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

Fukuda M.,[1] Dzomeku I.K.,[2] Avornyo V.K.,[2] Nakamura S.,[1] Nagumo F.,[1] and Tobita S.[1]

[1]Japan International Research Center for Agricultural Sciences (JIRCAS), Tsukuba, Japan
[2]University for Development Studies (UDS), Tamale, Ghana

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).

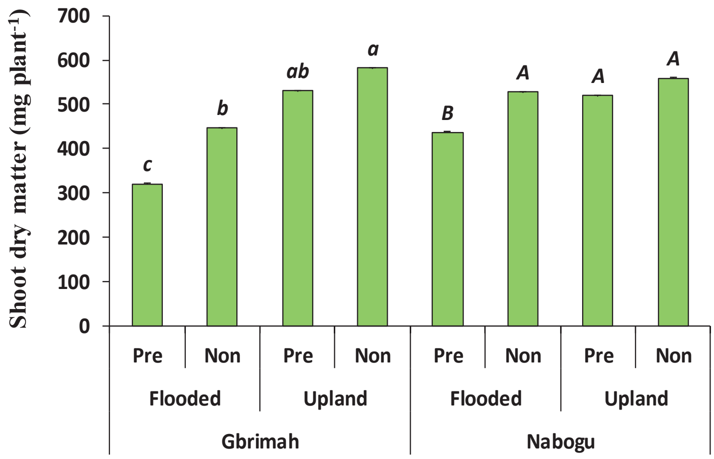

Figure 1 Shoot dry matter of rice (IR74) affected by pre-incubating (Pre) and non-incubating (Non) the soils (Gbrimah and Nabogu) with BPR before transplanting plants under flooded and upland conditions (n = 3) in the incubation study.

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*

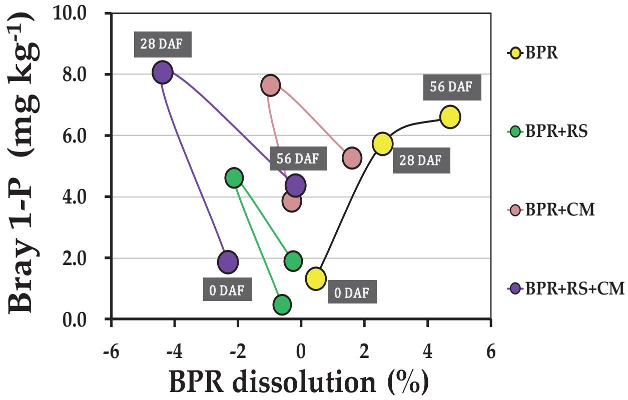

Figure 2 Trends of BPR dissolution and available P in incubated soil affected by directly applied BPR and co-applied BPR with RS and/or CM during 0, 28, and 56 days after flooding (DAF) the soil.

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.

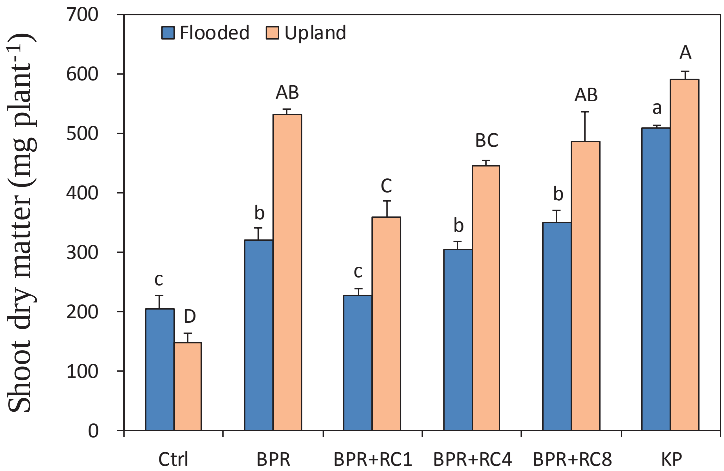

Figure 3 Shoot dry matter of rice (IR74) affected by directly applied BPR and co-applied BPR with rice straw composts (1, 4, and 8 week-composted RCs as RC1, RC4, and RC8, respectively) and chemical P fertilizer potassium dihydrogen phosphate; KH_2PO_4 (KP)

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.

REFERENCES

Food and Agriculture Organization of the United Nations (FAO) (2004) Use of phosphate rocks for sustainable agriculture. FAO Fertilizer and Plant Nutrition Bulletin No. 13. Rome, Italy, pp. 148.

Fukuda M, Nagumo F, Nakamura S, Tobita S (2013a) Ineffectiveness of directly applied Burkina Faso phosphate rock on rice growth. *Soil Sci. Plant Nutr*., **59** (3): 403-409.

Fukuda M, Nakamura S, Nagumo F, Tobita S (2013b) Effectiveness of directly applied Burkina Faso phosphate rock on rice grown in Ghanaian flooded and moist soils. *The Proc. Int. Plant Nutr. Colloquium* XVII. pp. 832-833. Istanbul, Turkey.

Fukuda M, Nagumo F, Nakamura S, Tobita S (2012a) Burkina Faso phosphate rock is an effective P fertilizer for rice grown on acidic and low P Ghanaian soil: Incubation study. *Res. Trop. Agric*., **5** (extra issue 1): 73-74.

Fukuda M, Nagumo F, Nakamura S, Tobita S (2012b) Effects of water conditions on the effectiveness of Burkina Faso phosphate rock for rice grown on different acidic soils. Abstracts of the Annual Meeting, Japanese Society of Soil Science and Plant Nutrition (4–6 September 2012), vol. 58, Tottori, Japan.

Fukuda M, Nakamura S, Nagumo F, Ito O, Tobita S (2011) Organic amendments decrease phosphate rock dissolution. Abstracts of the Annual Meeting, Japanese Society of Soil Science and Plant Nutrition, vol. 57 (8–10 August 2011), Tsukuba, Ibaraki, Japan.

Nakamura S, Issaka R, Dzomeku I, Fukuda M, Buri MM, Avornyo V, Owusu-Adjei E, Awuni J, and Tobita S (2013) Effect of Burkina Faso phosphate rock direct application on Ghanaian rice cultivation. *Afr. J. Agric. Res*., **8**(17), 1779-1789.

Nakamura S, Fukuda M, Issaka R, Dzomeku I, Buri MM, Avornyo V, O Adjei E, Awuni J, and Tobita S (2016) Residual effects of direct application of Burkina Faso phosphate rock on rice cultivation in Ghana, *Nutr. Cycl. Agroecosyst*., **106**(1), 47-59.

Rajan, SSS, Watkinson JH, Sinclair AG (1996) Phosphate rocks for direct application to soils. *Adv. Agron*., **57**, 77-159.

Simpson PG (1998) Reactive phosphate rocks: their potential role as P fertilizer for Australian Pastures. Technical Bulletin. La Trobe University. Melbourne, Australia, pp. 20.