Phosphorus adsorption, rice dry matter yield, and P use efficiency as influenced by phosphorus fertilizer rates in rainfed lowland soils in Togo

K. A. Ablede[1], K. Koudjega[1], I. Y. D. Lawson[2*], M. K. Abekoe[2], E. Owusu-Bennoah[2]

[1] *Institut Togolais de Recherche Agronomique, ITRA (Lomé, Togo)*

[2] *Department of Soil Science, University of Ghana (Legon, Accra)*

*Corresponding Author: *idlawson@ug.edu.gh*

Abstract

The study focused on improving phosphorus (P) fertilizer recommendation in rainfed lowland rice soils in Togo. Phosphorus adsorption was conducted on four soils to determine their P adsorption characteristics and standard phosphorus requirement (SPR). The adsorption maximum ranged from 143 to 200 mg P/kg. The amount of P adsorbed range from 62.70 to 74.85 mg P/kg. Greenhouse experiment was conducted to determine rice response to phosphorus rates based on the SPR values, and to assess rice P uptake and use efficiency. Five phosphorus rates, Control: 0 mg P kg^{-1}, P recommended rate (RR): 5 mg P kg^{-1}, 4 × RR: 20 mg P kg^{-1}, 50% SPR and 100% SPR were used. Results indicated no significant difference between the Control treatment and the P recommended rate (RR), and between the 50% SPR and the 100% SPR with reference to shoot dry matter yield. P uptake and P use efficiency were significantly and positively influenced by the various P fertilizer rates. From the study, the blanket P recommended rate is inappropriate, however, site-specific P fertilizer rate of 50% SPR may be recommended to improve rainfed lowland rice yields in Togo.

Keywords: Phosphorus fertilizer rates, rainfed lowland rice, standard phosphorus requirement,Togo

Introduction

In Togo, rice is mainly cultivated under rainfed lowland ecosystems and that accounts for more than 50% of the country's total rice production areas and contributes to about 60% of the national rice production (NRDS, 2010). Rice yields are low and the national average in 2016 was only 1.73 t ha^{-1} (DSID, 2017).

Phosphorus (P) is one of the major nutrients required by rice but most of the lowland rice growing acid soils in Togo are deficient in P. A number of research findings have shown positive effect of phosphorus on rice yield components like panicle number, number of grains per panicle and grain weight which increase significantly with P fertilizer application (Usman, 2013; Kato et al., 2016).

Apart from the inherent low P availability of such highly weathered acid soils, the application of soluble inorganic P fertilizers on these soils leads immediately to their conversion into insoluble P forms bound to Fe and Al oxides (Juo and Fox, 1977; Abekoe and Sahrawat, 2001). It is generally known that the inherent low fertility of acid soils and the inadequate nutrient management are among the main biophysical constraints which contribute to increase yield gap in rice (Bationo et al., 2008 and Niang et al., 2017).

In Togo, the blanket P fertilizer application rate of 5 mg P/kg recommended for rainfed lowland rice cropping (ITRA, 2007) could be one of the causes for non-realization of the yield potential of the local and improved rice varieties in the country. Such blanket P fertilizer rate is outmoded since it does not take into account the P requirements of the soils. Research on site-specific P needs of lowland rice fields is needed for the appropriate P recommendation rates since it is fundamental in ensuring high yields of rice in the country. Since research on P adsorption and standard P requirements (SPR) is lacking in Togo, these parameters are useful in managing phosphorus availability. Therefore, the objective of the study was to determine the appropriate P fertilizer rates needed to increase rice yield parameters such as plant height, number of tillers, dry matter yield, P uptake and P use efficiency in the rainfed lowland rice fields in

Togo using the standard P requirement (SPR) of the soils.

Materials and Methods

Study areas, soil sampling and analysis

Soil samples were collected at the depth of 0-20 cm from four (4) rainfed lowland rice fields located in three agroecological zones of Togo: *Tchitchao* (9°37'21"N, 1°8'45.92"E) in the dry savanna zone, *Tchangaide* (8°19'6.64"N, 1°3'16.85"E) and *Kaniamboua* (8°36'23.47"N, 1°0'12.89"E) in the humid savanna and *Akata Adame* (7°3'58.18"N, 0°43'1.52"E) in the semi-deciduous forest. The soil samples were air-dried, passed through 2 mm-sieve and analyzed for particle size distribution (Day, 1951), bulk density (core method), pH (1:1 soil : water suspension), organic carbon (Walkley & Black, 1934), total carbon and nitrogen (dry combustion with LECO Trumac CNS Analyzer), total phosphorus (H_2SO_4-H_2O_2 digestion method), available phosphorus (Bray and Kurtz, 1945), exchangeable bases (ammonium acetate, pH 7.0 extraction method) and exchangeable acidity.

Phosphorus adsorption study

Phosphorus adsorption was conducted in replicate of two grams (2 g) soil sample weighed into 50 ml centrifuge tubes. Twenty milliliters (20 mL) of 0.01 M KCl supporting electrolyte containing P standard solution (KH_2PO_4) with graded concentrations (0, 5, 10, 15, 20, 25, 30, 35 and 40 mg P L^{-1}) were added. Three drops of toluene were added to each centrifuge tube containing the soil-P mixture to prevent microbial activity. The sample solutions were shaken on a mechanical shaker for 30 minutes twice a day for six conservative days (Fox and Kamprath, 1970). At the end of the sixth day, the soil suspensions were centrifuged for 10 minutes at 10,000 rpm, and then filtered through a No.42 Whatman filter paper. The supernatant was analysed for P, using ascorbic acid-molybdate blue colour method (Murphy and Riley, 1962) and the phosphorus concentration in the solution was read on UV-spectrophotometer at a wavelength of 712 nm. The amount of P adsorbed by the various soils was determined as the difference between the concentration of P added and that left in the equilibrium solution. The sorption data was fitted into the linear form of Langmuir equation below:

$$\frac{C}{x} = \frac{1}{kb} + \frac{C}{b} \qquad \text{[Eq. 1]}$$

Where:

C (mg P L^{-1}) = P concentration in the equilibrium solution

x (mg P kg^{-1}) = the amount of P adsorbed per unit mass of soil

k (L mg^{-1}) = affinity index or constant relating to bonding energy

b = slope of the equation

The Standard Phosphorus Requirement of the soils defined as the amount of P required by the soils to attain equilibrium P concentration of 0.2 mg P L^{-1} was determined by solving for y in the logarithmic equation in Fig. 1.

Greenhouse experiment

A pot-experiment was conducted in a greenhouse at University of Ghana. Four (4) kg of air-dried 2 mm-sieved soil was weighed into 4-L cylindrical plastic containers to about 4 cm to the top of the containers. Five rates of P namely, Control: 0 mg P kg^{-1}, P recommended rate (RR): 5 mg P kg^{-1}, 4 × RR: 20 mg P kg^{-1}, 50% SPR and 100% SPR. The corresponding SPR values in terms of triple superphosphate (TSP) were 62.70, 65.43, 70.40 and 74.85 mg P kg^{-1} for *Kaniamboua*, *Tchangaide*, *Tchitchao* and *Akata Adame*, respectively. Three seeds of rice variety IR841 (commonly grown in Togo) were sown in the pots and after 10 days the seedlings were thinned to one per pot. The treatments were arranged in a completely randomized design with three replicates. All the pots were supplied with 30 mg N kg^{-1} soil as urea (46% N) and 10 mg K kg^{-1} soil as muriate of potash (60% K_2O) as basal nutrients. At 15 days after sowing (DAS), the total amount of K was applied whereas the urea was split into two equal parts of 15 mg N kg $soil^{-1}$ at 21 and

45 DAS.

Plant height was taken at 14, 28, 42, 56 and 70 DAS and the number of tillers was counted at 21, 35, 49 and 63 DAS. At the end of the experiment (70 DAS), the rice shoot was harvested by cutting close to the soil surface and weighed for fresh weight. Roots were separated from the adhering soil by carefully washing off the soil with tap water. After air-drying them, the shoot and roots were oven-dried at 70°C for 3 days and weighed for the dry matter yield. Thereafter, the samples were milled and analyzed for the P uptake using H_2SO_4-H_2O_2 digestion. Phosphorus concentration in the digest was determined using the phospho-molybdate blue method of Murphy and Riley (1962). Phosphorus uptake in the rice plant was calculated by multiplying the P concentration in the plant by the dry matter yield (Eq. 2).

$$\text{P uptake}_{\text{plant}}\ (\text{mg pot}^{-1}) = \text{P content}_{\text{plant}}(\text{mg g}^{-1}) \times \text{SDM(g) pot}^{-1} \quad \text{[Eq. 2]}$$

Where: SDM = Shoot Dry matter

Phosphorus use efficiency (PUE) was determined using Eq. 3 below.

$$\text{PUE (\%)} = \frac{\text{P uptake}_{\text{treatment}} - \text{P uptake}_{\text{control}}}{\text{Amount of P applied}_{\text{treatment}}} \times 100 \quad \text{[Eq. 3]}$$

Statistical analyses

Statistical analysis was run with GenStat software (12th Edition, 2009). The data was submitted to analysis of variance at 0.05 probability level and means were compared using Duncan's post-hoc multiple range at 5%.

Results and discussion

Soil properties

The physicochemical properties of the soils are presented in Table 1. Soils from all sites were sandy loam except *Tchitchao* which was loamy sand. The highest sand content (82%) was found at *Tchitchao* and the highest clay content was observed at *Akata Adame* (17%). All the four soils had pH which varied from 4.8 to 5.6. This pH range indicates that the soils are acidic in nature and consequently, are expected to fix P, hence the low available phosphorus in them. The available P of the soils was 6.61 mg kg^{-1} in *Akata Adame*, 7.21, 7.72 and 6.4 mg kg^{-1} for the *Tchangaide*, *Kaniamboua* and *Tchitchao*, respectively. The low soluble P of the soils may be inadequate for optimal growth of rice since their Bray1-P values were far below a critical range of 12.5 to 15 mg P kg^{-1} required for obtaining 90% rice grain yield (Sahrawat et al., 1997). Therefore, the studied soils may require P fertilizer application for sustainable rice grain yields. Exchangeable Ca^{2+} is high in the soils whilst Mg^{2+} and Na^{+} are low. Exchangeable K^{+} content is adequate for crop production in the soils. The percent base saturation (%BS) of the soils are similar and are in the range of 34.96 to 36.99 cmol(+)/kg soil.

TABLE 1

Selected physical and chemical properties of the soils

Soil parameter	Sampling sites			
	Akata Adame	Tchangaide	Kaniamboua	Tchitchao
Sand (%)	63	74	70	82
Silt (%)	20	15	18	7
Clay (%)	17	11	12	11
Textural Class	Sandy Loam	Sandy Loam	Sandy Loam	Loamy Sand
Bulk density (g cm^{-3})	1.32	1.31	1.28	1.36
pH water (1:1)	4.8	5.3	5.6	5.2
Total carbon (g kg^{-1})	8.37	10.73	10.27	4.06
Organic carbon (g kg^{-1})	7.06	9.25	9.67	3.57
CEC (cmolc kg^{-1})	8.02	9.18	10.08	7.92
Total N (g kg^{-1})	0.84	1.24	0.79	0.54

TABLE 1 *cont.*
Selected physical and chemical properties of the soils

Soil parameter	Sampling sites			
	Akata Adame	Tchangaide	Kaniamboua	Tchitchao
Total P (mg kg^{-1})	117	135	120	143
Available P (Bray-1, mg kg^{-1})	6.61	7.29	7.72	6.40
Exchangeable Ca^{2+} ($cmol_c$ kg^{-1})	2.17	2.38	2.95	2.24
Exchangeable Mg^{2+} ($cmol_c$ kg^{-1})	0.28	0.31	0.33	0.26
Exchangeable Na^{+} ($cmol_c$ kg^{-1})	0.09	0.17	0.10	0.14
Exchangeable K^{+} ($cmol_c$ kg^{-1})	0.26	0.46	0.32	0.29
Base saturation (%)	34.91	36.17	36.71	36.99
Exch. acidity [H^{+} + Al^{3+}] ($cmol_c$ kg^{-1})	1.17	0.98	0.53	1.09
Effective CEC ($cmol_c$ kg^{-1})	3.97	4.30	4.23	4.02

Phosphorus sorption isotherms

The P sorption isotherms of the studied soils are shown in Figure 1. The adsorbed phosphorus increased with increasing rates of added P but flattened at higher P solutions. For all the soils, the P sorption data fitted well the Langmuir isotherm model (Figure 2). Similar results were obtained by Huang et al. (2014) and Yan et al. (2017) on acid paddy soils in China, and also by Muindi et al. (2015) in maize growing acid soils in western Kenya. The Langmuir sorption maximum followed

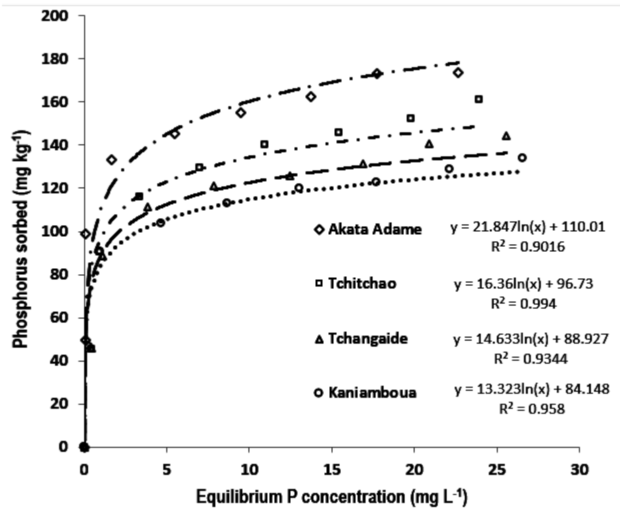

Figure 1 Phosphorus sorption isotherms of the studied soils

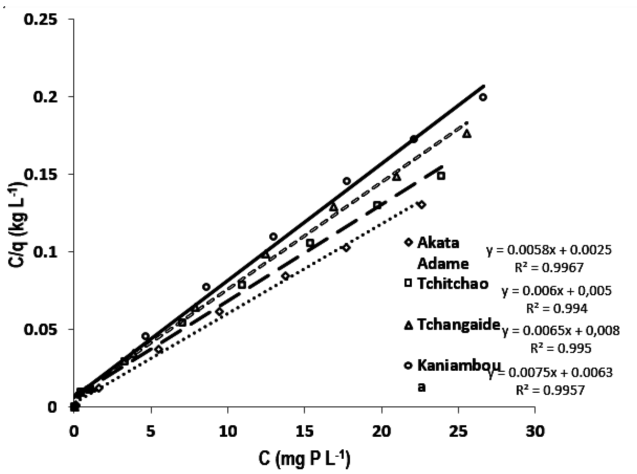

Figure 2 Linearized Langmuir isotherm model for the four paddy soils

the order: Akata Adame (200 mg P kg^{-1}) > Tchitchao (167 mg P kg^{-1}) > Tchangaide (154 mg P kg^{-1}) > Kaniamboua (143 mg P kg^{-1}). The difference in P adsorption of the various soils clearly implies that the use of blanket P fertilizer recommendation may not be useful for rainfed lowland rice cropping in Togo since the recommended rate may not be sufficient for optimum rice growth. The standard P requirements (SPR) ranged from 62.70 mg P kg^{-1} at *Kaniamboua* to 74.85 mg P kg^{-1} at *Akata Adame* (Table 2). These soils can be considered as having low P fertilizer requirements (Juo and Fox, 1977; Mokwunye et al., 1986).

TABLE 2

Phosphorus sorption characteristics of the paddy soils (0-20 cm) as described by Langmuir model and Standard P requirements (SPR)

Location	Linearized Langmuir model			P adsorbed at SPR (mg P kg^{-1})
	b (mg kg^{-1})	k (L mg^{-1})	R^2	
Akata Adame	200	0.83	0.996	74.85
Tchitchao	167	1.20	0.994	70.40
Tchangaide	154	0.81	0.995	65.43
Kaniamboua	143	1.17	0.995	62.70

b: adsorption maximum, k: affinity index

Pot experiment

Effect of phosphorus on rice shoot height and number of tillers

The effect of increasing P rates on the rice shoot height is presented in Table 3. No significant difference ($p > 0.05$) in shoot height was observed at 14 days after sowing (DAS) in the four soils. The highest height at 14 DAS was obtained with the 100% SPR and 50% SPR treatments. At *Akata Adame*, there was no significant difference between the 100% SPR, the 50% SPR and the 4×RR at 28 and 42 DAS. Similar results were observed at *Tchangaide* and *Tchitchao* at 28 DAS. However, the shoot height obtained with the 100% SPR treatment was statistically different from that of 50% SPR at 56 and 70 DAS at *Akata Adame* and *Tchangaide* but at *Tchitchao*, it was only significant at 70 DAS. At all the four sites, there was a positive response in tiller numbers per pot to applied P rates at different days after sowing (Figure 3). The highest tiller numbers were obtained with the 100% SPR and 50% SPR treatments.

Effect of phosphorus on rice shoot and root dry matter yield

The influence of P fertilizer rates on the shoot

TABLE 3

Influence of applied phosphorus on rice shoot height

Site	Treatment	P rate (mg kg^{-1})	Time (days after sowing)				
			14	28	42	56	70
Akata Adame	CTRL	0	22.67	33.33 b	48.00 b	56.00 c	58.67 d
	RR	5	22.17	42.00 ab	57.00 a	59.67 bc	62.83 cd
	4xRR	20	22.50	47.00 a	62.00 a	66.33 b	69.00 bc
	50%SPR	37.5	23.33	48.50 a	64.33 a	66.00 b	71.33 b
	SPR	75	24.00	49.33 a	61.00 a	80.33 a	84.00 a
	P-value		*NS*	*0.02*	*0.012*	*<0.01*	*<0.01*
	CV (%)		*9*	*11.8*	*8*	*6.7*	*5.8*

TABLE 3 *cont.*

Influence of applied phosphorus on rice shoot height

Site	Treatment	P rate (mg kg^{-1})	Time (days after sowing) 14	28	42	56	70
Tchangaide	CTRL	0	26.00	40.00	54.67	67.33 c	70.33 c
	RR	5	19.00	42.00	56.33	69.33 c	73.00 c
	4xRR	20	23.17	48.00	60.17	71.00 c	74.33 c
	50%SPR	32.5	24.67	52.00	65.5	78.67 b	82.33 b
	SPR	65	24.83	47.67	67.33	84.67 a	90.33 a
	P-value		*NS*	*NS*	*NS*	*<0.01*	*<0.01*
	CV (%)		*11.9*	*15.6*	*9.9*	*4.4*	*4.3*
Kaniamboua	CTRL	0	24.50	33.00 c	44.33 b	48.67 c	51.17 d
	RR	5	25.00	36.50 bc	50.67 b	57.33 b	61.00 c
	4xRR	20	25.17	44.00 ab	60.00 a	67.33 a	71.00 b
	50%SPR	31.5	27.00	47.17 a	65.00 a	71.67 a	75.50 ab
	SPR	63	26.50	51.67 a	65.00 a	72.00 a	78.67 a
	P-value		*NS*	*0.03*	*<0.01*	*<0.01*	*<0.01*
	CV (%)		*7.4*	*10.5*	*7.2*	*4.6*	*4.4*
Tchitchao	CTRL	0	24.83	35.00 b	50.33 c	54.00 c	57.17 d
	RR	5	26.50	48.33 a	58.17 b	61.00 b	65.00 c
	4xRR	20	24.40	48.67 a	58.67 b	61.67 b	65.67 c
	50%SPR	35	26.83	55.00 a	65.00 a	68.00 a	71.83 b
	SPR	70	23.50	53.33 a	63.67 a	70.00 a	76.17 a
	P-value		*NS*	*<0.01*	*<0.01*	*<0.01*	*<0.01*
	CV (%)		*11.5*	*7.3*	*4.3*	*4.3*	*3.2*

CTRL = Control, RR = P recommended rate, SPR = Standard Phosphorus Requirement, NS = non-significant
Values followed by the same letter are not significantly different using Duncan's multiple range test (P < 0.05)

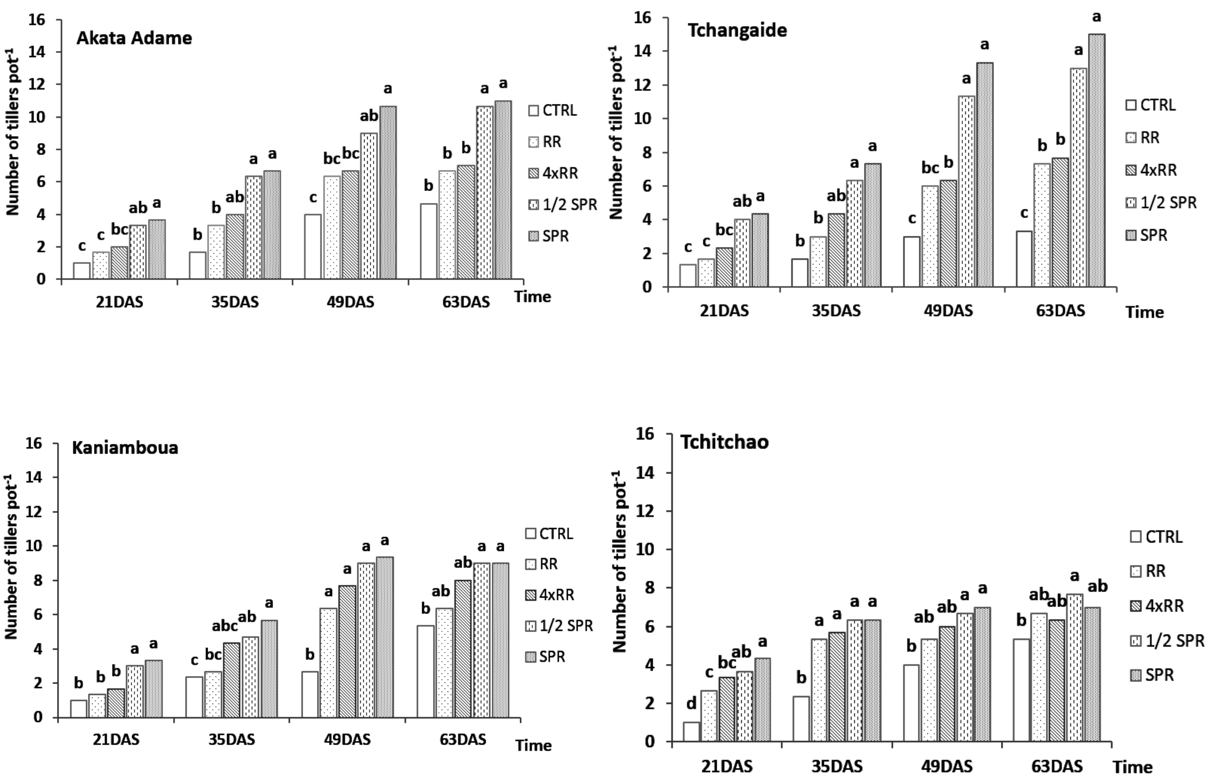

Figure 3 Number of rice tillers at various days after sowing (DAS) as affected by P rates at different sites
Means represented by histograms with similar letters are not significantly different at p = 0.05

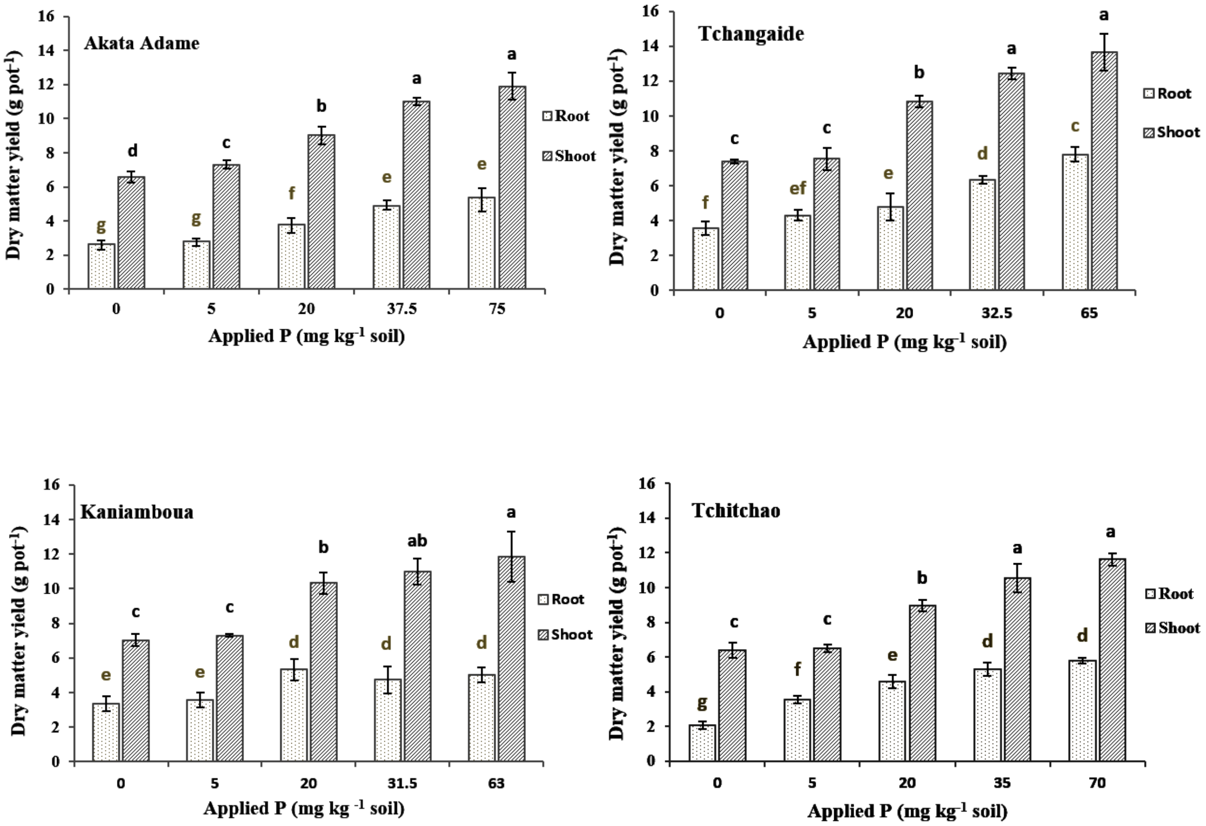

Figure 4 Effect of applied P on shoot and root biomass at 70 DAS
Histograms show means of 3 replicates and error bars represent standard deviation of the means

and root dry matter yields in the soils is shown in Figure 4. Except for Akata Adame, the lowest shoot dry matter yields were recorded with the Control (0 P) and the P Recommended Rate (5 mg P kg^{-1} soil) treatments at 70 DAS. In all the soils, the 100% SPR treatment had the highest shoot dry matter yield which is statistically similar to 50% SPR. The same trends were obtained for the root dry matter yields but the highest root dry matter yields were obtained with the 100% SPR and 50% SPR treatments in all the soils except in Tchangaide. In addition, apart from Tchitchao soil, there was no significant ($p > 0.05$) difference in root dry matter between Control and the P Recommended Rate. The increase in rice dry matter yield as a result of phosphate fertilizer application has also been reported by Shekifu (1999), Hameed et al. (2002) and Hussain et al. (2004). The improvement in shoot and root dry matter yields with increasing P fertilizer rates was expected because all the four soils were deficient in available P (6.4 to 7.72 mg kg^{-1} soil).

No significant difference in the shoot dry matter (SDM) yield was obtained between the Control and the P recommended rate (except Akata Adame) and in the shoot dry matter yields between 50% and 100% SPR treatments. The recommended P rate of 5 mg kg^{-1} is therefore not adequate to produce significant dry matter yield in all the soils. The similar dry matter yields obtained with treatments 50% SPR and the 100% SPR for all the soils suggests that applying P fertilizer rate of 50% SPR may be sufficient for obtaining satisfactory rice grain yields.

Effect of phosphorus rates on P concentration, P uptake and P use efficiency

Phosphorus concentration

Phosphorus concentration in plant and P uptake in roots and shoot in the various soils are presented in Tables 4-7. In all the soils, P concentration in the shoot and roots significantly ($p < 0.05$) increased with increased applied P. In Akata Adame soil, P concentration in roots varied from 0.66 to 1.65 mg g^{-1} with the lowest values obtained with the Control and P recommended rate which were statistically similar ($p > 0.05$). The 100% SPR recorded the highest value which did not differ markedly from that of the 50% SPR. The P content in the rice shoot ranged from 1.39 to 4.48 mg g^{-1}. Contrary to P concentration in the roots, shoot P content obtained with the SPR was significantly different ($p < 0.05$) from that of the 50% SPR (Table 4). Phosphorus content in the roots ranged from 0.62 to 1.51, 0.89 to 1.79 and 0.81 to 1.55 mg g^{-1} in Tchangaide, Kaniamboua and Tchitchao, respectively whereas P accumulated in the shoot varied from 1.70 to 3.92, 1.56 to 4.05 and 1.48 to 4.02 mg g^{-1} in Tchangaide, Kaniamboua and Tchitchao, respectively (Table 5-7). In general, P concentration in the shoot is higher than that of the roots. Both roots and shoot recorded the highest P contents with the 100% SPR and the lowest with the control (without P). Phosphorus content in the plant significantly increased with phosphorus levels applied. Average P concentrations in shoot were 2.75, 2.68, 2.70 and 2.67 mg g^{-1} for Akata Adame, Tchangaide, Kaniamboua and Tchitchao, respectively. These results are in line with the shoot P content range (2.23 to 3.02 mg g^{-1} dry weight) of *indica* rice IR-28 at 60 days after sowing as reported by Islam et al. (2008) in Japan.

The ratio of P concentration in shoot to P content in roots varied from 2.02:1 in Kaniamboua

TABLE 4

Phosphorus concentration and uptake in rice roots and shoot at Akata Adame

Trt	P rate (mg kg^{-1})	Roots			Shoot			Total P uptake (mg P pot^{-1})
		DW (g pot^{-1})	P content (mg P g^{-1})	P uptake (mg P pot^{-1})	DW (g pot^{-1})	P content (mg P g^{-1})	P uptake (mg P pot^{-1})	
CTRL	0	2.67 c	0.73 b	1.95 d	6.58 d	1.40 d	9.19 e	11.14 e
RR	5	2.81 c	0.66 b	1.85 d	7.30 c	1.77 d	12.93 d	14.78 d
4×RR	20	3.82 b	1.20 ab	4.58 c	9.02 b	2.53 c	22.86 c	27.44 c
50 % SPR	37	4.87 a	1.47 a	7.14 b	11.03 a	3.57 b	39.35 b	46.49 b
SPR	75	5.36 a	1.65 a	8.84 a	11.90 a	4.48 a	53.37 a	62.21 a
P-value		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
LSD (0.05)		0.64	0.55	0.93	0.87	0.56	3.21	2.87
CV (%)		9.1	26.4	10.5	5.2	11.1	6.4	4.9

CTRL = Control, RR = P recommended rate, SPR = Standard Phosphorus Requirement
Within a column, values followed by the same letter are not significantly different using Duncan's multiple range test ($P < 0.05$)

TABLE 5

Phosphorus concentration and uptake in rice roots and shoot at Tchangaide

Trt	P rate (mg kg^{-1})	Roots			Shoot			Total P uptake (mg P pot^{-1})
		DW (g pot^{-1})	P content (mg P g^{-1})	P uptake (mg P pot^{-1})	DW (g pot^{-1})	P content (mg P g^{-1})	P uptake (mg P pot^{-1})	
CTRL	0	3.56 d	0.62 c	2.21 e	7.40 d	1.70 d	12.61 e	14.82 e
RR	5	4.31 cd	0.87 bc	3.76 d	7.54 d	2.01 cd	15.13 d	18.89 d
4×RR	20	4.80 c	1.14 abc	5.47 c	10.83 c	2.47 c	26.79 c	32.26 c
50 % SPR	33	6.32 b	1.38 ab	8.72 b	12.43 b	3.31 b	41.17 b	49.90 b
SPR	65	7.79 a	1.52 a	11.82 a	13.65 a	3.92 a	53.49 a	65.31 a
P-value		<0.01	0.03	<0.01	<0.01	<0.01	<0.01	<0.01
LSD (0.05)		0.85	0.56	0.97	0.68	0.57	1.64	1.99
CV (%)		8.7	28	8.3	3.6	11.7	3	3

CTRL = Control, RR = P recommended rate, SPR = Standard Phosphorus Requirement
Within a column, values followed by the same letter are not significantly different using Duncan's multiple range test ($P < 0.05$)

TABLE 6

Phosphorus concentration and uptake in rice roots and shoot at Kaniamboua

Trt	P rate (mg kg^{-1})	Roots			Shoot			Total P uptake (mg P pot^{-1})
		DW (g pot^{-1})	P content (mg P g^{-1})	P uptake (mg P pot^{-1})	DW (g pot^{-1})	P content (mg P g^{-1})	P uptake (mg P pot^{-1})	
CTRL	0	3.35 b	0.90 c	3.01 c	7.02 c	1.56 c	10.98 d	13.99 d
RR	5	3.58 b	1.14 bc	4.09 c	7.30 c	1.89 bc	13.82 d	17.90 d
4×RR	20	5.33 a	1.27 abc	6.77 b	10.33 b	2.47 b	25.51 c	32.26 c
50 % SPR	31	4.74 a	1.57 ab	7.46 b	11.01ab	3.54 a	38.98 b	46.44 b
SPR	63	5.01 a	1.79 a	8.96 a	11.85 a	4.06 a	48.07 a	57.03 a
P-value		<0.01	0.037	<0.01	<0.01	<0.01	<0.01	<0.01
LSD (0.05)		1.01	0.56	1.43	1.45	0.83	5.42	6.48
CV (%)		12.6	23.1	13	8.4	16.9	10.8	10.6

CTRL = Control, RR = P recommended rate, SPR = Standard Phosphorus Requirement
Within a column, values followed by the same letter are not significantly different using Duncan's multiple range test (P < 0.05)

TABLE 7

Phosphorus concentration and uptake in rice roots and shoot at Tchitchao

Trt	P rate (mg kg^{-1})	Roots			Shoot			Total P uptake (mg P pot^{-1})
		DW (g pot^{-1})	P content (mg P g^{-1})	P uptake (mg P pot^{-1})	DW (g pot^{-1})	P content (mg P g^{-1})	P uptake (mg P pot^{-1})	
CTRL	0	2.07 d	0.81 c	1.68 e	6.41 d	1.48 d	9.49 e	11.17 e
RR	5	3.54 c	0.93 bc	3.32 d	6.51 d	1.77 d	11.53 d	14.85 d
4×RR	20	4.58 b	1.25 ab	5.71 c	8.95 c	2.75 c	24.58 c	30.30 c
50 % SPR	35	5.30 a	1.51 a	8.03 b	10.55 b	3.35 b	35.30 b	43.32 b
SPR	70	5.79 a	1.55 a	8.99 a	11.62 a	4.02 a	46.70 a	55.69 a
P-value		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
LSD (0.05)		0.51	0.40	0.65	0.60	0.53	1.65	1.99
CV (%)		6.5	18.2	6.4	3.7	10.9	3.6	3.5

CTRL = Control, RR = P recommended rate, SPR = Standard Phosphorus Requirement
Within a column, values followed by the same letter are not significantly different using Duncan's multiple range test (P < 0.05)

to 2.42:1 in Tchangaide, indicating that P accumulated in the shoot was at least double the P build up in the roots. As shown by Islam et al. (2008), the P content in the shoot would be decreasing from the maximum tillering stage throughout panicle initiation and heading stages up to the harvesting stage where it would be much lower compared to the P content in the grain.

Phosphorus uptake and P use efficiency

In the four soils, phosphorus applied significantly ($p < 0.05$) influenced positively the P uptake in the shoots and roots. The total P uptake by the whole plant differed significantly ($p < 0.05$) in all the soils and the highest values (62.21, 65.31, 57.03 and 55.69 mg P pot^{-1}) were obtained with the 100% SPR at Akata Adame, Tchangaide, Kaniamboua and Tchitchao (Tables 4-7). The total P uptake by the whole rice plant biomass at high P rates (75, 65, 63 and 70 mg P kg^{-1} soil) was approximately 5.5, 4.5, 4 and 5 times higher than the Control at Akata Adame, Tchangaide, Kaniamboua and Tchitchao, respectively. The relationship between P uptake and shoot dry matter yield is presented in Table 8. Thus, knowing the shoot dry matter yield per pot, the P uptake can be predicted within 89-98% accuracy for the various soils.

The phosphorus use efficiency (PUE) by the rice crop differed significantly with the

TABLE 8
Relationship between P uptake and shoot dry matter yield

Site	Equation	R^2	*P*-value
Akata	SDMy (mg pot^{-1}) = 5.785 + 0.1229 P uptake (mg pot^{-1})	0.955**	< 0.01
Kaniamboua	SDMy (mg pot^{-1}) = 5.759 + 0.1363 P uptake (mg pot^{-1})	0.894**	< 0.01
Tchitchao	SDMy (mg pot^{-1}) = 5.617 + 0.1593 P uptake (mg pot^{-1})	0.945**	< 0.01
Tchangaide	SDMy (mg pot^{-1}) = 5.037 + 0.1477 P uptake (mg pot^{-1})	0.977**	< 0.01

SDMy: Shoot dry matter yield

TABLE 9
Phosphorus use efficiency (%) by rice

Treatment	Site			
	Akata Adame	Tchangaide	Kaniamboua	Tchitchao
RR	18.19 bc	20.38 ab	19.59 ab	18.39 bc
4×RR	20.37 b	21.80 ab	22.86 ab	23.91 a
50 % SPR	23.57 a	26.78 a	25.96 a	21.43 ab
SPR	17.02 c	19.27 b	17.22 b	14.84 c
P-value	< 0.01	0.174	0.021	0.019
LSD (0.05)	2.2345	7.4	7.4747	5.0246
CV (%)	6	17.8	18.5	13.6

RR = P recommended rate, SPR = Standard Phosphorus Requirement
Within a column, values followed by the same letter are not significantly different using Duncan's multiple range test (P < 0.05)

various P rates applied to the soils (Table 9). At Akata Adame and Tchangaide, the highest PUE (23.57 and 26.78%) was obtained by the 50% SPR. The same trend was observed at Kaniamboua and Tchitchao where the 50% SPR gave 25.96 and 21.43 % as PUE. However, at Tchangaide and Kaniamboua, the PUE obtained with treatments RR and 4×RR were similar to that of 50% SPR and in Tchitchao the maximum PUE (23.91%) was obtained with the treatment 4×RR which was similar to that of the 50% SPR.

Conclusion

The study was carried out to examine phosphorus requirements of rainfed rice production in lowland acid soils in Togo and to improve upon P fertilizer recommendations based on standard phosphorus requirements of the soils. The maximum P adsorption obtained in the study varied from 143 to 200 mg P kg^{-1} with the standard P requirements (SPR) ranging from 62.70 mg P kg^{-1} soil at Kaniamboua to 74.85 mg P kg^{-1} soil at Akata Adame. The results from the greenhouse study showed that rice shoot and root dry matter yields were positively correlated with the increasing P fertilizer levels. Significant improvements in rice yield indicators were obtained with the application of the 50% SPR. This P application rate may be recommendedfor rainfed lowland rice farmers in Togo.

Acknowledgments

This work was supported by West Africa Agricultural Productivity Program - Togo Project (WAAPP-Togo).

References

Abekoe, M. K., and Sahrawat, K. L. (2001). Phosphate retention and extractability in soils of the humid zone in West Africa. *Geoderma*, **102**(1-2), 175-187.

Bationo, A., Kihara, J., Vanlauwe, B., Kimetu, J., Waswa, B.S., Sahrawat, K.L. (2008). Integrated nutrient management: concepts and experience from Sub-Saharan Africa. In: Aulakh, M.S., Grant, C.A. (Eds.), Integrated Nutrient Management for Sustainable Crop Production. The Haworth

Press, Taylor and Francis Group, New York, NY, USA, pp: 467-521.

Bray, R. H., and Kurtz, L. T. (1945). Determination of total, organic, and available forms of phosphorus in soils. *Soil science*, **59(1)**, 39-46.

Day, P. R. (1951). Particle fractionation and particle-size analysis. In Black, C. A. (Ed.), Methods of Soil Analysis. *American Society of Agronomy*, Madison. pp. 545-567.

DSID, Direction des Statistiques, de l'Information et de la Documentation (2017). Evolution des superficies, de la production et des rendements du riz paddy au Togo de 2012 à 2016.

Fox, R. L., and Kamprath, E. J. (1970). Phosphate sorption isotherms for evaluating the phosphate requirements of soils. *Soil Science Society of America Journal*, 34(6), 902-907.

Hameed, E., Shah, W. A., Shad, A. A., Taj, F. H., and Bakht, J. (2002). Yield and yield components of wheat as affected by different planting dates, seed rate and nitrogen levels. *Asian Journal of plant Sciences*.

Huang, L. M., Thompson, A., and Zhang, G. L. (2014). Long-term paddy cultivation significantly alters topsoil phosphorus transformation and degrades phosphorus sorption capacity. *Soil and Tillage Research*, **142**, 32-41.

Hussain, N., Hyder, N. and Ahmad, N. (2004). Influence of phosphorus application on growth and yield components of wheat cultivar Punjab-96. *Indus J. Plant Sci.*, **3:** 276–9

Islam, M. A., Islam, M. R., and Sarker, A. B. S. (2008). Effect of phosphorus on nutrient uptake of Japonica and Indica rice. *Journal of Agriculture & Rural Development*, **6(1)**, 7-12.

ITRA (2007). Situation de reference sur les principales céréales cultivées au Togo: maïs-riz- sorgho-mil. 107p.

Juo, A. S. R., and Fox, R. L. (1977). Phosphate sorption characteristics of some bench-mark soils of West Africa. *Soil Science*, 124(6), 370-376.

Kato, Y., Tajima, R., Toriumi, A., Homma, K., Moritsuka, N., Shiraiwa, T., and Jongdee, B. (2016). Grain yield and phosphorus uptake of rainfed lowland rice under unsubmerged soil stress. *Field crops research*, **190**, 54-59.

Mokwunye, A. U. S. H., Chien, S. H., and Rhodes, E. (1986). Phosphate reactions with tropical African soils. In Management of nitrogen and phosphorus fertilizers in Sub-Saharan Africa (pp. 253-281). Springer, Dordrecht.

Muindi, E. M., Mrema, J. P., Semu, E., Mtakwa, P. W., Gachene, C. K., and Njogu, M. K. (2015). Phosphorus adsorption and its relation with soil properties in acid soils of Western Kenya. *Int. J. Plants & Soil Sci*, **4(3)**, 203-211.

Murphy, J., and Riley, J. P. (1962). A modified single solution method for the determination of phosphate in natural waters. *Analytica chimica acta*, **27**, 31–36.

NRDS (National Rice Development Strategy)-Togo. 2010. Ministry of Agriculture, Livestock and Fisheries. Republic of Togo. 48p.

Niang, A., Becker, M., Ewert, F., Dieng, I., Gaiser, T., Tanaka, A., and Segda, Z. (2017). Variability and determinants of yields in rice production systems of West Africa. *Field crops research*, **207**, 1-12.

Sahrawat, K. L., Jones, M. P., and Diatta, S. (1997). Extractable phosphorus and rice yield in an Ultisol of the humid forest zone in West Africa. *Communications in soil science and plant analysis*, **28(9-10)**, 711-716.

Shekifu, C. Y. (1999). Evaluation of iron oxide impregnated filter paper method for predicting available phosphorus in selected paddy soils of Tanzania. Unpublished Dissertation for award of MSc degree at Sokoine University of Agriculture, Morogoro, Tanzania. 87 p.

Usman, K. (2013). Effect of phosphorus and irrigation levels on yield, water productivity, phosphorus use efficiency and income of lowland rice in northwest Pakistan. *Rice Sci.* 2013, **20**, 61–72.

Walkley, A., and Black, I. A. (1934). An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil science*, **37(1)**, 29-38.

Yan, X., Wei, Z., Hong, Q., Lu, Z., and Wu, J. (2017). Phosphorus fractions and sorption characteristics in a subtropical paddy soil as influenced by fertilizer sources. *Geoderma*, **295**, 80-85.