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ASSESSMENT OF PHOSPHORUS AVAILABILITY FROM UNREACTIVE TOGO PHOSPHATE ROCK BY LEGUME AND CEREAL CROPS IN TWO GHANAIAN SOILS

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Abstract

Purpose: In recent years, phosphate rock (PR) for direct application has been tested in tropical acid soils as a potential alternative to conventional water-soluble P fertilizers like Single Superphosphate (SSP) and Triple Superphosphate (TSP). However, direct application of PR with low reactivity does not always give satisfactory results. Legume and cereal crops represent a strategy that can be used to solubilize P from some of these unreactive PRs. The objective of this study was to assess the availability of P from unreactive Togo Phosphate Rock (TPR) relative to TSP by six (6) crop species in two Ghanaian soils.

Methodology: The study was conducted in the greenhouse of the Crop Science Department, University of Ghana. Three P rates, 0mg, 50mg and 100mg P of TPR and TSP were applied to a kilogram of soil per pot in the two soil series. Randomized Complete Block Design was used to do the analyses.

Results/Findings: Application of TSP resulted in higher dry matter and P uptake irrespective of the soil type. Among the legumes, cowpea gave the highest dry matter yield. Fairly, a similar trend was obtained with the application of TPR. Among the cereals, the average P uptake by sorghum from TPR was the highest, followed by maize and millet in the Nzema soil. In the Adenta series, P uptake by maize was the highest, followed by sorghum and millet. Phosphorus (P) uptake by the cereals from TPR was generally better in the Adenta than the Nzema soil.

Unique contribution to theories, practice and policy: Results show increasing the rate of TPR to 100mg P/pot resulted in an increase in dry matter yield and P uptake in both soils, but was inferior to 100mg P/pot TSP application. Consequently, the rate of application of TPR should always be high if farmers want the best from their investments. Again, the low relative agronomic effectiveness of TPR for all the crops, proved the low reactivity of the material and its subsequent low performance compared with the water-soluble P. The low reactivity and the high molar mass of PO_4^{3-}/CO_3^{2-} of the TPR will always make it difficult for P to be made available from the TPR despite the acidity of the soil, the high density of the crops and the ability of the tested crops to exude organic acids, which facilitate phosphorus availability from TPR, therefore making TPR unsuitable for direct application.

Key words: *Phosphate rock, Adenta, Nzema, Paleustalf, Relative Agronomic Effectiveness, Organic acids*

1.0 INTRODUCTION

One of the major problems that have constrained the development of an economically successful, sustainable agriculture in in the whole world, particularly the Sub-Saharan Africa (SSA) is a prevalent poor soil fertility for crop production. Many of the agricultural soils in the tropical and subtropical regions are low in both total and available phosphorus (P), which is an essential plant nutrient (Bationo *et al*., 1998; Vanlauwe *et al.*, 2002). Phosphorus is critically needed to improve soil fertility for crop production in large areas of developing countries due to phosphorus fixation by Fe and Al oxides (Sample *et al*., 1980). Manufactured water-soluble phosphorus (WSP) fertilizers such as superphosphates are commonly recommended for correcting P deficiencies. However, most developing countries, including Ghana, import these fertilizers, which are often in limited supply and represent a major capital outlay for resource-poor farmers (Owusu-Bennoah *et al*., 2000). Thus, finding economical material to overcome phosphorus deficiency is an integral part of any solution to the problems of agricultural development in most developing countries of SSA.

Due to the low income of Ghanaian farmers, there is an increasing interest in the use of cheaper alternative phosphorus fertilizers such as indigenous phosphate rock for direct application. The direct application of phosphate rock is an agronomic and economically sound alternative to the more expensive superphosphates in the tropics (Diata, 2014; Chien & Hammond, 1978; Truong *et al*., 1978; Zapata *et al*., 1986; Hammond *et al.*, 1986b; Chien and Hammond, 1989; Chien *et al*., 1990a; Bationo & Mokwunye, 1991; World Bank, 1992; Gerner & Baanante, 1995; Kuyvenhoven & Lanser, 1999; Sale & Mokwunye, 1993). The major constraint on the application of PRs however, is the low reactivity of the many locally available PR sources. According to Chien and Hammond (1978), the effectiveness of local phosphate rock depends on its chemical and mineralogical composition. To increase PR solubility for direct application, biological, physical, and chemical methods have been employed.

For example, Phosphate-Solubilizing Bacteria (PSB) have been known to have the ability to solubilize PR effectively so that its performance can equate that of triple superphosphate (TSP) (Amankwa, 2010). The challenge with this method, however, is that using PSB on acid soils will not yield the needed results for legumes since the rhizobia cannot grow effectively and poor nodulation and low N have been recorded (Dakora & Philip, 2002; Giller, 2001; Hungaria & Vergas, 2000; Danso, 1977). Most workers have also recommended organic amendments as the best alternative (Singh & Amberger, 1990; Akande *et al* 1998, 2005) but sources of these organic materials are severely restricted and where available tend to be very bulky and expensive to transport. Partially acidulating rock phosphate has also been said to be as effective as SSP or TSP (Sahrawat *et al.*, 2001) but acidulation also has its consequential effects of polluting water, soil and the environment.

Several studies have shown that legumes are particularly suited for the use of PRs (Ankomah *et al.*, 1995; Kamh *et al.*, 1999 Randhawa 2003). They are effective in dissolving PR and in absorbing its dissolution products because of their demand for Ca and the acidifying effect of nitrogen (N) fixation in the soil near the root system (rhizosphere) (Ankomah *et al*., 1995; Kamh *et al.*, 1999; Randhawa 2003). This effect of using legumes with PRs can be utilized to improve the P nutrition of a companion crop (intercropping) or that of the subsequent crop in a rotation

(Horst & Waschkies, 1987; Vanlauwe *et al.*, 2000). Some plant species, for example, rapeseed, lupines and pigeon pea have been studied for their ability to secrete organic acids that result in an enhanced dissolution of PR (Jones, 1998; Hoffland, 1992; Adams & Pate, 1992; Ae *et al*., 1990; Montenegro & Zapata, 2002). Recent studies by Chien (2003) indicated that reactive PRs may have potential applications, even in alkaline soils with organic-acid secreting crops such as rapeseed. Hinsinger & Gilkes (1995) and Habib *et al*., (1999) have also found enhanced PR dissolution in the rhizosphere of some crop species in alkaline soils. If legumes can enhance PR dissolution, then there is an opportunity to use them for increasing the agronomic effectiveness of PR.

Cereals constitute a major staple food crop in SSA. They are grown extensively by the smallholder farmers and serve as a source of energy for the local farmers and the entire farming community. It has been shown that cereal growth is dependent on availability of P in the soil, but soils in SSA have low available P. Flach *et al* (1987) demonstrated that some cereal crop species have the mobilizing capacity to solubilize P from PRs. Petersen and Bottger (1991) have also shown that cereals, especially maize, were able to solubilize P from PR by excreting organic acids. Campaore *et al.* (2011) have also shown that maize was able to solubilize P from Burkina Kodjare phosphate rock while on the contrary; Chien *et al.* (1995) have shown that the RAE of PR for crops with lower P demands, such as legume crops is higher than for cereal crops such as maize.

The direct application of ground, natural PR as a source of P for crops is a practice that has been utilized with varying degrees of popularity over the years. Numerous field and greenhouse experiments have been conducted during the past 100 years or more to assess the capabilities of these materials to supply P to crops and to define the most favourable conditions for their application. The results obtained have been reported as erratic and sometimes conflicting, leading to confusion and disagreement on the utilization of PRs (Khasawneh and Doll, 1978).

As interest in the use of PRs for crop production in the whole world increases, especially South Saharan Africa, more research is needed to compare the Relative Agronomic Effectiveness of local deposits of PRs such as Togo Rock Phosphate, as influenced by local crop species because of conflicting reports over the years regarding utilization of PR, therefore it is imperative to conduct this research so that screening of these local crops with respect to their ability to utilize phosphorus from sparingly soluble PRs from the region will enhance the selection of appropriate crop combinations for cereal-based cropping systems, optimizing crop production and economic benefit. Though the many countries seem to do more in the area of direct application of phosphate rock, Ghana in particular, has done little and it is about time more researches are carried out in this field so as to boost the production of the small holder farmers in the country, hence this research.

The hypothesis of this study is that the RAE of unreactive Togo PR would be higher for crops with lower P demand such as legume crops than cereal crops.

The objective of the study, therefore was to assess P availability from unreactive Togo PR by legumes (cowpea, soybean, pigeon pea) and cereals (maize, millet, sorghum) in two Ghanaian soils due It is hoped that the findings of this study will help improve legume/cereal cropping systems of farmers in the region by using sparingly PR as against the more expensive WSP fertilizers and thereby halting the declining per capita food production in SSA.

2.0 MATERIALS AND METHODS

Soils and sampling

Five representative surface samples from the plough layer (0-15 cm) of each of two the soil series, Adenta and Nzema, representing the Coastal savanna and Forest zones of Ghana, were taken. The samples were air-dried, crushed and passed through a 2 mm sieve to obtain the fine earth fraction.

Adenta series

The Adenta series has been classified as Paleustalf and Hypedystric Acrisol according to USDA (1999, 2003) and ISSS-ISRIC-FAO (WRB) (1998) respectively, and it occupies the middle slope position on the landscape of the Legon hill in the Greater Accra of Ghana. It is a well-drained soil. Baah (2010) also classified it as Paleustalf and it is acidic with pH of 5.8 in the surface horizon but increases in acidity with depth. The mean annual temperature and rainfall is 27^{0}C and 800 mm respectively

Nzema series

The Nzema series (Ultisol), described as Paleustalf (USDA 1999), was sampled from the Agricultural Research Station, Kade (6043 N: 1036 W) in the Eastern Region of Ghana. It also occupies the middle slope position of the catena with mean annual rainfall ranging from 1500 to 2000mm. It is found in a semi-deciduous rainforest and it is acidic with a pH ranging from 4.9-5.2. It is a moderately-well drained soil.

Soil physical analysis

Particle size analysis

Particle size distribution was carried out by the Bouyoucos method (1962). Forty gram sample of a 2 mm sieved soil was weighed into a beaker and 100 ml of 5% calgon (sodium hexametaphosphate) solution was added. The suspension was shaken on a mechanical shaker for 2 h. The suspension was thereafter transferred into a graduated sedimentation cylinder and distilled water added to bring the level to the 1 litre mark. A plunger was used to stir the suspension vigorously by moving the plunger in and out several times and the first and second hydrometer readings were taken at 5min and 5h from the time of mixing the suspension, representing silt + clay and clay respectively. The sand fraction was obtained by decanting the suspension from the sedimentation cylinder and recording the dried weight after it had been oven-dried for two (2) days and cooled in a desiccator. Blank hydrometer readings of sodium hexametaphosphate solution at 5min and 5h were taken.

The percentages of the various soil separates were then determined as follows:

a) Silt (%) + Clay (%) = Corrected hydrometer reading at 5 min x100 / sample weight (g)
b) Clay (%) = Corrected hydrometer reading at 5 h x 100 / sample weight (g)
c) Silt (%) = a-b

d) Sand (%) = 100-a

The texture of the soil was determined using the USDA textural triangle.

Field Capacity Determination

One (1) kg of each of the soils was weighed in triplicate and was saturated with water and allowed to drain in plastic pots for two days in an open air. Sub samples were taken from the wet soil and oven-dried at a temperature of 105^0C for 24 h to constant weight and final weight recorded. The difference between the moist weight and the dry weight was taken as the mass of the water at field capacity.

$$\% \text{ Water content at field capacity} = \frac{(\text{Weight of moist soil}) - (\text{Weight of oven-dried soil}) \times 100}{(\text{Weight of oven-dried soil})}$$

Soil Chemical Analysis

Soil pH

Soil pH was determined in both distilled water and 0.01M calcium chloride using a MV 88 Pracitronic pH glass electrometer. Ten grams (10 g) of the soil sample were weighed into a 50 ml beaker and 10ml of distilled water was added. The soil-liquid suspension was then stirred several times for 30 min and allowed to stand for most of the suspended clay to settle out. Using buffer solutions of pH 4.0 and 7.0, the pH electrometer was standardized. The standardized electrode was then inserted into the supernatant of the suspension to measure the pH of the soil sample. The procedure was repeated with 20 g of soil and 40 ml of 0.01M $CaCl_2$.

Organic carbon

The wet combustion method of Walkley and Black (1934) was used to determine the organic carbon contents of the soils. Ten millimeters of 0.167M potassium dichromate ($K_2Cr_2O_7$) solution and 20 ml concentrated Sulphuric acid (H_2SO_4) were added to 0.5 g soil (which had been passed through a 0.5 mm sieve) in an Erlenmeyer flask. The flask was then swirled to ensure full contact with the soil with the solution, after which it was allowed to stand for 30 min. The unreduced $K_2Cr_2O_7$ remaining in solution after the oxidation of the oxidizable organic material in the soil sample was titrated against 0.2M ferrous ammonium sulphate solution after adding 200 ml of distilled water, 10 ml of orthophosphoric acid and 2 ml of barium diphenylamine sulphate indicator till colour changed from a brown colour to a bright green end point.

The percent organic carbon was calculated as:

$$\%C = \frac{0.3[10-(XN)] \times 1.33}{W}$$

Where: X = ml of Fe $(NH_4)_2(SO_4)_2$ required for the titration

N = normality of Fe $(NH_4)_2(SO_4)_2$

W = Weight of soil sample

Available Phosphorus determination

Available phosphorus was determined using Bray 1 method. Five grams (5 g) of soil was weighed into a centrifuge bottle and 50 ml of Bray 1 solution (0.03N NH_4F + 0.025 N HCl) was added. The suspension was shaken for about 5 min on a mechanical shaker and thereafter was made to stay overnight for the suspension to settle after which the suspension was filtered through a No. 42 Whatman filter paper into a 100 ml volumetric flask and made up to the volume. Available phosphorus in the filtrate was determined using molybdate-ascorbic acid method of Watanabe and Olsen (1965) as follows:

Five (5) ml aliquots of the filtrate from the Adenta soil and 10ml aliquots of the filtrate from Nzema soil were taken into a 50 ml volumetric flask in duplicates. The pH was adjusted using P-nitrophenol indicator and neutralized with a few drops of 4M NH_4OH until the solution turned yellow. The solutions were diluted to 40 ml with distilled water after which 8 ml of a mixture of 12 g ammonium molybdate, 0.29 g potassium antimony tartrate, 140 ml concentrated H_2SO_4 and 1.056 g of ascorbic acid (reagent B) were added. The solutions were mixed thoroughly by shaking and allowing standing for 15 min for the colour to stabilize (The colour changed to blue of different shades depending on the concentration of the P in each sample. A blank was prepared with distilled water and 8ml of reagent B. The spectrophotometer was calibrated using 25 mg L^{-1} standard P solution in the same manner as above. The intensity of the blue colour was measured using the Philips PU 8620 spectrophotometer at a wavelength of 712 nm. The P concentration was read on the spectrophotometer and calculated as follows:

$$P\ (\text{mg kg}^{-1})\ \text{soil} = \frac{(\text{Spectrophotometer reading-blank reading}) \times \text{volume of extract}}{\text{Volume of aliquot} \times \text{sample weight (g)}}$$

Total Phosphorus determination

Total P was determined by digesting 2 g of 0.5 mm sized soil with 25 ml of a mixture of concentrated HNO_3 and 60% $HCIO_4$ in the ratio 2:3.The solution was heated on a digestion rack until the solution became colourless. The digest was cooled, diluted and filtered through a Whatman filter paper No. 42 into 250ml volumetric flask. The samples were analyzed for phosphorus using Murphy and Riley method (1962). The colour intensity was read using a spectrophotometer at a wavelength of 712 nm.

P was calculated using the formula:

$$P\ (\text{mg/kg}) = \frac{(\text{Sp. Reading-Blank}) \times \text{Vol. of extract}}{\text{Vol. of aliquot} \times \text{weight of soil}}$$

$$\text{RAE}\ (\%) = \frac{\text{Tested Phosphate Rock} \times 100}{\text{Standard Fertilizer}}$$

Exchangeable bases

Ten grams of each soil sample was weighed into a 100 ml centrifuge tube and 20 ml of 1M NH_4OAc at pH 7.0 solution was added. The bottles with their contents were shaken for 1h, centrifuged at 1000 rpm for 10 min and filtered through a Whatman No. 42 filter paper. The ammonium saturated soil was washed three times with 95% ethanol by shaking for 15 min on a mechanical shaker and then centrifuged at 1000 rpm for 10 min. Calcium and magnesium in the extract were determined using Atomic Absorption Spectrometry. Potassium and sodium were determined by flame photometry.

%Ca = (AAS Reading/1000) x (100/1000) x (100/wt)

AAS= atomic absorption spectrometry, to get mg/kg multiply %Ca by 10000

%K = (ASS Reading x Extract x 100)/ wt of soil x 10^6

Exchangeable acidity ($Al^{3+,}$ H^+) and ECEC

Twenty-five mL of 1M KCl was added to 10g of soil sample in a 250mL conical flask. The content was mixed by swirling and then allowed to stand for 30min. The suspension was filtered through a Whatman No. 42 filter paper into a volumetric flask. The soil was consecutively leached with five (5) batches of 25ml 1M KCl to a total volume of about 150 ml. Four drops of phenolphthalein were added to the leachate and titrated against 0.1M NaOH to the first permanent pink endpoint. Potassium chloride extractable exchangeable acidity was calculated as:

C mol kg^{-1} KCl acidity = (ml NaOH Sample- ml NaOH blank) x M x 100 / Sample (g)

Where, M is the molarity of NaOH.

For estimation of Al^{3+} and H^+, the titre for NaOH was recorded; 10 ml of 1M NaF was added to the NaOH and titrated with 0.1M HCl until the pink colour disappeared. The solution was then allowed to stand for about 30 min and additional HCl added to a clear endpoint (Thomas, 1982). The effective cation exchange capacity (ECEC) was obtained by summation of the exchangeable bases and exchangeable acidity (Coleman et al., 1959). Percent Aluminium saturation was calculated as:

(Exchangeable Al) / ECEC * 100.

The green house set up, research design, population, sampling technique, data collection procedure and data analysis

The Greenhouse Experiment

Two soil series, Nzema and Adenta, were used for the experiment. Two hundred and sixteen plastic pots were arranged in greenhouse benches at the University of Ghana's greenhouse. Each of the pots was filled with a kilogram of soil each from one soil series (Adenta or Nzema) mixed with acid-washed sea sand. The sand was first washed continuously with tap water for 7 days, after which it was thoroughly washed again with distilled water to get rid of the sea water. The silver nitrate solution was used to check the level of saltiness in the sand intermittently. Concentrated Hydrochloric acid (HCl) solution was poured onto the sand and was made to stand for 3 days to dissolve the $CaCO_3$ concretions and other organic materials in the sand. The sand was further washed thoroughly with distilled water for four continuous/consecutive days to get rid of the HCl after which the sand was dried in the sun for 2 days. One kg of the soil and acid-washed sand were weighed in each of the 15.2-cm diameter pots.

Two P sources, Togo PR and Triple superphosphate (TSP) were applied at rates of 0mg P kg^{-1}, 50mg P kg^{-1}, 100mg P kg^{-1} soil equivalent to 0g, 0.3125g and 0.625g PR and 0g, 0.25g and 0.50g

TSP. The rates were based on the percent total P content in both sources. The total P content of the TSP is 20%, while that of Togo PR is 16% (using 1% citric acid). Six test crops were used, namely; Soybean {*Glycine max*-(TGX 1912-13F)}, Cowpea {*Vigna unguiculata* (Black eye)}, Pigeon pea {*Cajanus cajan*}, Sorghum {*Sorghum bicolor*--(Naga white)}, Millet {*Pennisetum typhoides*-(Local millet)}, and Maize {*Zea mays* L - (Obatanpa)}. The treatments were replicated three times giving a total of 216 experimental units (6 crops x 2 sources of soil x 3 levels of P x 2 sources of P x 3 replications). The soil in each pot, except those for control treatments, was transferred to a bigger pot and a weighed amount of the P fertilizer was added, thoroughly mixed with the soil and returned to their respective pots.

The pots were laid out as a randomized complete block design with the pots re-randomized within each block and then rotated weekly to minimize uneven environmental effects within the greenhouse. Each pot received five seeds of the test crop and was thinned to two plants after emergence. Distilled water was added daily to maintain the soil at 45-60% field capacity. Each pot containing a legume crop was supplied with the basal nitrogen application of 50mg N kg^{-1} equivalent to 0.1 g urea whilst each pot containing a cereal crop received the normal nitrogen recommendation of 100mg N kg^{-1} of urea. Potassium Sulphate was supplied to all pots at a rate of 150mg K kg^{-1}. This application was done 7 days after seedlings had emerged. The plants were grown for 42 days, after which the tops of the crops were harvested. The crops were cut at the soil level and immediately the fresh weight of the shoot was taken. The harvested plants were thoroughly washed with distilled water to remove any soil particle on them. The washed plants were dried on a pad or tissue paper and placed in paper bags and dried in an oven at 70^{0}C for 72 h to constant weight. Dry weights of the nodules were similarly taken. The dried plant materials were ground to pass through a 1 mm sieve after which they were stored for subsequent N, P and Ca analysis.

Digestion of plant material

One-tenth gram (0.1g) of the plant sample was weighed into a 25ml flask and 5ml of concentrated Sulphuric acid was added after which the flasks with its contents were each swirled intermittently to facilitate contact between the sample and the Sulphuric acid. The flask was allowed to stand overnight for the Sulphuric acid to dissolve the plant sample entirely. Thereafter, each solution was heated for some time after which Hydrogen Peroxide (H_2O_2) was added until the solution became clear. Distilled water was added and the solutions were allowed to stand overnight to cool and settle after which they were decanted into 100 ml flask. P in the digest was determined according to the method of Watanabe and Olsen (1965). Calcium in the extract was determined using atomic absorption spectrometry, while the total nitrogen was determined by the macro-kjedahl method (Bremner, 1965).

Statistical Analysis

Data were collected, averaged and analyzed after which ANOVA was performed on them using GenStat (9th edition) software.

3.0 RESULTS

3.1 Physico-chemical characteristics of the soils

Table 1 gives the physical and chemical characteristics of the soils used for the study. According to the soil particle size analysis, the topsoil of Nzema soil can be classified as sandy clay loam, while that of Adenta soil is clay to sandy clay. The results showed a sand content of 550g/kg in Nzema, which was higher than the 475g/kg in Adenta. The silt content was also higher in Nzema (125g/kg) than in Adenta (75g/kg) while the clay content was lower in Nzema (325g/kg) than in Adenta (450g/kg). The relative composition of Nzema and Adenta followed: Sand>Clay>Silt .The analysis also indicated that Nzema was strongly acidic with a pH of 4.4 (1:1 soil: water) while Adenta was slightly acidic (pH 6.3).

The organic carbon content of Nzema series (19.6g/kg) was higher than that of Adenta series (17.5g/kg). Total nitrogen was found to be higher in Nzema soil (2.8g/kg) than the Adenta soil (2.3g/kg). Soil extractable Bray-1 in Nzema soil (7.45mg P/kg^{-1}) was lower than the Adenta soil (16.1mg P/kg). In general, exchangeable Ca^{2+} and Mg^{2+} cations were higher in the Coastal savanna soil (Adenta) than the Nzema soil in the semi-deciduous forest zone, as shown in Table 1. The Nzema soil had higher exchangeable acidity than the Adenta soil

Table 1. Some physico-chemical properties of the topsoil (0-15cm) of the Nzema and Adenta series

Properties	Nzema series	Adenta series
Sand (gkg^{-1})	550	475
Silt (gkg$^{-1)}$	125	75
Clay (gkg^{-1})	325	450
pH (water)	4.4	6.3
pH (0.01M $CaCl_2$)	4.2	6.1
Total N (gkg^{-1})	2.8	2.3
Total C (gkg^{-1})	19.6	17.5
Organic matter (gkg^{-1})	33.7	30.1
Available P (mgkg^{-1})	7.45	16.1
Exchangeable bases (cmol (+)/kg^{-1})		
Ca^{2+}	2.85	3.21
Mg^{2+}	2.26	2.90
K^{+}	0.30	0.40
Na	0.38	0.36
Exchangeable acidity (cmol (+)/kg^{-1}		
Al^{2+}	0.40	0.30
H^{+}	1.38	0.40
ECEC	7.57	7.27
(%) Al saturation	5.28	4.12

3.2 Effect of TSP and TPR on the dry matter yield of tested crops on both soils

Figures 1 and 2 show the dry matter yields (DMY) of maize, millet and sorghum obtained under the different P treatments on the Nzema and Adenta soils, respectively. The growth of the plants in both the Nzema and Adenta soils varied with the species, soil type, the P source and P rates. All the cereal crops showed significant improvement in DM yield with the two rates of TSP application irrespective of the soil type. However, there was no significant difference (p>0.05) in dry matter yield between the 50mg and 100mg P/pot rates of TSP. In contrast, the response of the cereal crops to TPR at both 50mg and 100mg P/pot was generally very poor and not significant in the two soils (Figs 1 and 2). Among the three crops, response of millet to TPR was low in both Nzema and Adenta soils.

With the TSP application, sorghum in Nzema soil gave the highest dry matter yield (13.62g/pot) followed by maize (10.94g/pot). The trend was sorghum>maize>millet (Fig. 1 and 2). In Adenta series sorghum again produced the highest dry matter yield of 10.06g/pot whilst millet yielded the lowest dry matter (0.52g/pot) in the same soil. The performance trend was thus sorghum>maize>millet, which was similar to that of Nzema soils. Without P fertilizers, average dry matter yield in the Nzema soil, was low, about 1.12g per pot.

Figure 2 shows that the DMY of the crops from the control treatments were slightly better in Adenta soil with higher P than in Nzema soil. The results (Figs. 3 and 4) show that the legume crops responded markedly to the addition of the water soluble phosphorus fertilizer. However, the dry matter yields of the crops were significantly different (p<0.05) under TSP application rates in all the soils, with cowpea giving the highest dry matter yield response to TSP in both the Adenta and the Nzema soils (Figs 3 and 4).

The dry matter yields of soybean and pigeon pea also appeared to respond to TPR application at the two rates even though the responses were not significant. There were no significant differences (p>0.05) in dry matter yield between the control and the 50mg P/pot rates of TPR application for soybean and pigeon pea in Nzema soil, however, the application of 100mg P/pot produced significant increases the DMY of the crops in both soils. In general, the DMY of the cereal crop species obtained with TSP application followed the trend: Sorghum>maize>millet while the legume crops also followed a trend, cowpea>soybean>pigeon pea. Fairly, a similar trend was obtained with the application of TPR.

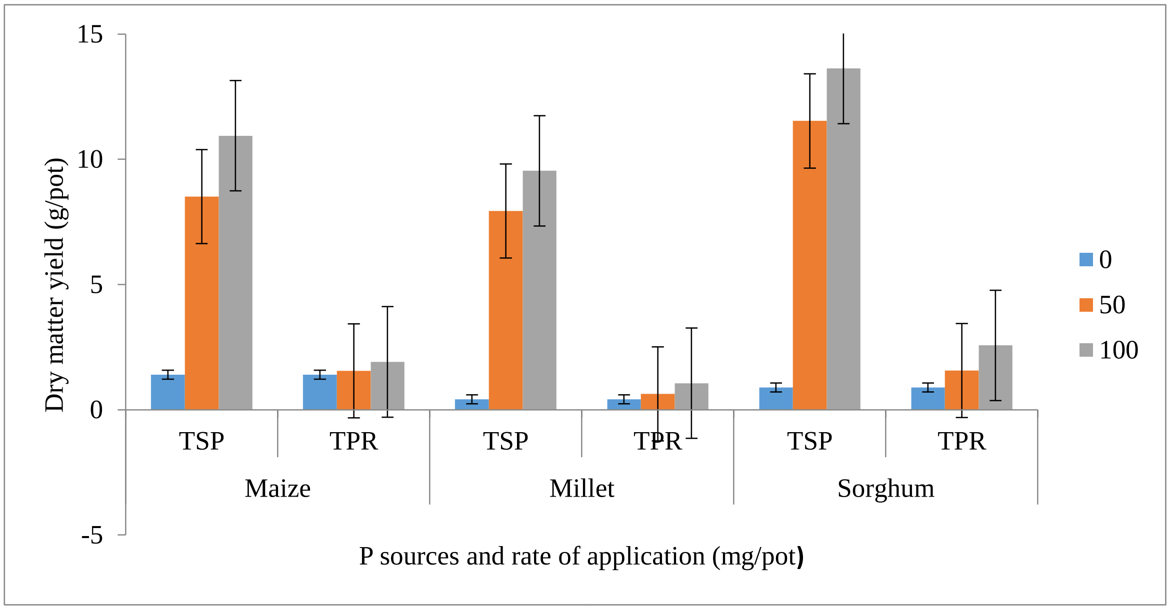

Fig. 1 Effect of TSP and TPR application rates on dry matter yield of maize, millet and sorghum on the Nzema soil

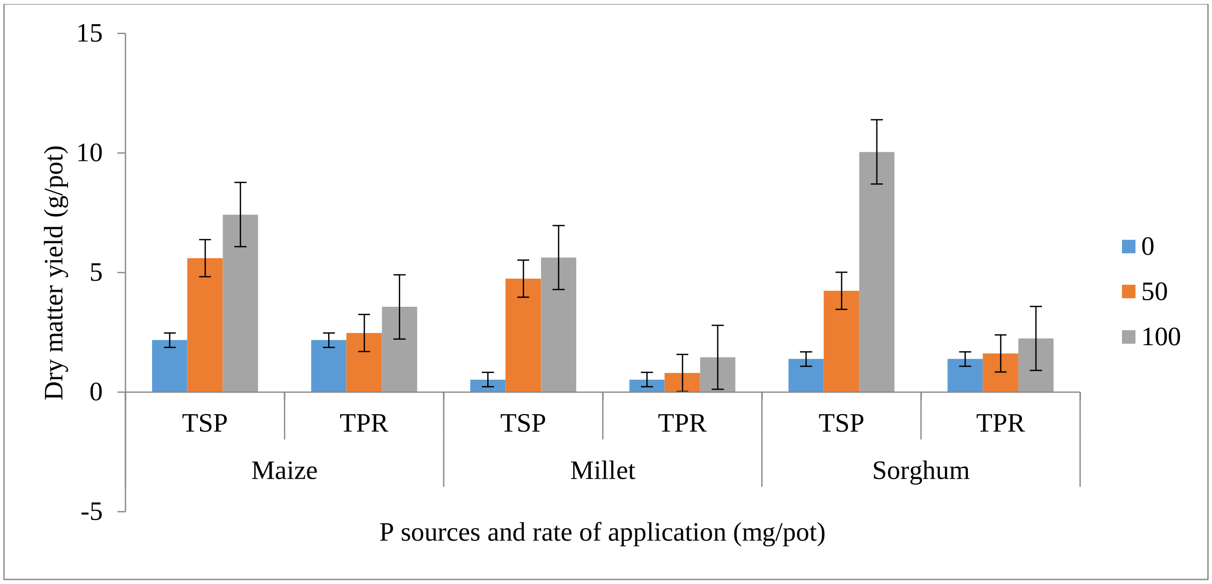

Fig. 2 Effect of TSP and TPR application rates on dry matter yield of maize, millet and sorghum on the Adenta soil

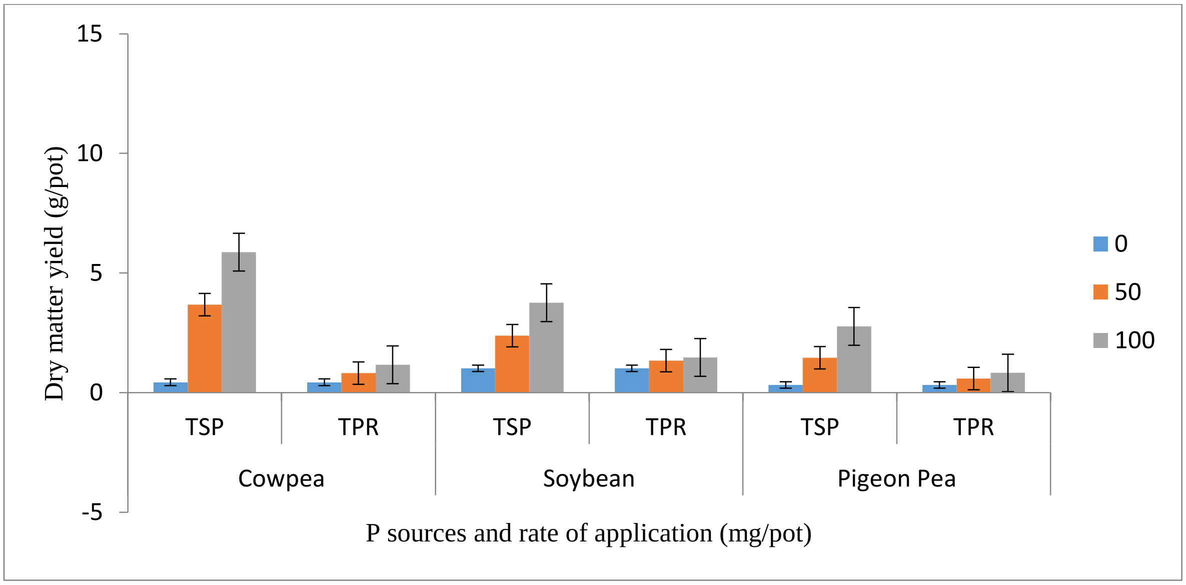

Fig. 3 Effect of TSP and TPR application rates on dry matter yield of cowpea, soybean and pigeon pea on the Nzema soil

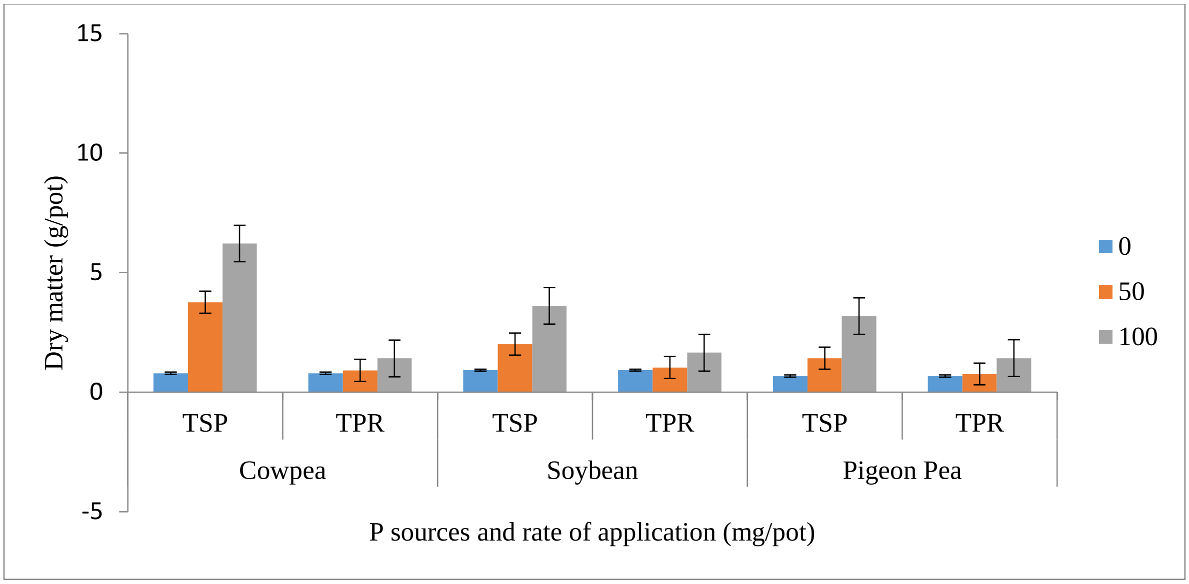

Fig. 4 Effect of TSP and TPR application rates on dry matter yield of cowpea, soybean and pigeon pea on the Adenta soil

3.3 Effect of TSP and TPR application on P uptake by the six crops

The effects of TSP and TPR application on P uptake by the six test crops are given in Figs. 5 and 6. Generally, there were significant differences ($p<0.05$) in P uptake by all the three cereal crops in both soils under TSP application. Among the cereals, total P uptake by sorghum was the highest, followed by millet and maize in that sequence in the Nzema soil. In Adenta soil the total P uptake was again highest with sorghum, but this time followed by maize before millet. Phosphorus uptake by the cereals from the TSP was 25% higher in the Nzema soil than the Adenta soil. Increasing the P rates to 100mg P/pot increased further the P uptake by all the cereals. The P uptake at 50mg P/pot was significantly lower ($p<0.05$) and higher at the 100mg P/pot rate.

As shown in Figs. 5 and 6 the P uptake by cereal plants did not increase significantly with the application of TPR except for maize in the Adenta soil. Phosphorus uptake by the crops at 50 mg P/pot was fairly similar to that of their control counterparts in both soils. The data further showed that although not significant in almost all cereals there was the tendency for the P uptake by the crops to increase with an increase in the quantity of TPR applied. In general, the quantity of P taken up by all the cereal crops in TPR treatments was far lower to that for TSP.

Figs. 7 and 8 present the effect of TSP and TPR application on P uptake by the legume crops. The results showed that P uptake by the crops from TSP increased significantly with the application 50 mg P/pot ($p<0.05$), being in all cases, in both soils. Except for P uptake by soybean in Nzema, there were significant differences ($p<0.05$) in P uptake between the 50mg P/pot and 100mg P/pot rates. The data (Figs. 7 and 8) show that among the legume crops, uptake of P from the water-soluble P fertilizer by cowpea was significantly higher than either soybean or pigeon pea, in both soils. The P uptake from the TPR by the legume crops was very low and far less than from TSP. The leguminous crops took very little P from TPR at 50mg P/pot, but the uptake was slightly enhanced with the application of 100mg P/pot in all the soils. The cereals in most cases took up more P from the TSP, especially, in the Nzema soil than the legumes.

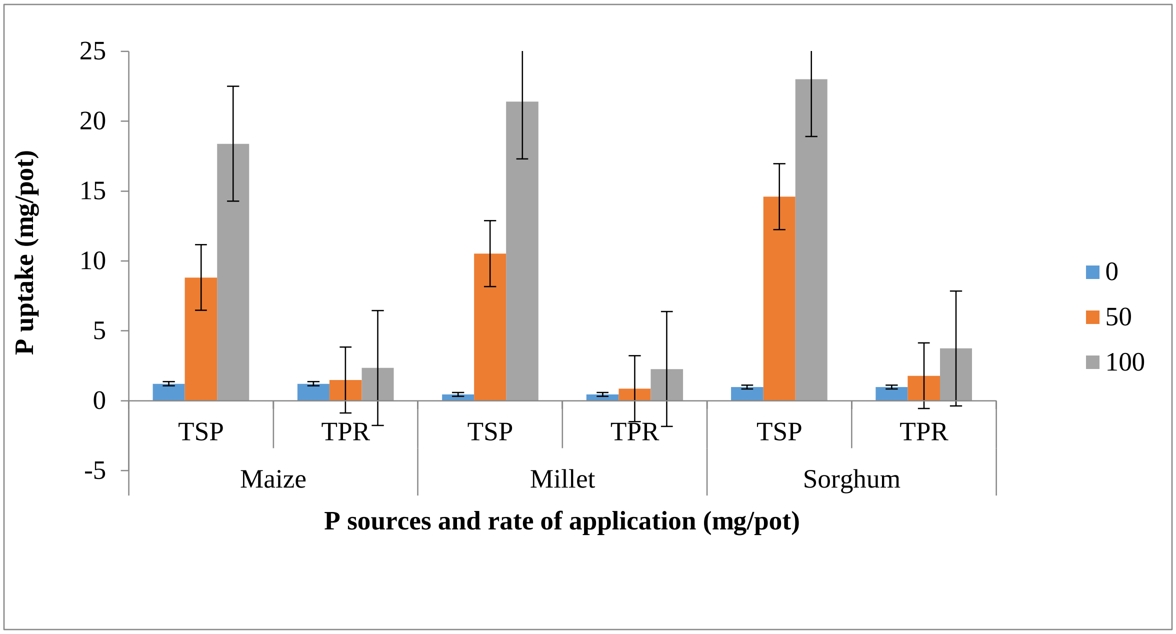

Fig. 5 Effect of TSP and TPR application on P uptake by maize, millet and sorghum in the Nzema soil

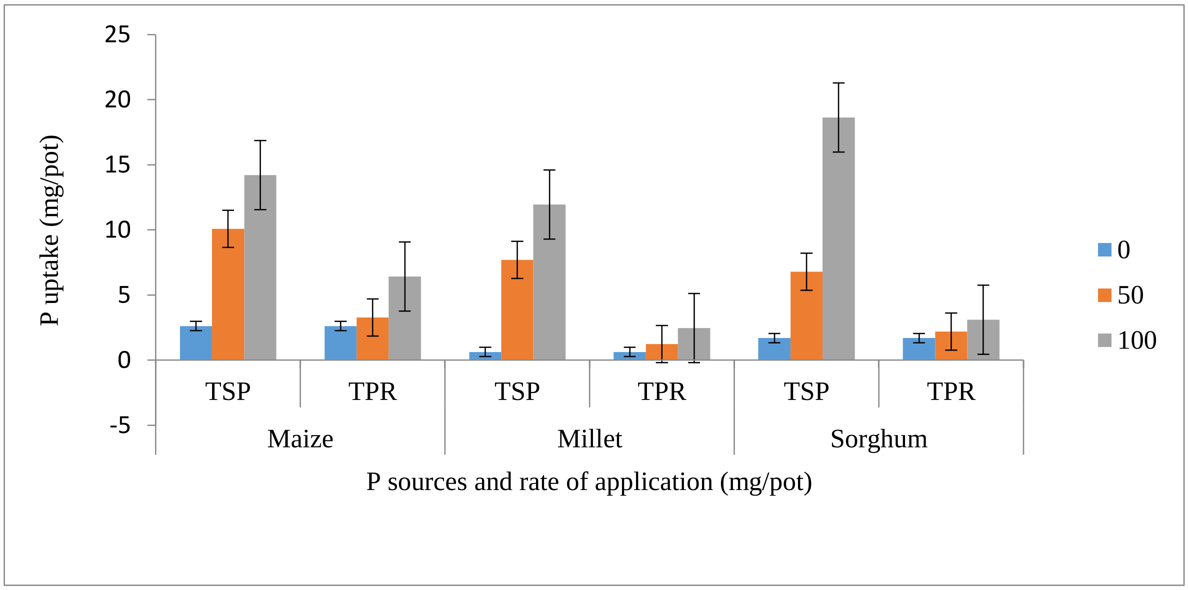

Fig. 6 Effect of TSP and TPR application on P uptake by maize, millet and sorghum in the Adenta soil

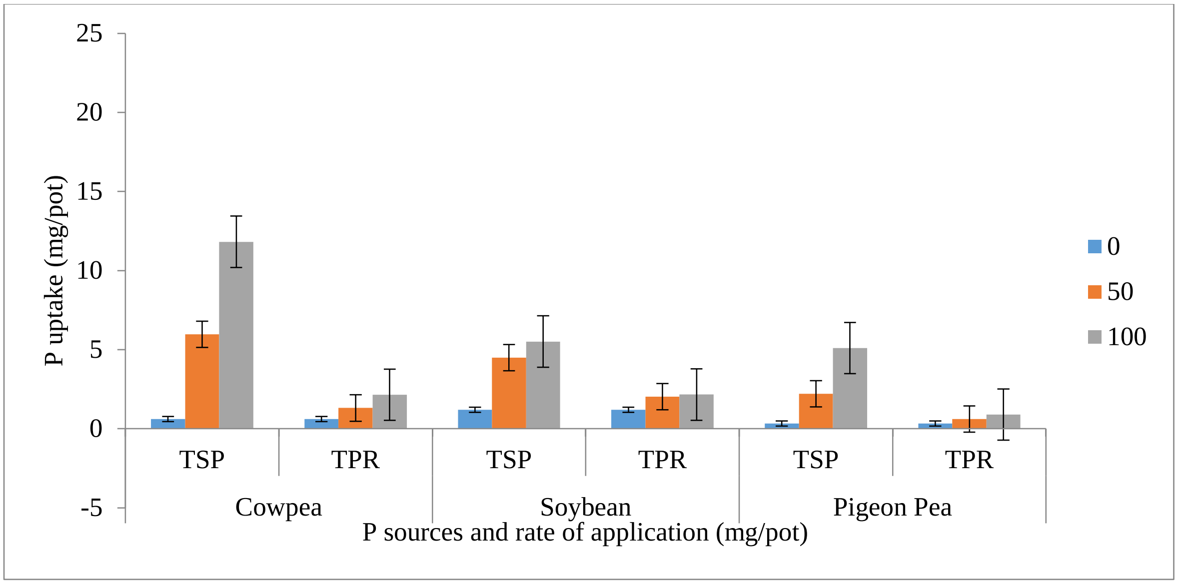

Fig. 7 Effect of TSP and TPR application on P uptake by cowpea, soybean and pigeon pea in the Nzema soil

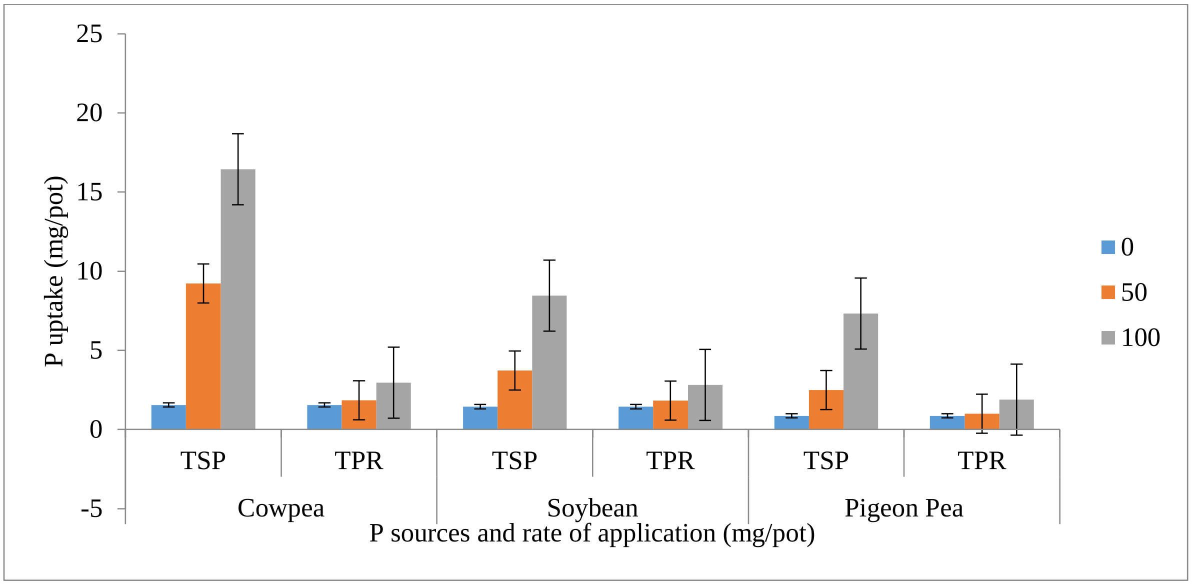

Fig. 8 Effect of TSP and TPR application on P uptake by cowpea, soybean and pigeon pea in the Adenta soil

3.4 Relative Agronomic Efficiency (RAE) of dry matter yield (DMY) of Togo Phosphate Rock on six crops grown in two soils

The relative agronomic efficiency (RAE) of Togo PR relative to the TSP at the two P rates is presented in Table 2. Among the cereals, the RAE of maize on the Adenta series was the highest (26.3%) at TPR_{100} whilst RAE of maize on the Nzema series was the lowest percent. Millet gave the second highest RAE (18.2%) after maize and this occurred in the Adenta soil. Generally, the RAEs of maize and millet were higher in Adenta series than in Nzema series except sorghum, which had RAE higher in Nzema soil than Adenta soil (Table 2). The trend of performance of cereals in terms of their RAE of the dry matter yield followed the trend: sorghum>millet>maize in Nzema soil and maize>millet>sorghum in Adenta (Table 2). The results further showed that increasing the rates of the TPR improved the RAEs of all the crops irrespective of the soil.

Among the legumes, pigeon pea gave the highest RAE of the dry matter yield (29.9%) followed by soybean (27.1%) in the Adenta soil (Table 2). A similar pattern was observed on Nzema soil. The lowest RAE of the dry matter yield was recorded by cowpea on both Nzema and Adenta soil. The RAE was increased with an increase in rate of Phosphorus. This trend was consistent among all the six crops and in the two soils.

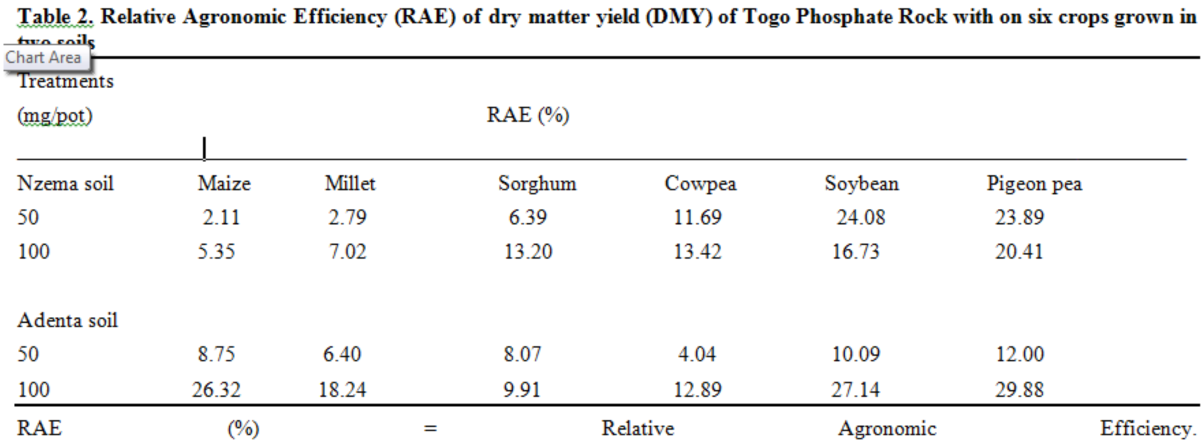

Table 2. Relative Agronomic Efficiency (RAE) of dry matter yield (DMY) of Togo Phosphate Rock with on six crops grown in two soils

Treatments (mg/pot)	RAE (%)					
Nzema soil	Maize	Millet	Sorghum	Cowpea	Soybean	Pigeon pea
50	2.11	2.79	6.39	11.69	24.08	23.89
100	5.35	7.02	13.20	13.42	16.73	20.41
Adenta soil						
50	8.75	6.40	8.07	4.04	10.09	12.00
100	26.32	18.24	9.91	12.89	27.14	29.88

RAE (%) = Relative Agronomic Efficiency.

Discussion

Physicochemical properties of Nzema and Adenta soil

The Nzema series used in the study was more acidic than Adenta and the low pH of the Nzema soil may be attributed to the nature of the parent materials and partly to the intense leaching of bases caused by the high precipitation in the semi-deciduous zones. The high exchangeable acidity of the Nzema soil conforms to its low pH and moderate Al saturation. The low pH and moderate Al saturation of the Nzema soil may imply that there is a need for P application in order to improve crop growth on the soil because fairly high exchangeable H^+ and Al cations in soil do significantly affect plant growth (Buol *et al.*, 1973). The relatively higher organic carbon content of the Nzema soil was consistent with the observation that surface soils from the uncultivated forest soils have higher organic carbon content than those from the coastal savanna soil (Jones & Wild, 1957). The available P in the Adenta soil was found to be within the critical range suggested by Sahrawat *et al* (1997) while that of the Nzema soil was below the critical range.

Effect of TSP and TPR on the growth of plant (dry matter yield)

Differences in the dry matter yield of the crops from both soils treated with the different P sources were primarily due to the differences in the water-soluble P contents of the fertilizers used and other factors such as pH, crop species and available P. Characterization of the fertilizers indicated that triple superphosphate had the highest soluble P (with water solubility of 98%) while Togo Phosphate Rock was almost insoluble in water; hence TSP application gave the higher dry matter yield in both soils whilst lower dry matter yield was realized with TPR application. These differences reflected in early plant development, promoting higher root formation, cell enlargement and subsequently higher dry matter by TSP (Khasawneh & Doll, 1978; Paul, 1988).

Without P addition, the dry matter yields of the crops were very low, indicating the very low available P in the soils. Dry matter yield was higher in the Nzema soil than the Adenta soil under TSP application rates. The higher dry matter yields of the cereals obtained from the Nzema soil with the TSP could be attributed to the high level of organic matter and total nitrogen in the Nzema soil coupled with the supply of soluble P which was deficient.

It has also been suggested that at higher levels of P application, as the solution P increases above the threshold concentration for net P uptake by plants, crop yield rises steeply (Rajan, 1973; Fox *et al.*, 1986) and this increment of P content coupled with high organic matter and total nitrogen content might have ensured higher dry matter yield obtained in this study. The organic ions in the organic matter and humus can also reduce P sorption capacity of soils by blocking P sorption sites and by forming complexes with iron and aluminum hydrous oxides, leading to increased P concentration in solution (Manickam, 1993) resulting in higher dry matter being realized. The maximum yield obtained by the different P sources at the same level of application was in order TSP>TPR implying that maximum dry matter yield was a function of solubility (Butegwa *et al*, 1996).

Generally, P uptake from TPR at the two rates is expected to have been high in the Nzema soil because of low solution concentration of Ca, low P fertility levels and high organic matter content, but the situation turned out to be the opposite for all the cereals except sorghum at TPR_{100}. These opposite effects realized for maize and millet in the Nzema soil is similar to the findings of Wild (1995), Owusu-Bennoah (1997) and Dakora *et al* (2002) who showed that dry matter yield of crops was low despite P application in acid soils. The behaviour of the cereals on the two soils is supported by a similar observation by Frederick *et al.* (1992) and Lompo *et al.*, (1994). The significant performance of maize and millet on the Adenta soil may be due to the high level of available P which promoted the early development of root and better growth of the crop and subsequently higher P uptake.

The results from the study showed a positive relationship between shoot dry matter yields, P uptake and P application. Legumes compared to the control produced significantly higher dry matter yield on both soils, with both TSP and TPR application. The positive effect on the legumes with respect to dry matter yield from TPR treatments could be due to the augmentation ability of P absorbed from sparingly soluble soil with fertilizer P, which eventually led to increase in the shoot dry matter yield (Horst *et al*. 2001; Krasilnikoff *et al*, 2003; Nuruzzaman *et al*, 2005; Bekele *et al.*, 1983; Haynes, 1983, 1992).

The improvement in the dry matter yield of pigeon pea and cowpea on Adenta soil and soybean on the Nzema soil at TPR_{50} and TPR_{100} shows the importance of Phosphorus application to dry matter yield of legumes. Significant difference that was shown by cowpea on Nzema soil could be attributed to the ability of the crop to desorp P from sparingly available P sources through exudation of high amounts of organic acid anions, mainly citrate (Gerke *et al*, 1992). The dry matter yield of TPR was very far inferior to that of TSP because of the low solubility of the TPR.

Effect of TSP and TPR application rates on P uptake by the six crops

Phosphorus uptake by maize and millet from TPR on the Nzema soil was lower than for sorghum. This is in agreement with the assertion that although PR dissolution may be increased by a high P sorption capacity of the soil, PR effectiveness is lower in such soils (Mokwunye and Hammond, 1992). Hammond *et al.* (1986) ascribed this poor performance of PRs in soils with high P sorption capacity to poor root development during the early stages of crop growth due to P deficiency. The improvement in performance of maize and sorghum with TPR rates in the Adenta soil may, probably, be due to their root morphology, specifically, their root density.

According to Chien *et al* (1990), plants with higher root densities in the surface layers of the soil are better able to acquire dissolved P from PR because of the greater volume of soil the root system can explore. The significant performance of maize with TPR in the Adenta soil, which turned out to be the highest P uptake by the cereals may be attributed to its high root densities as well as its ability to excrete of organic acids (Nene and Shiela, 1990; Okalebo *et al*., 2002; Campaore et al., 2011).

Control treatments in the Adenta soil performed better in its P uptake than their counterparts in the Nzema soil. It may be due to the higher level of available P in the original Adenta soil which may have enhanced early development of the roots of the crops examined. This effect resulted in higher shoot dry matter yield in the Adenta soil and it confirm the important role P availability plays in terms of P uptake and dry matter yield of crops (Marschner, 1993).

Togo Phosphate Rock application to legumes resulted in higher P uptake in the Nzema soil than the Adenta soil. It has been suggested that some legume genotypes, especially cowpea, have the capacity to acidify the rhizosphere. The acidification of the rhizosphere due to concomitant release of protons for maintaining the charge balance would contribute particularly to the solubilization of the PR applied as P fertilizer (Gerke *et al*. 2000; Kania *et al* 2003; Neumann and Romheld 1999; Bekele *et al*., 1983; Hinsinger and Gilkes, 1997).

In a study to investigate phosphorus benefits from grain-legume crops to subsequent maize grown on acid soils of southern Cameroon it was observed that enhanced exudation of organic acid anions and root surface phosphatase activity served as important plant traits for genotypic P acquisition efficiency (Jemo *et al*. 2006; Hoffland, 1992). It has been suggested that in this way, legumes revalue the PR into a more available P source.

Relative Agronomic Efficiency (RAE) of Togo Phosphate Rock relative to TSP

The high RAEs with TPR in dry matter yield and total P of cowpea, soybean and pigeon pea relative to TSP on the Nzema soil was as a result of the fact that crops with lower P demands, such as legume crops, tended to have higher RAE than cereals. The data is supported by Khasawneh and Sample (1979) who suggested that the concentration of soil solution P required by cowpea for maximum growth potential may be only two-thirds the concentration required by maize. According to Chien *et al* (1995), the RAE of PR would be higher for crops with lower P demands, such as legume crops than for cereal crops, such as maize, supporting the data for this study. Different research results (Bationo *et al*, 1986) have shown that leguminous crops are more efficient in using PR than cereals. The low level of P, Ca and pH serve as precursors for P dissolution, thus Nzema soil, having these features, was able to dissolve more P from TPR.

The high legumes RAE of TPR relative to TSP could also be explained by the fact that they have the capacity to acidify the rhizosphere. The acidification of the rhizosphere due to concomitant release of protons for maintaining the charge balance would contribute particularly to the solubilization of unreactive PR applied as P fertilizer (Gerke *et al*. 2000; Kania *et al* 2003; Neumann and Romheld 1999; Bekele *et al*., 1983; Hinsinger and Gilkes, 1997). The above explanation could further be used to account for TPR dissolution in the Coastal savanna soil (Adenta soil) with a pH of 6.3 contrary to the view that the dissolution of PR diminishes with increasing pH up to 5.5 but declines more rapidly above this pH level (Bolan and Hedley, 1990).

The study also showed that maize and millet did better in the Adenta soil in terms of RAE with TPR in their dry matter yield, and P uptake with increased P rate. This is in agreement with the work of Khasawneh and Sample (1979) that cereals require and take up more P where available. The available P in the Adenta soil might have been taken by these crops to increase the effectiveness of PR utilization. The high RAE with TPR in sorghum dry matter yield in Nzema soil might be due to the root density of the crops and also the inherent capacity of the soil to make P available due to its low pH level. The agricultural effectiveness of TPR for all the crops proved the low reactivity of the material and its subsequent low performance compared with the water-soluble P (Bationo *et al*,. 1986; Bationo and Mokwunye, 1991; Bationo and Kumar, 1999).

The low reactivity of the Togo PR may be attributed to the high molar ratio PO_4^-/CO_3 of the material (Roy and McCallan, 1986). According to Gachon (1977) and Mokwunye (1994) a molar mass of PO_4/CO_3 less than 5 is an indicator of phosphorus solubilization of PR. The increased RAE of Togo PR with increased P rate may seem to suggest that there was enough solubilized P available for the crops. Similar results have been reported by Bonzi *et al*, (2011).

4.0 CONCLUSIONS AND RECOMMENATIONS

Conclusion

Conclusively, increasing the rate of TPR to 100mg P/pot resulted in an increase in dry matter yield and P uptake in both soils, but was inferior to 100mg P/pot TSP application. It is therefore imperative to make sure that the rate of application of TPR should always be high if farmers wants the best from their lot. Again it is seen that the agricultural effectiveness of TPR for all the crops proved the low reactivity of the material and its subsequent low performance compared with the water-soluble P. The results from these studies show that unreactive Togo PR cannot be used as a substitute for TSP in cereal/legume cropping systems. The low reactivity and the high molar mass of PO_4^{3-}/CO_3^{2-} make it unsuitable for direct application.

Recommendations

Future work should increase the TPR rates and conduct over a long period. Follow up work can also be done to determine the level of other inexpensive rock phosphate sources such as Gafsa PR and Tilemsi PR required for optimal growth. In a further step, research should be targeted at screening for high potential N-fixing legumes and cereals with ability to excrete organic acids for their ability to mobilize P from the various PR deposits in West Africa. In this pot experiment the small volume of 1 kg soil per pot used might be a limiting factor, because the soil was rapidly explored by plant roots before they achieved their maximum development. Therefore it will useful to repeat this kind of experiment with 5 kg soil per pot that might favour a better growth of plants. More research work is needed to evaluate the agronomic effectiveness of Togo PR, especially under field trials for long term effects.

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