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.

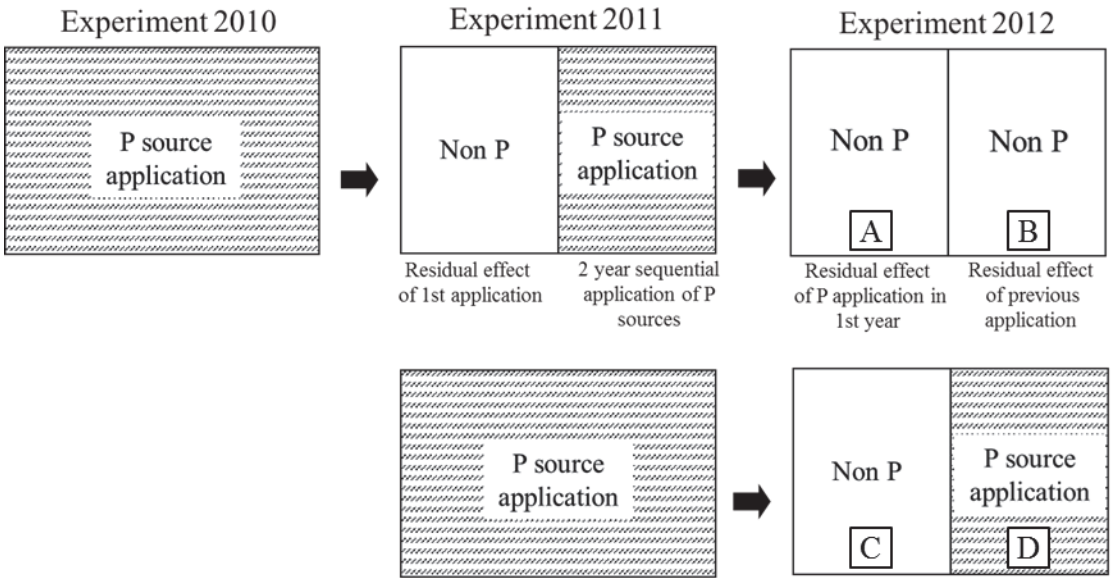


Figure 1 Outline of conducted experiments. The P sources are Burkina Faso phosphate rock (BPR) or triple super phosphate (TSP). All plots received N and K fertilisers at recommended levels for each study site. ABCD are indications of treatments shown in Figure 3 and 4.

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.

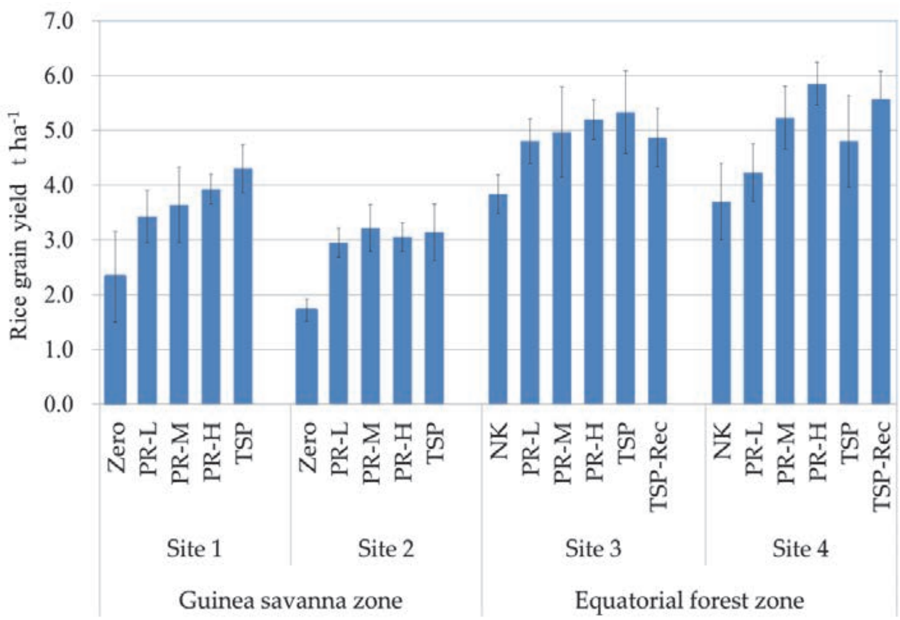


Figure 2 The effect of BPR direct application on rice yield in the Guinea savanna and Equatorial forest zones. Error bars indicate standard error (n = 3).

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.

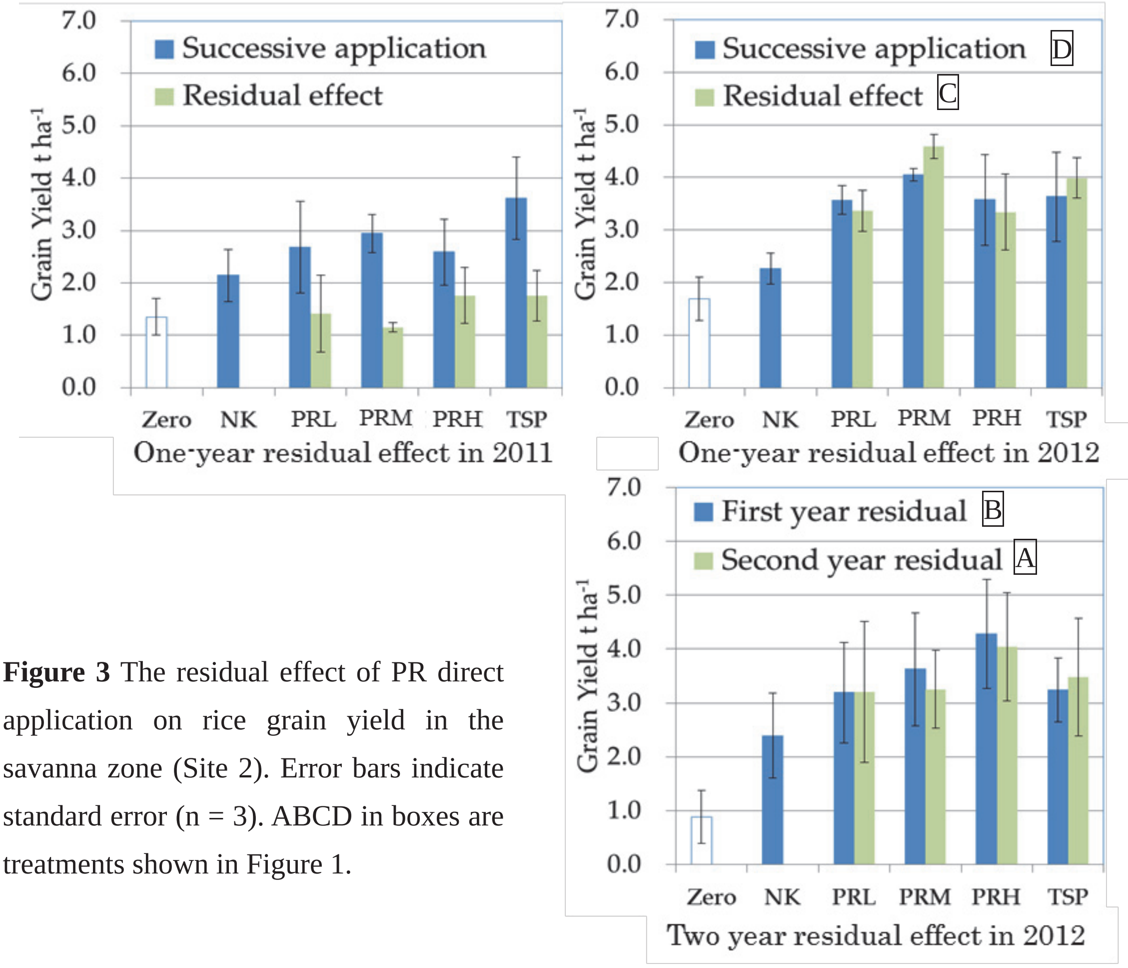
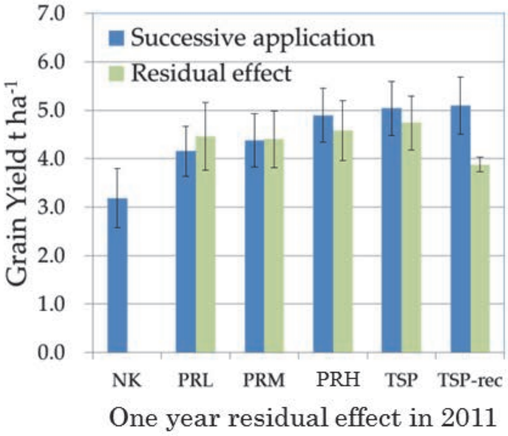


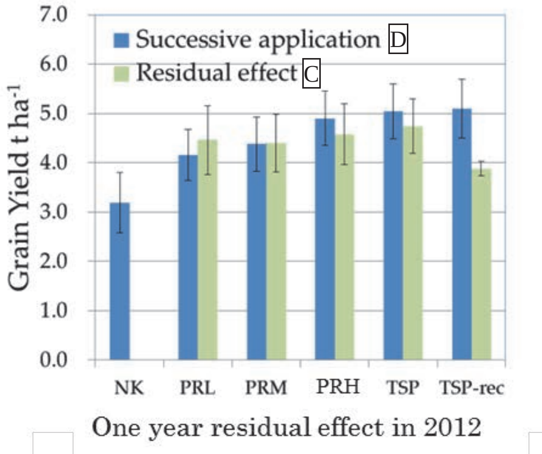
Figure 3 The residual effect of PR direct application on rice grain yield in the savanna zone (Site 2). Error bars indicate standard error (n = 3). ABCD in boxes are treatments shown in Figure 1.

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.





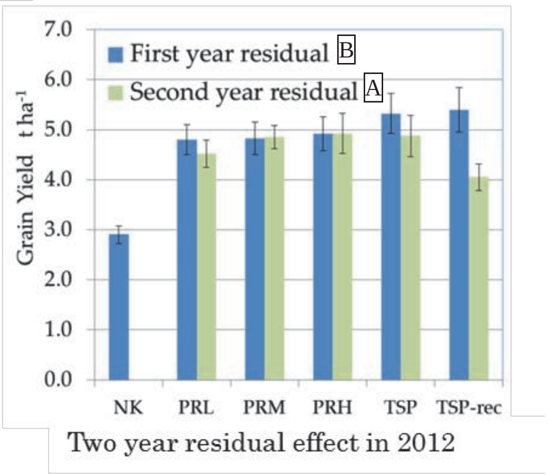


Figure 4 The residual effect of PR direct application on rice grain yield in the Equatorial forest zone (Site 3). Error bars indicate standard error (n = 3). ABCD in boxes are treatments shown in Figure 1.

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·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·ha^{-1} in addition to the previously applied 60 kg P_2O_5·ha^{-1} in 2010. For the one-year residual effect plot, only 60 kg P_2O_5·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·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·ha^{-1}, in the case 60 kg P_2O_5·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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