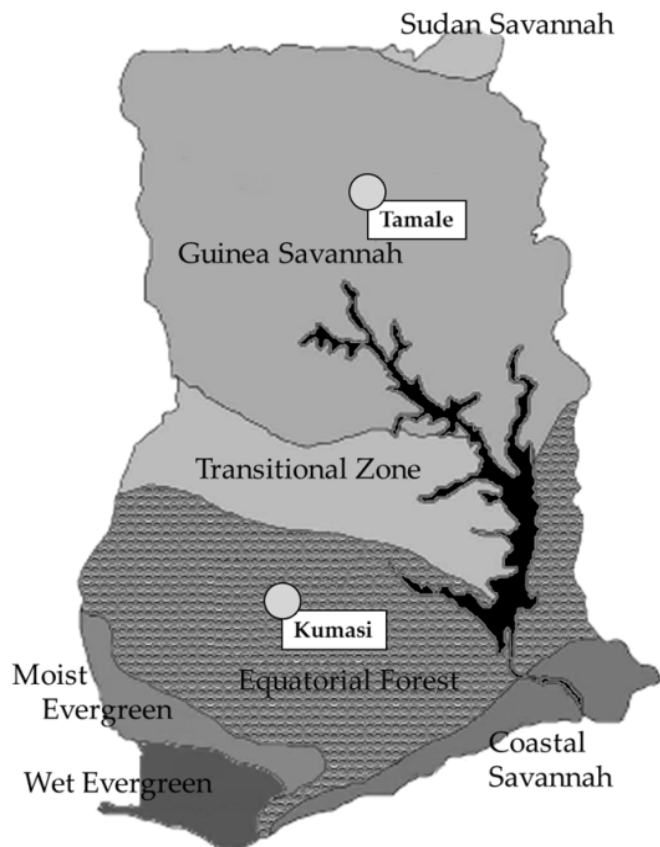


Figure 1. Agro-ecological zones in Ghana.

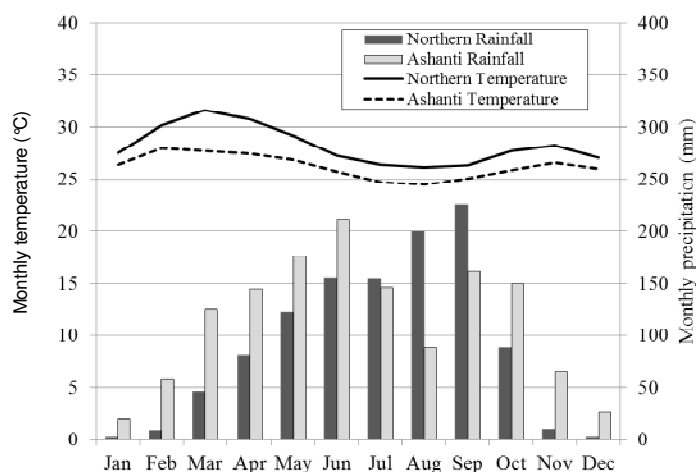


Figure 2. Monthly precipitation and temperature in Northern region and Ashanti region. Obtained from the Ghana Meteorological Agency (Accra, Ghana).

as potassium (K) fertilizer, at the rates of 90 kg N ha⁻¹ and 60 kg K₂O ha⁻¹, was applied to all treatments in Ashanti region, while 60 kg N ha⁻¹ and 30 kg K₂O ha⁻¹ was applied in Northern region. All the potassium and half of the nitrogen were applied one week after planting. The other half of the nitrogen was top-dressed five weeks

after planting. The summary of application rates for the two sites is as shown in Table 1.

Yield survey was conducted by quadrat sampling from 16 m² of internal subplot settled in each plot. 1 m² quadrat was placed twice on each plot during panicle initiation to determine the number of effective tillers and the average worked out for each plot. And the data collected was subjected to statistical analysis using Kyplot ver. 4.0 (KyensLab Inc. Japan).

Soil analysis

Soil samples were taken before the application of treatments and at harvest from each site, at 0 to 20 cm depth. The samples were air-dried and sieved using a 2 mm mesh. Soil pH was measured at 1: 2.5 of extraction ratio by the glass electrode method. Total carbon was determined by the dry combustion method using an NC analyzer (Sumigraph NC-220, Sumika Chemical Analysis Service, Ltd., Japan), and verified by the Walkley-Black method (Walkley and Black, 1934). Total Nitrogen was determined with the use of the NC analyzer. Available P was extracted according to Bray-1 method (Bray and Kuntz, 1945), and determined by the ascorbic acid-molybdenum blue method using a spectrophotometer (UV-2400, Shimadzu Inc., Japan) at the wavelength of 710 nm. Exchangeable bases were extracted by 1.0 M ammonium acetate solution and the concentrations of the cations were determined by inductively coupled plasma atomic emission spectrometry (ICPE-9000, Shimadzu Inc., Japan).

Plant analysis

Five flag leaves in each plot were randomly collected from throughout the field at the time of harvest. These leaf samples were oven dried at 80°C for 48 h and then fine-powdered by a vibration mill. These samples were used for chemical analysis. Nitrogen and carbon content were determined by the dry combustion method via the same methodology described for the soil samples. Phosphorus content in flag leaves were determined by the dry ash method in accordance with Cakmak et al. (1994). The powdered sample in an Alumina boat was heated at 550°C for 2 h using a muffle furnace. After cooling, the resulting ash was thoroughly washed with a total of 5 ml of 0.5 M HCl in a test tube and the volume topped up to 10 ml with distilled water. The sample was stirred well by a lab-mixer, and centrifuged at 3,000 rpm for 5 min to sediment the ashes in the tube. The supernatant was used for phosphorus determination by the ascorbic acid-molybdenum blue method using the spectrophotometer at the wavelength of 710 nm.

PRDSS

Phosphate rock decision support system (PRDSS) Version 2.0.0.1., International Fertilizer Development Center, Muscle Shoals, Alabama, USA was used to estimate the effect of the BPR direct application onto Ghanaian soils. The PRDSS was developed to aid making the decision to apply PR to meet the nutritional demands of a particular crop at a specified agro-environment (Chien et al., 2010). The system initially calculates the basic relative agronomic effectiveness (RAE) of PRs from their characteristics, soil pH condition, and crop species. The initial RAE value is then multiplied by several soil factors, e.g., organic carbon content, moisture level, and P fixation/leaching (Smalberger et al., 2006). For these parameters, the users can employ some reference data originally prepared in the program, if there is no observed data available. In our use of this program, we used the measured values listed in Table 2 as soil parameters.

Table 1. Fertilizer application rates (kg ha⁻¹) at the study sites of Northern and Ashanti regions.

Treatment	P-source	Northern region			Ashanti region		
		P ₂ O ₅	N	K ₂ O	P ₂ O ₅	N	K ₂ O
Control	none	0	0	0	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

Table 2. Selected soil chemical properties of research sites.

Location	pH	Bray 1-P mg kg ⁻¹	T-C	T-N	C/N	Ex-K	Ex-Ca	Ex-Mg	Ex-Acidity
			g kg ⁻¹						
Northern region									
Fuu	5.60	5.96	5.58	0.54	10.3	0.17	2.54	1.27	1.28
Gbrimah	5.83	11.06	3.04	0.27	11.2	0.13	1.21	0.94	0.78
Ashanti region									
Baniekrom B	4.53	5.33	11.67	0.90	13.0	0.23	5.13	1.97	0.93
Baniekrom C	5.70	4.65	9.00	0.73	12.4	0.25	5.08	2.05	0.78

RESULTS AND DISCUSSION

Soil chemical properties of research sites

Soil chemical properties in each research sites are listed in Table 2. The soil pH values of the two communities in the Northern region were weakly acidic and there was a difference of available P content between Fuu (5.96 mg P kg⁻¹) and Gbrimah (11.06 mg P kg⁻¹). The soils in the two Ashanti region sites also showed acidic properties and low available P content. The soil pH did not show any difference between Ashanti and Northern regions. Exchangeable cations, total nitrogen, total carbon, however, indicated lower levels in the Northern region compared with those in the Ashanti region. Northern region and Ashanti region are located in different agro-ecological zones, the Guinea savannah zone and equatorial forest zone, respectively. Our results are consistent with Buri et al. (2010),

indicating that the soils of the Equatorial forest zone show relatively higher values in soil fertility indices, e.g., total nitrogen, soil organic matter content, and exchangeable cations than those of Guinea savannah zone.

Prediction of BPR direct application effect on rice yield using PRDSS

The prediction of PR direct application effect on research

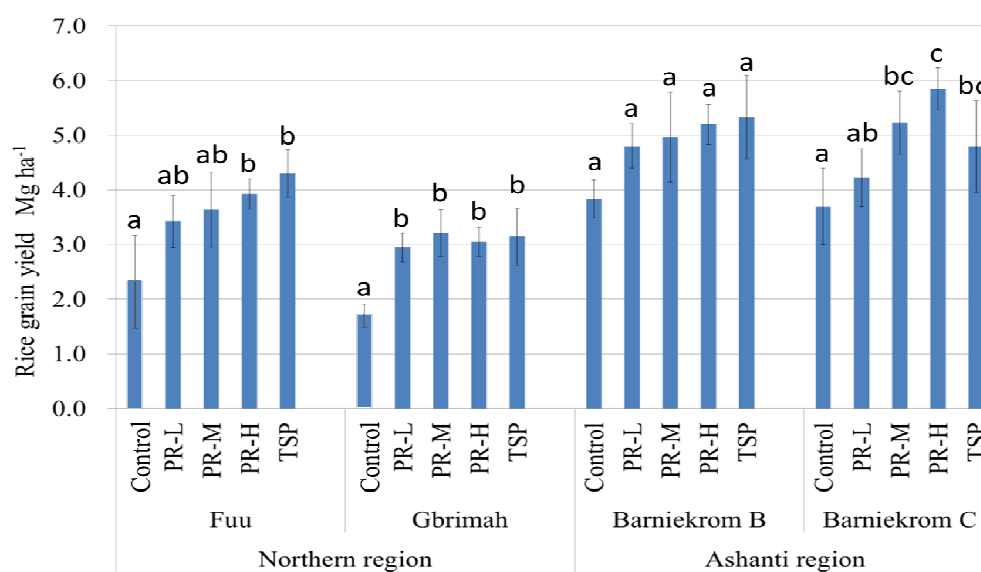
sites were calculated by PRDSS using the observed soil chemical properties in each research sites. The predicted initial RAEs of the investigated PR were related with soil pH values (Tables 2 and 3). It is well known that soil pH is one of the most important factors determining the agronomic effectiveness of directly applied PR (Smalberger et al., 2006; Chien et al., 1980; Robinson et al., 1994). Chien et al. (2010) has shown that soil pH alone accounts for 56% of variability of RAE in his investigation of highly reactive Tunisian PR direct application.

In the Northern region, moisture factors calculated were observed to be lower than Ashanti region (Table 3), a variation reflecting the annual precipitation of each region. The moisture effect of PR dissolution seemed to be the factor that limits RAE of PR direct application in the Northern region unlike in Ashanti region. Final estimates of RAE were very low for all sites, that is, 3% in Fuu, 2% in Gbrimah, 20% in Baniekrom B, and 5% in Baniekrom C (Table 3).

Results simulated with the PRDSS predict that the effect of direct application of BPR will be very low compared with those achieved through use of WSP fertilizer in rice cultivation in the two specified ecological zones in Ghana, a result attributable to the program's weighting of the inputted soil pH and soil water conditions for this trial. This RAE calculated by PRDSS is in consonance with earlier reports indicating low agronomic performance of BPR direct application (Truong et al., 1978; Fukuda et al., 2010).

Table 3. Predicted relative agronomic efficiencies (RAEs) and several factors calculated by phosphate rock decision support system (PRDSS).

Factor	Northern region		Ashanti region	
	Fuu	Gbrimah	Baniékrom B	Baniékrom C
Initial estimated relative agronomic effectiveness (RAE) (%)	10.00	8.02	38.79	9.14
Factors for final RAE calculation				
Organic carbon effect	0.95	0.92	0.99	0.97
Rainfall effect	1.00	1.00	1.00	1.00
Relative influence of P fixation on this rock	0.75	0.75	0.75	0.75
Relative effect of moisture on rock dissolution	0.45	0.45	0.71	0.71
Relative effectiveness of aluminum saturation	0.00	0.00	0.00	0.00
Final estimated agronomic effectiveness (%)	3	2	20	5

**Figure 3.** The effect of BPR direct application on rice yield in Northern and Ashanti region. Each treatments received 0 kg (Control), 67.5 kg (PR-L), 135 kg (PR-M), 270 kg (PR-H, and TSP) of P_2O_5 per hectare, respectively. Error bars indicate standard error ($n = 3$), and the same letters are not significantly different at 5% level by Tukey's multiple comparison.

The effect of BPR direct application on rice yields

As discussed above, PRDSS predicted that PR direct application would not show the significant positive effect on rice cultivation compared with chemical fertilizer in Ghana. Therefore, actual application effect of PR direct application on rice yield needs to be elucidated for validation of PRDSS prediction in comparison with actual values.

The effect of PR direct application on rice yield at the two sites (Northern and Ashanti regions) is shown in Figure 3. This figure indicates that PR direct application was effective on rice yield enhancement, and that rice yield increased with PR application at all four sites. Rice yields in the BPR applied plots did not show any significant difference when compared to those in TSP

applied plots. This suggests that application of unprocessed PR can be a viable alternative to TSP as a P fertilizer in the Guinea savannah (Northern region) and Equatorial Forest (Ashanti region) zones of Ghana.

Mean rice yield in Ghana is 1.6 t/ha (IITA, 1992). Abdulai and Huffman (2000) reported that the average rice production of farmers in the lowlands of the Northern region was about 1.5 Mg ha⁻¹, with an absolute range of 0.5 to 2.1 Mg ha⁻¹. In this study, rice grain yield for the control plot was 2 Mg ha⁻¹, a value at par with the farmers' average. In contrast, sites that received BPR application showed clear enhancement and improvement in rice yields, up to c.a. 4 Mg ha⁻¹ in Fuu, and c.a. 3 Mg ha⁻¹ in Gbrimah, in PR-H plots. In addition, PR-L plots produced about 3.3 and 3.0 Mg ha⁻¹, at Fuu and Gbrimah, respectively.

In Ashanti region, observed rice yield levels were higher than in the Northern region, probably because sites were cultivated under 'Sawah' eco-technology (Wakatsuki et al., 1998; Ofori et al., 2005). Ofori et al. (2005) reported that under irrigated 'Sawah' in the Ashanti region with chemical fertilizer (NPK) application of 90-45-45 kg NPK ha⁻¹ rate, rice yield was above 4.5 Mg ha⁻¹. The control plot in this study yielded 3.7 Mg ha⁻¹ of rice grain. Rice yield from the BPR application plots also increased, to 5.2 and 5.8 Mg ha⁻¹ in PR-H plot at Baniékrom site B and C, respectively. The PR-L treated plots at each site produced 4.2 and 4.8 Mg ha⁻¹, respectively. These results demonstrate that BPR application is effective for Ghanaian rice cultivation in both Guinea savannah and Equatorial forest agro-ecological zones. Although the crop yield increased with BPR application rate, PR-L (67.5 kg P₂O₅ ha⁻¹) appears to be sufficient to increase rice grain yields at these sites, significantly.

Relative agronomic efficiencies of Burkina Faso phosphate rock

As mentioned earlier, the PRDSS program predicted that the BPR direct application would produce little effect compared with TSP. However, the actual results showed a definite positive and significant effect of BPR direct application on rice grain yield. RAE from observed results was calculated by the following formula, introduced in Chien et al. (1990).

$$RAE(\%) = 100 \times \frac{Y_{PR} - Y_0}{Y_{WSP} - Y_0}$$

Where, Y_{PR} = yield of PR plot at a P rate (rice yield from PR-H plot), Y_{WSP} = yield of WSP plot at the same P rate (rice yield from TSP plot), Y_0 = yield of no P application (rice yield from Control).

In the Northern region, the control plots did not receive nitrogen and potassium fertilizer. Therefore, the RAEs of these sites should be considered as reference. The RAEs calculated from actual data of Fuu and Gbrimah were 73.8 and 93.8%, respectively. The BPR plots at the same P level of TSP (PR-H) produced 87.4 and 97.2% of rice grain yields against TSP plots. In the Ashanti region, results also indicate that PR direct application produced a definite increase to the rice yield, and that the rice yield increased in proportion to the PR application rate. The RAEs were 91.1% in Baniékrom B and 195.5% in Baniékrom C. The BPR/TSP ratios were 118 and 115% at Baniékrom B and C, respectively.

Furthermore, the trial in the Ashanti region showed that PR direct application can produce an even or greater enhancement of rice production under reduced/anaerobic conditions. Fukuda et al. (2010) indicated that BPR showed higher solubility under oxidative condition than under reduced condition, a property examined in a pot

trial. BPR dissolution may be affected by differences in environmental factors such as water dynamics. In Fukuda's pot trial, water content and levels were controlled, and hence, the water dynamics in its sample soils differed from those of this study's field environment. Difference in water dynamics can therefore be considered as the cause for the changes in rates of PR solubility in the soil.

Even allowing for this soil solubility difference factor, the effect of BPR direct application on rice grain yields produced results comparable to those achieved through TSP application in both the Northern and Ashanti regions. The RAEs observed in this study supports Vincent's result which showed that direct application of BPR is a highly effective method to increase production (yields of rice) in SSA (Vincent, 1991).

The great differences between actual and predicted RAEs, while supporting our hypothesis, require further investigation. Such differences between predicted and observed RAE values could be the reason why varied results as the efficacy of BPR direct application have been reported. PRDSS calculates the PR dissolution rate without incorporating a redox potential factor, an omission likely attributable to the fact that this system is mainly focusing on upland crop cultivation. However, it is well known that redox potential changes can affect phosphorus availability (Krairapanond et al., 1993; Shenker et al., 2005). Therefore, the verification of PRDSS estimation for lowland rice requires further consideration taking into account the effect of redox potential changes.

The effects of PR direct application on rice plant nutrition

PR direct application showed positive effect on rice yield. Then, the P content in flag leaves were determined to elucidate the mechanism of PR direct application because it is known that PR shows the various positive effects such as soil neutralization due to calcium supply from PR, not just P fertilization. P content in flag leaves indicated little difference within the treatments in both regions (Figure 4). On the other hand, the number of tillers from each rice plant clearly increased on fields that received BPR (Figure 5). This increase that can be directly linked to the BPR treatment as the role of P application on enhancing tillering of rice plants is well documented (Tanaka et al., 1959). A comparison of the study sites according to the different agro-ecological zones revealed that P content in flag leaves were higher in the Ashanti region, while tiller counts were higher in the Northern region. One possible explanation for these differing effects could be in the timing of PR dissolution. PR dissolution varied as a result of different water conditions and redox potentials. As rice plants P nutrition has two sensitive peaks in relation to the plant's growth

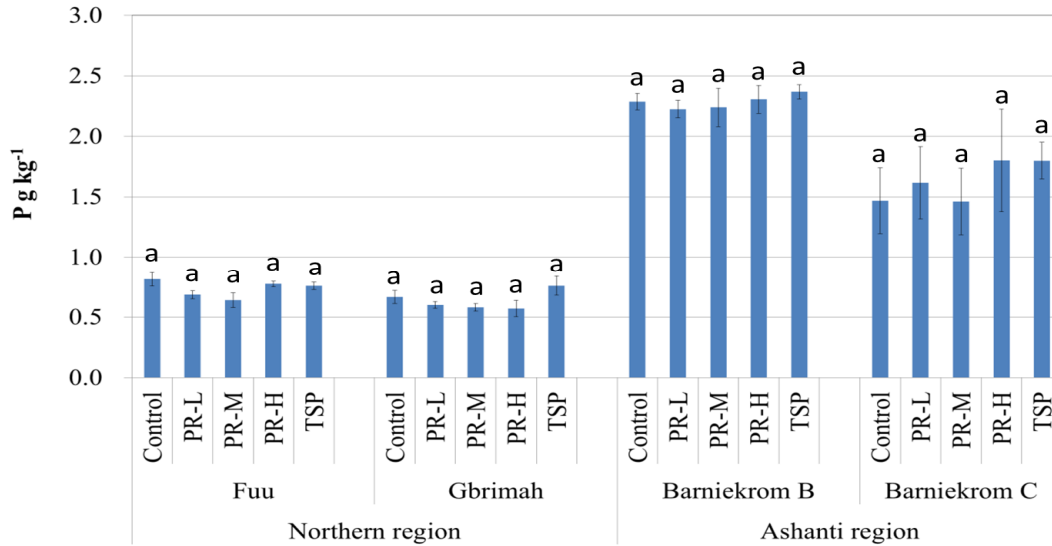


Figure 4. The effect of BPR direct application on P content in flag leaves in Northern and Ashanti region. Error bars indicate standard error (n = 3), and the same letters are not significantly different at 5% level by Tukey's multiple comparison.

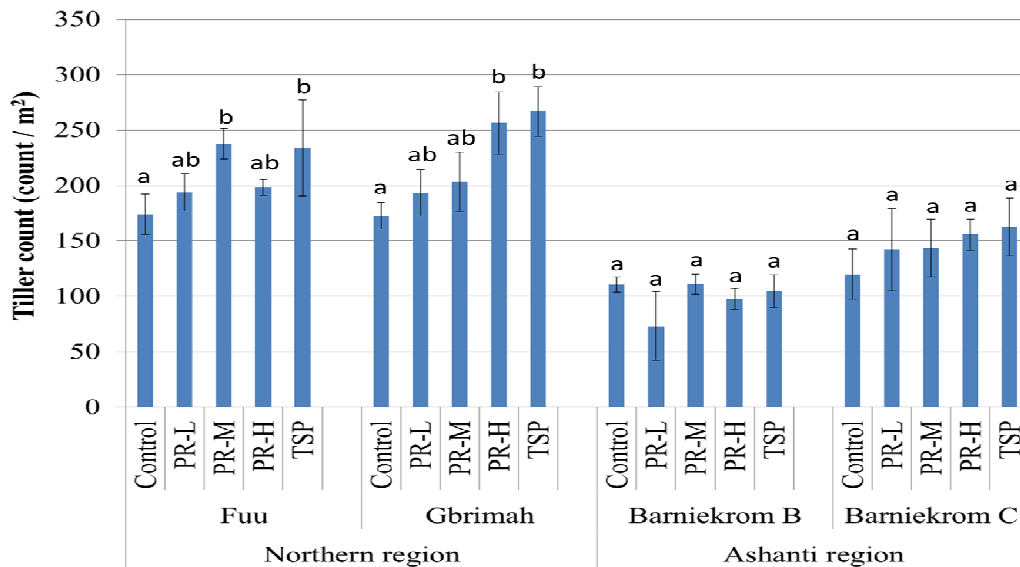


Figure 5. The effect of BPR direct application on tiller counts in Northern and Ashanti region. Error bars indicate standard error (n = 3), and the same letters are not significantly different at 5% level by Tukey's multiple comparison.

stage, that is, at the end of vegetative growth stage, and at the reproductive stage, varied dissolution rates could impact negatively on growth by differential availability across these peak influential times (Hasegawa and Sasaki, 2009). During the vegetative growth stage, rice plants uptake P together with N to increase biomass and tillers. The PR application in the Northern region

might therefore have affected vegetative growth through relatively earlier dissolution. Meanwhile, in the Ashanti region, BPR dissolution may have been delayed, thus the rice plant only accumulated the solubilized P during its reproductive stage. Nevertheless, we cannot at this stage rule out attributing this variance to the differences between direct sowing and transplanting, and the stage

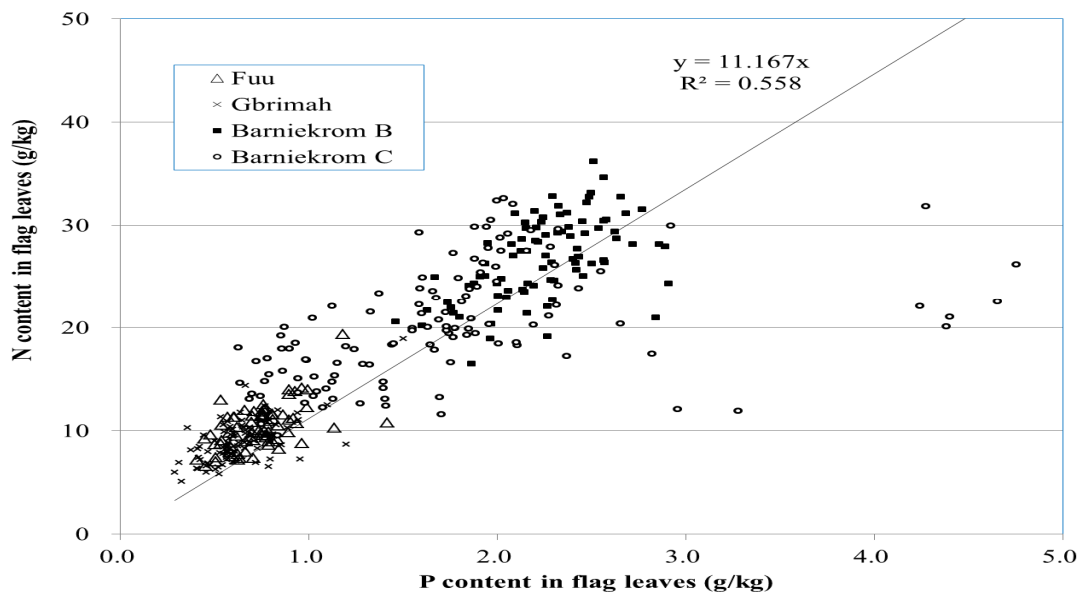


Figure 6. The relationship between P and N plant uptakes in rice cultivation of Northern and Ashanti region, Ghana. Block and triangle symbols indicate Northern and Ashanti regions, respectively.

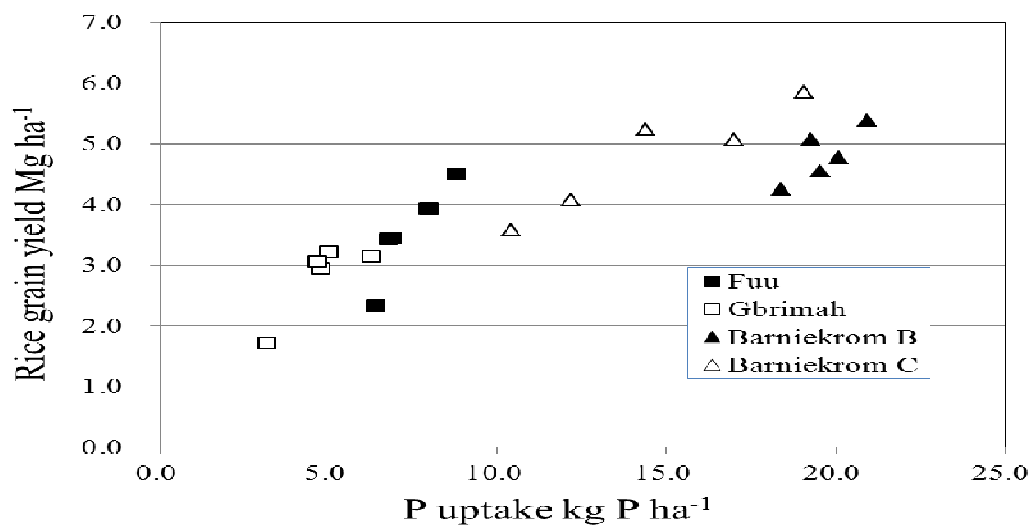


Figure 7. The relationship between P uptake and rice grain yield in Northern and Ashanti region, Ghana. Block and triangle symbols indicate Northern and Ashanti regions, respectively.

of plant growth at the date of sampling.

The levels of N and P found in the flag leaves showed a significant correlation (Figure 6). There are some reports that N and P uptake by rice plants are dependent on each other (Oikeh et al., 2008). In this trial, N fertilization was adequate in keeping with the recommended levels for the Northern and Ashanti regions respectively. Therefore, it could be inferred that N uptake of cultivated rice plants was limited by P deficiency, and was improved by P application as either TSP or PR. P uptake, roughly estimated by multiplication

of P contents in flag leaves and total dry matter, is significantly correlated with rice grain yield (Figure 7). Although N uptake also correlated with rice grain yield, P uptake would be the limiting factor under this investigation because of the reasons mentioned earlier. Therefore, the result of this study demonstrates that PR direct application improved rice grain yield in the Northern region due to increased P uptake by the rice plants, while N uptake rates also showed an increase, which can be attributed to the link between increased P uptake with increasing number of tillers.

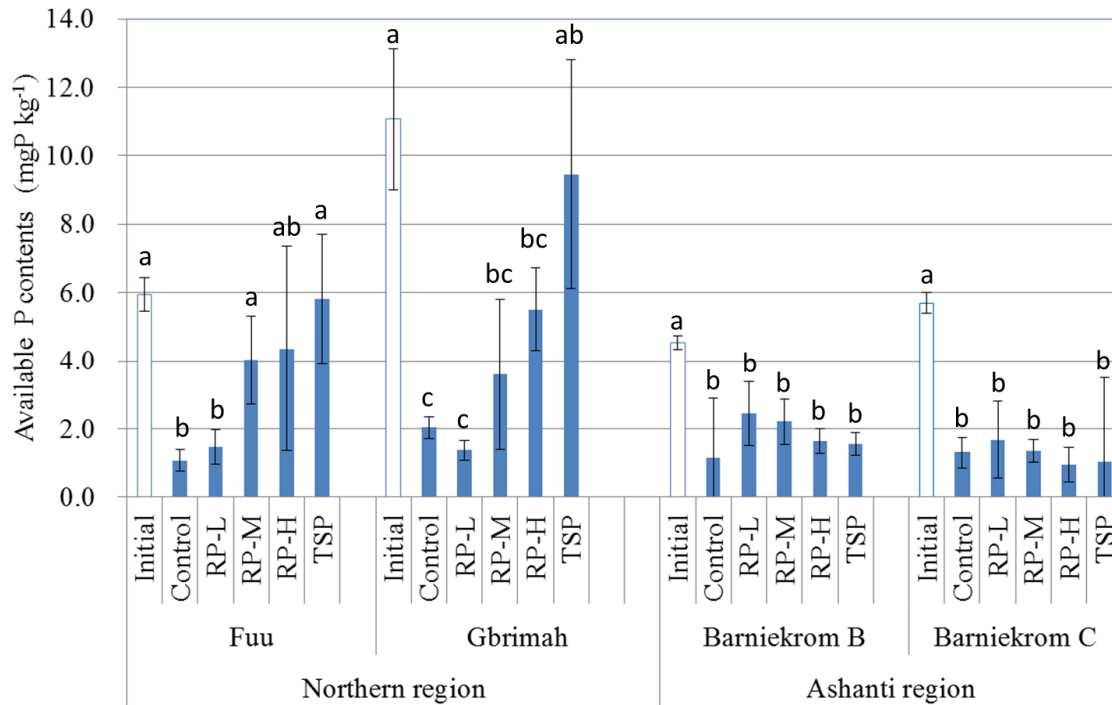


Figure 8. Soil available P content (Bray1-P) before and after cultivation. Error bars indicate standard error ($n = 3$), and the same letters are not significantly different at 5% level by Tukey's multiple comparison.

Residual soil available phosphorus content after cultivation

As discussed above, the effect of PR direct application on lowland rice cultivation in Ghana was positive. In addition to this current effect of PR application, Bationo et al. (2012) suggests that local PR should be used to recapitalize soil fertility, and/or to improve capital pool of phosphorus in the soils on long-term aspect. And so soil available P content extracted by Bray-I method was investigated as the potential factor of soil P fertility, affected by PR application. The soil-available P content before and after cultivation was shown in Figure 8. After rice cultivation, soil-available P content in the Northern region was definitely low in the low-P application rate plots, while the TSP plot showed the highest value. However, in the Ashanti region, there were not significant differences of available P despite the plots having been subject to several P application rates. One can conclude that P solubility was higher in the Ashanti region, and therefore applied P could not remain as same levels as Northern region sites. It could also have been affected by the difference in water dynamics and/or conditions within the two ecological zones. As mentioned earlier, the Northern region has less precipitation with a uni-modal pattern, and hence, the soil water condition was probably dry especially during the long dry season. On the other hand, rice fields in Ashanti region were kept submerged

because of the heavy rainfall with a bimodal pattern and the water resource management techniques, such as 'Sawah' technology, in the inland valleys (Wakatsuki et al., 1998). It is known that soil P solubilized under submerged condition with reductive reaction (Patrick and Mahapatra, 1968).

The data obtained seemed to be considered that PR direct application did not maintain soil available P contents as large as TSP application in savanna zone. And in equatorial forest zone, neither PR nor TSP showed increase in soil available P after rice cultivation. It may ought to be considered that PR application could not enhance potential P fertility. However, although soil available P in PR amended soil can be evaluated by Bray-I method (Gikonyo et al., 2010), also there are reports pointing Bray-I method may not work well in soils fertilized with PR (FAO, 2004). Therefore, it needs to evaluate the residual effect of PR application on next crop cultivation as potential P effect reflecting PR application.

Conclusion

This study examined the impact of direct application of phosphate rocks on rice cultivation under two agro-ecological conditions of the Guinea savannah (Northern Region) and Equatorial forest zones (Ashanti Region) of

Ghana, using PR from Burkina Faso. While the PRDSS simulation predicted that BPR direct application makes little fertilization effect compared with chemical water-soluble P fertilizer (WSP), observed effects of BPR direct application on rice grain yield were comparable to WSP in both agro-ecological zones.

This implies that BPR direct application was effective on rice yield enhancement, and that PRDSS calculations might be incomplete in their estimation of BPR dissolution under tropical lowland rice cultivation systems. Therefore, future studies verifying the accuracy of PRDSS simulations need to be conducted in order to develop better tools for accurate estimation of PR direct application's effect on rice cultivation in Sub-Saharan Africa. The findings about the effect of local PR application on lowland rice can contribute enhancement of rice cultivation in SSA, with improvement of P deficiency in this region. It is suggested that local PRs can be attractive alternatives of expensive chemical P fertilizer without any processing, specifically in paddy field. Although proper conditions to maximize effect of PR application needs to evaluate and adjust PRDSS for lowland rice to be able to contribute to predict appropriate site for PR direct application in lowland rice.

ABBREVIATIONS

BPR, Burkina Faso phosphate rock; **PRDSS**, phosphate rock decision support system; **PR**, phosphate rock; **RAE**, relative agronomic efficiency; **SSA**, Sub Saharan Africa; **TSP**, triple super phosphate; **WSP**, water soluble phosphate.

REFERENCES

- Abdulai A, Huffman W (2000). Structural adjustment and economic efficiency of rice farmers in Northern Ghana. *Econ. Dev. Cult. Chang.* 48(3):505-520.
- Abe SS, Buri MM, Issaka RN, Kiepe P, Wakatsuki T (2010). Soil fertility potential for rice production in West African lowlands. *JARQ* 44:343-355.
- Africa Rice Center (AfricaRice). (2011). Boosting Africa's Rice Sector: A research for development strategy 2011-2020. Cotonou, Benin. pp. 2-77.
- Bationo A, Chien SH, Henao J, Christianson CB, Mkwunye AU (1990). Agronomic evaluation of two unacidulated and partially acidulated phosphate rocks indigenous to Niger. *Soil Sci. Soc. Am. J.* 54:1772-1777.
- Bationo A, Mkwunye AU (1991). Alleviating soil fertility constraints to increased crop production in West Africa: The experience in the Sahel. *Fertil Res.* 29:95-115.
- Bationo A, Pinto-Toyi AK, Ayuk E, Mkwunye AU (2012). Agronomic and Economic Evaluation of Fertilizer Use in West Africa from Long-Term Experiments: Alternative Phosphorus Fertilizer Sources in Different Agro-Ecological Zones of Togo. In *Lessons learned from Long-term Soil Fertility Management Experiments in Africa*, A. Bationo et al. (eds.), DOI 10.1007/978-94-007-2938-4_9, Springer Science + Business Media Dordrecht.
- Bray RH, Kurtz LT (1945). Determination of total, organic and available forms of phosphorus in soils. *Soil Sci.* 59:39-45.
- Buri MM, Issaka RN, Fujii H, Wakatsuki T (2010) Comparison of Soil Nutrient status of some Rice growing Environments in the major Agro-ecological zones of Ghana. *J. Food Agric. Environ.* 8:384-388.
- Cakmak I, Hengeler C, Marschner H (1994). Partitioning of shoot and root dry matter and carbohydrates in bean plants suffering from phosphorus, potassium and magnesium deficiency. *J. Exp. Bot.* 45:1245-1250.
- Chien SH, Leon LA, Tejeda HR (1980). Dissolution of North Carolina phosphate rock in acid Colombian soils as related to soil properties. *Soil Sci. Soc. Am. J.* 44:1267-1271.
- Chien SH, Prochnow LI, Mikkelsen R (2010). Agronomic use of phosphate rock for direct application. *Better Crops* 94:21-23.
- Chien SH, Sale PW, Friesen DK (1990). A discussion of the methods for comparing the relative effectiveness of phosphate fertilizers varying in solubility. *Fertil. Res.* 24:149-157.
- Diamond RB (1979). Views on marketing of phosphate rock for direct application. Special Publication. IFDC-S1, International Fertilizer Development Center, Muscle Shoals, Alabama, USA. pp. 448-463.
- FAO (2004). Use of phosphate rocks for sustainable agriculture, FAO Fertil. Plant Nutr. Bull. 13:148.
- Fukuda M, Nagumo F, Tobita S, Ito O (2010). Influence of phosphate rock application on rice growth. P. 106. Abstracts of the annual meetings, Jpn Soc. Soil Sci. Plant Nutr. September 2010, Sapporo, Japan. P. 5.
- Ghana Seed Company (1988). Regional Branch Annual Report, Tamale.
- Gikonyo EW, Zaharah AR, Hanafi MM, Anuar AR (2010). Extractable Bray-1 phosphorus and crop yields as influenced by addition of phosphatic fertilizers of various solubilities integrated with manure in an acid soil. *Nutr. Cycl. Agroecosyst.* 88:79-90.
- Hammond LL, Chien SH, Roy AH, Mkwunye AU (1989). Solubility and agronomic effectiveness of partially acidulated phosphate rocks as influenced by their iron and aluminium oxide content. *Fertil. Res.* 19:93-98.
- Hasegawa E, Sasaki J (2009). A sustainable NPK dairy uptake speeds of paddy rice plant (in Japanese). *Tohoku Agric. Res.* 62:39-40.
- IITA (1992). Food production in Sub-Saharan Africa. 1. IITA's contributions, IITA, Ibadan, Nigeria. P. 208.
- Krairapanond A, Jugsujinda A, Patrick Jr. WH (1993) Phosphorus sorption characteristics in acid sulfate soils of Thailand: Effect of uncontrolled and controlled soil redox potential (Eh) and pH. *Plant and soil.* 157:227-237.
- McClellan GH, Notholt AFG (1986). Phosphate deposits of tropical sub-Saharan Africa. In A.E. Mkwunye and P.L.G. Viek, eds. *Management of nitrogen and phosphorus fertilizers in sub-Saharan Africa, Developments in Plant and Soil Sciences* 24. Dordrecht, The Netherlands, Kluwer Academic Publishers pp. 173-224.
- Ministry of Food and Agriculture, The Republic of Ghana. (MOFA) (2009). National Rice Development Strategy (NRDS). [http://www.riceforafrica.org/downloads /NRDS/ghana_en.pdf](http://www.riceforafrica.org/downloads/NRDS/ghana_en.pdf). Accessed April 11st 2013.
- Ofori J, Hisatomi Y, Kamidouzono A, Masunaga T, Wakatsuki T (2005). Performance of Rice Cultivars in Various Sawah Ecosystems Developed in Inland Valleys, Ashanti Region, Ghana. *Soil Sci. Plant Nutr.* 51:469-476.
- Oikeh SO, Nwilene F, Diatta S, Osiname O, Touré A, Okeleye A. (2008). Response of Upland NERICA Rice to Nitrogen and Phosphorus in Forest. *Agroecosyst. Agron. J.* 100:735-741.
- Patrick WH, Mahapatra IC (1968). Transformation and Availability to Rice of Nitrogen and Phosphorus in Waterlogged Soils. *Adv. Agron.* 20:323-359.
- Robinson JS, Syers JK, Bolan NS (1994). A simple conceptual model for predicting the dissolution of phosphate rock in soils. *J. Sci. Food Agric.* 64:397-403.
- Shenker M, Seitelbach S, Brand S, Haim A, Litaor MI (2005). Redox reactions and phosphorus release in re-flooded soils of an altered wetland. *Eur. J. Soil Sci.* 56:515-525.
- Smalberger SA, Singh U, Chien SH, Henao J, Wilkens WJ (2006). Development and validation of a Phosphate Rock Decision Support System. *Agron. J.* 98:471-483.
- Somado AE, Becker M, Kuehne RF, Sahrawat KL, Vlek PLG (2003). Combined Effects of Legumes with Rock Phosphorus on Rice in West Africa. *Agron. J.* 95:1172-1178.
- Tanaka A, Patnaik S, Abichandani CT (1959). Studies on nutrition of rice plant (*Oryza sativa* L.) Part II. Influence of Increasing Levels of

- Phosphate and Potash on Growth, Yield and Nutrient Uptake by Rice Plant (*O. sativa* var. *indica*). *Proc. Plant Sci.* 50:305-318, DOI: 10.1007/BF03051878.
- Truong B, Pichot J, Bennard P (1978). Caracterisation et comparaison des phosphates naturels tricalciques d'Afrique de l'Ouest en vue de leur utilisation directe en agriculture *Agronomie Tropicale.* 32:136-145.
- Vincent BB (1991). Etude de l'Efficacité du Burkina Phosphate en riziculture. Centre National de la Recherche Scientifique et Technologique. Institut d'Etudes et de Recherches Agricoles, Ouagadougou, Burkina Faso. P. 42.
- WARDA (2008). 2007 Rice Trends. West Africa Rice Development Authority: Cotonou, Benin.
- Wakatsuki T, Shinmura Y, Otoo E, Olaniyan GO (1998). Africa-based Sawah System for the Integrated Watershed Management of the Small inland valley of West Africa. *FAO Water Rep.* 17:56-79.
- Walkley A, Black IA (1934). An examination of the method for determining soil organic matter and proposed modification of the chromic acid titration method. *Soil Sci.* 37:29-38.