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Improving grain legume yields using local Evate rock phosphate in Gùrué District, Mozambique

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Acid, infertile reddish-brown soils characterize large amounts of central Mozambique. Few of these soils are in food production representing a missed opportunity for agricultural productivity and a missed alternative to improve the food security of the country. Low levels of soil nutrients such as calcium, phosphorus, and potassium limit crop growth. Local agricultural amendments for acid, infertile soils such as limestone and rock phosphate exist but are unexploited. An experiment was conducted to assess the feasibility of using local Evate rock phosphate (40.7% total P_2O_5) as a corrective to supply phosphorus. The rock phosphate was applied at rates of 20, 40, 80 and 160 kg total P ha^{-1}. Comparison triple super phosphate was also added at four P levels (0, 10, 20 and 40 kg P ha^{-1}). A long growth cycle crop of pigeon pea (*Cajanus cajan* L., Mill sp. variety "ICAEP00020") with a growth cycle of 190 days was used to assess effectiveness of the local rock phosphate. A pigeon pea grain yield of 1000 kg grain ha^{-1} was possible with an application of 80 kg ha^{-1} of total P added as Evate rock phosphate. By comparison 20 kg P ha^{-1} as TSP was needed to reach a maximum yield of pigeon pea grain. This ratio suggests that Evate rock phosphate was 25% as effective as TSP on a total P basis. This research suggests that the Evate rock phosphate can be an effective amendment that can enable or enhance food grain production on the acid, infertile upland soils of Central Mozambique. Whether for direct application for acid-tolerant crops or acid soils or processed into soluble fertilizer phosphate, the existence of such a valuable resource provides a great opportunity for improved local food crop production.

Key words: Rock phosphate, pigeon pea, acid soils, food grains, food security.

INTRODUCTION

In Sub-Saharan Africa (SSA), phosphorus has long been identified as the major limiting nutrient in the vast majority of soils (Bationo et al., 1997). Such soils constitute up to 55% of the agricultural land in SSA (Bationo et al., 1986). SSA contains numerous rock phosphate deposits, and some are sufficiently reactive for direct application

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(Buresh et al., 1997) and some are not. Direct application of indigenous rock phosphates has been viewed as an attractive option for building soil phosphorus (P) fertility because it potentially involves lower production costs and capital investments than the production of water-soluble P fertilizers from indigenous rock phosphate sources (Hammond et al., 1986; Rajan et al., 1996).

Food security has been the focus of recent agricultural projects including the Legume Innovation Laboratory, which is conducting farmer decision-making research regarding grain legume crops. A consistent limitation to food security has been the extremely low fertility and acidity of the highly weathered soils of the country (Maria and Yost, 2006). Recent studies indicate that such conditions are wide-spread in the central, potentially highly productive region of Mozambique. Soil management of nutrient poor acid soils has been highly successful in regions with acid soils (Fageria et al., 2013) and multiple management alternatives are possible.

In Mozambique, fertilizers such as superphosphates are exceedingly expensive, of low quality, and seldom available in local markets. Recent research has explored the possible use of indigenous agro-minerals such as rock phosphates, as substitutes for expensive, imported fertilizers. According to Zavale et al. (2005), Mozambique can increase the production of all of crops by using its enormous potential of natural resources, improving agricultural infrastructure, and increasing household adoption of improved crop varieties and other new agricultural technologies.

Local food grain - pigeon pea

One of the crops of growing popularity among farmers in the acid soil region of Mozambique is pigeon pea (*Cajanus cajan*, L., Millsp.) (ICRISAT, Malawi). The crop is moderately tolerant of the acid soil conditions characteristics of the region and also is well-known for drought resistance due to deep rooting. This crop is tolerant of the acid soil conditions that are favorable for the reaction and dissolution of rock phosphates and it has a long duration growth cycle also favorable for the slowly dissolving rock phosphate. The locally preferred cultivars of pigeonpea, for example, range in maturity from 170 to 190 days (O. Madzonga, ICRISAT/Malawi, personal communication, 2016; C. Malita (IIAM/Nampula), personal communication, 2016). Tolerance to soil acidity by pigeonpea is not well characterized, but several researchers have documented that the plant roots exude organic acids that dissolve and solubilize otherwise insoluble phosphates (Otani et al., 1996). These researchers report that pigeon pea exudes some 10-fold more malonic acid than do groundnut, cowpea or rice. Adugyamfi et al. (1990) report that pigeon pea tolerates low P conditions better than soybean. For these reasons, *C. cajan* may become a useful rotation crop in food production systems in this zone of Mozambique.

Local deposits of rock phosphate

Manhiça (1991) characterized Mozambican phosphate deposits as primarily deposits of apatite of two types: (1) Monte Muande-Monte Fema near Tete Province, and (2) The Evate deposits in Nampula Province. The first was original crystalline limestones of Pre-Cambrian replaced and metasomatized together with injection of apatite-carbonate, apatite-magnetite, and apatite-silicate. The second was carbonatites with low contents of apatite dispersed or in hydrothermal veins. The Evate deposit was discovered by the geophysical investigations for graphite by a Russian team in 1983. The Evate deposit was initially quantified at 155,413,000 tons of apatite ore with an average content of 9.32% P_2O_5. The analytical methodology used by the Russian Team was unknown, however. In preparation for this research a sample of the Evate rock phosphate was submitted to the International Fertilizer Development Center (IFDC) Laboratory in Alabama, USA, and the results are given in Table 1.

Yager (2014) reported that the corporation Vale S. A. of Brazil was engaged in a prefeasibility study on a new phosphate mine at the Evate deposit. Depending on the results of the study, predictions were that the mine could produce 2 million metric tons year^{-1} of Evate phosphate rock.

The objective of our study was to assess the potential of using Evate rock phosphate of Mozambique to supply P for food grain legumes in the acid, infertile soils of Central Mozambique. Specifically, the study is aimed at determining the amount of locally available Evate rock phosphate in comparison with the imported, expensive triple super phosphate needed to achieve maximum yield and biomass of pigeon pea in a reddish-brown soil of the summit topographic position in Mepuagiua community of Gùrué District, Zambézia Province, Mozambique.

MATERIALS AND METHODS

Study area

Mozambique researchers have been using FAO, USDA Soil Taxonomy and others to classify and attribute names to soils that they worked on. In this study, the soils of the study area are named by its color due to lack of sufficient soil data for an accurate soil classification.

The experiment was conducted in Mepuagiua community, Gùrué district of Mozambique. Gùrué district is about 5,606 km² with a population of nearly 303,000. Gùrué district is located at an elevation of 734 m and -15°27'48.8 (south latitude), 36°58'54.0 (east longitude). The district has wet/dry climate. Summer daily maxima temperatures range from 30 to 34°C. Winters have temperatures in the range of 17 and 20°C. Typical of tropical climates, winter is usually referred to as the dry season, while summer is called the rainy season. Average annual rainfall is 1900 mm. The climate in Gùrué has much more rainfall than the rest of

Table 1. Analytical results of Evate rock phosphate sample (International Fertilizer Development Center, Muscle Shoals, Alabama. Analyzed November 9, 2015).

Chemical	Results	Analyst	Method
Total P_2O_5 (%)	40.7	CSG	HNO_3/$HClO_4$- Molybdovanadate color method - visible spec
Citric Acid Sol. P_2O_5 (%)	3.75	CSG	SSSAP 1957 21 :183-188
Formic acid Sol. P_2O_5 (%)	2.12	CSG	ZPDB 1953 62:262-264
NAC Sol. P_2O_5 (% 1st ext.)	1.46	CSG	AOAC - Molybdovanadate color method - visible spec
NAC Sol. P_2O_5 (% 2nd ext.)	0.95	CSG	AOAC - Molybdovanadate color method - visible spec
Cd (ppm)	0.52	CSG	AFPC- HNO_3/HCL- ICP
Co (ppm)	7	CSG	AFPC- HNO_3/HCL- ICP
Cr (ppm)	9.8	CSG	AFPC- HNO_3/HCL- ICP
Cu (ppm)	14	CSG	AFPC- HNO_3/HCL- ICP
Mn (%)	0.1	CSG	AFPC- HNO_3/HCL- ICP
Mo (ppm)	2.2	CSG	AFPC- HNO_3/HCL- ICP
Ni (ppm)	4.7	CSG	AFPC- HNO_3/HCL- ICP
Pb (ppm)	14	CSG	AFPC- HNO_3/HCL- ICP
Zn (ppm)	22	CSG	AFPC- HNO_3/HCL- ICP

Table 2. Local soil names, topographic location and farmer reported suitable crops along a soil catena at Mepuagiua.

Soil types	Characteristics	Catena location	Predominant crops
Ehava	Sandy reddish- brownish	High elevation, back slope	Cassava, pineapple, sorghum and fava beans
Epupu	Blackish soil, less moist, less clay content	High elevation	Maize, common bean, pigeonpea and butter beans
Ekotchokwa	Reddish soil	High elevation	Cassava, sorghum, pineapple and fava bean
N'tchokwa	Blackish, high moist, high level of clay particles	Low elevation (river streams)	Rice, beans, maize and sugar cane

Table 3. Selected chemical and physical properties of soil of Mepuagiua community, Gùrué district, Mozambique.

Depth	pH	Soil C	Ca^{2+}	Mg^{2+}	K^+	Sand	Silt	Clay	ECEC	ECEC/clay
Cm		g kg^{-1}	cmol$_c$ kg^{-1}			%			cmol$_c$ kg^{-1}	cmol$_c$ kg^{-1} $\%^{-1}$
0-15	4.9-6.5	10.0-37.0	1.8-17.6	0.85-2.6	0.09-0.62	33-63	7.3-30.5	23.4-45.4	3.44-8.57	7.58-35.5
15-30	5.3-6.3	7.5-33.7	3.1-10.3	1.1-2.0	0.11-0.50	37-61	5.3-24.5	34.4-45.4	5.04-12.9	10.1-50.8

Soil pH was obtained from a 1:1 soil: water ratio, Cations Ca, Mg, were measured in a neutral salt extraction (1 *M* KCl). Potassium was measured in a sodium bicarbonate extractant used for phosphorus. Effective CEC was obtained by summing the cations plus the KCl-extractable acidity.

the province due to the orographic effect of the mountains that surround the town. The average maximum temperature is 24 to 25°C and average rainfall per day is 57 to 165 mm (https://www.worldweatheronline.com/gurue-weather-averages/zambezia/mz.aspx).

Soils

Soils of the summit topographic position "Ekotchokwa" (Table 2) with the minimum values of soil properties (Table 3) were selected for the study. These soils are, according to local farmer knowledge, not capable of producing the important local food crops, including common bean (*Phaseolus vulgaris* L.).

Soils from six sites in the Mepuagiua community were analyzed and selected chemical and physical properties are summarized in Table 3. The reddish-brown soils are located in the summit topographic position and are characterized by the minimum values in all soil properties (Table 3) and low pH, low soil Ca and Mg that suggest a highly weathered soil. The low levels of cations, especially the low Ca^{2+} and Mg^{2+} and low effective cation exchange capacity (ECEC), confirms the low activity of the clays and the status as being highly weathered and indicating a very low capacity of the soils to retain nutrient cations, a condition typical of highly weathered soils of the tropics. There is a wide range in soil C contents, but generally it is very low as well such that soil C may not

Table 4. Selected soil chemical properties of experimental plots, Mepuagiua community, Gùrué district, Mozambique. Depth 0-15 cm.

Parameter	pH	Bicarbonate P	Ca^{2+}	Mg^{2+}	K^{+}	KCl-extractable acidity (largely Al^{3+}
		mg kg^{-1}	cmol$_c$ kg^{-1}			
Median	5.03	15	0.62	0.53	0.40	0.40
Range	4.56 - 5.66	10 - 47	0.35 - 1.93	0.27 - 1.5	0.04 - 0.85	0.04 - 0.85

be contributing to soil nutrient content nor retention capacity. The variation in soil texture observed in field is reflected in the range of both soil sand and clay contents.

Soils from the experimental site (Table 4) represent the acid, more highly weathered range of soils reported in Table 3.

Rock phosphate analysis

Table 1 provides the analytical results of the Evate rock phosphate according to reference methodology of the International Fertilizer Development Center, a worldwide authority and reference on rock phosphate deposits and characteristics.

On-farm experiment

An on-farm rotation experiment was established to compare the availability of P supplied by Evate rock phosphate with that of the expensive, imported triple super phosphate (TSP). The experiment was a randomized complete block design with 3 replicates and 8 treatments per replication. An experimental plot consisted of 6 rows; 6 m long and 3 m wide. Furrows were opened for each line of 6 m long per plot using a hoe. Seeds were planted 0.5 m between each row and 0.4 m within the row. Seeds were placed on the left side of the furrow and fertilizer on the right side and then covered with soil. The Evate rock phosphate was applied at 20, 40, 80 and 160 kg total P ha^{-1} and the TSP was applied at 10, 20 and 40 kg total P ha^{-1}. Twenty kilogram of N was applied per hectare as urea and 40 kg of K_2O ha^{-1} was applied as potassium chloride as blanket applications of these nutrients for all treatments. Planting took place on 20 January 2016 and the first weeding was done on 5 February 2016. Harvest took place 27 August, 2016 after 220 days of growth.

Crop selection

The pigeon pea variety selected for the first crop in this rotation experiment (ICAEP00020) has a relatively long growth cycle of 190 days. Local farmers in Central Mozambique and Malawi are accustomed to using varieties of even longer growth cycles of 240 to 270 days (Dr. O. Madzonga, ICRISAT/Malawi, personal communication 2016). ICRISAT/Malawi has introduced varieties of medium duration (160 to 190 days) in the Gurue district, but adoption seems slow. Local practice is to seed at very low plant populations such as 1 m apart (Malawi recommendations are to space hills at 90 cm × 90 cm). For this experiment a much closer spacing of rows 50 cm apart with hills placed at 40 cm apart in the row was chosen. This plant population still seems too low to obtain maximum grain yield.

Data collection

Crop measurements

Non-destructive and destructive measurements of six selected plants were taken and recorded at approximately two week intervals throughout the growth cycle. These measurements included plant height, stem circumference and plant population. At harvest pigeon pea pods were collected from the four central rows, which comprised a harvest area of 12 m^2. Pods were weighed and air-dried for final weight and yield calculation. Above-ground biomass was also collected, weighted, and sub-samples taken for dry weight calculation.

Soil measurements

Soil samples were taken from each experimental plot after harvest to assess suspected gradients of soil pH. Samples of each plot were composites of 3 sub-samples taken from the plot harvest area. Soils were analyzed for soil water pH (1:1 ratio), 0.5 M sodium bicarbonate, soil calcium, magnesium and KCl-extractable aluminum determinations were also made. Effective cation exchange capacity was calculated by summing the cations Ca^{2+}, Mg^{2+}, K^{+} and KCl-extractable Al. The initial survey samples from six sites are listed in Table 3, while data from the experimental site are listed in Table 4.

Statistical analysis

A randomized complete block ANOVA was calculated on yields and above ground biomass yields using both Statistix® v. 10 statistical analysis software and JMP (SAS, 2017). The results were plotted using Sigmaplot® v. 12.5 graphics software. Plots of the relationship between grain, biomass, plant height and stem circumference and total amounts of applied P either in soluble TSP form or in the form of rock phosphate were developed. These plots served to quantitatively compare pigeon pea response to the Evate rock phosphate in relation to that of TSP and permitted a comparison of relative solubility and availability of the P in the Evate phosphate.

Because substantial variation in soil pH was observed among the experimental plots (Table 4), contour plots of soil pH, grain and biomass yields were prepared using the Surfer® version 12.8 software. Individual plot yields and corresponding mean soil measurements for the plot provided the basis for the contours. Other plots of yields in relation to soil measurements were developed to explore the effect of soil acidity on pigeon pea growth and response.

RESULTS AND DISCUSSION

Pigeon pea yielded as much as 1200 kg grain ha^{-1} (Figure 1). These yields were similar to or greater than average pigeon pea grain yields of the Gùrué District (2014) of about 800 to 1000 kg ha^{-1}(ICRISAT/Malawi, Dr. O. Madzonga, personal communication 2016). As expected, yields were greatest with the imported, highly soluble TSP fertilizer. Grain yields where the local rock

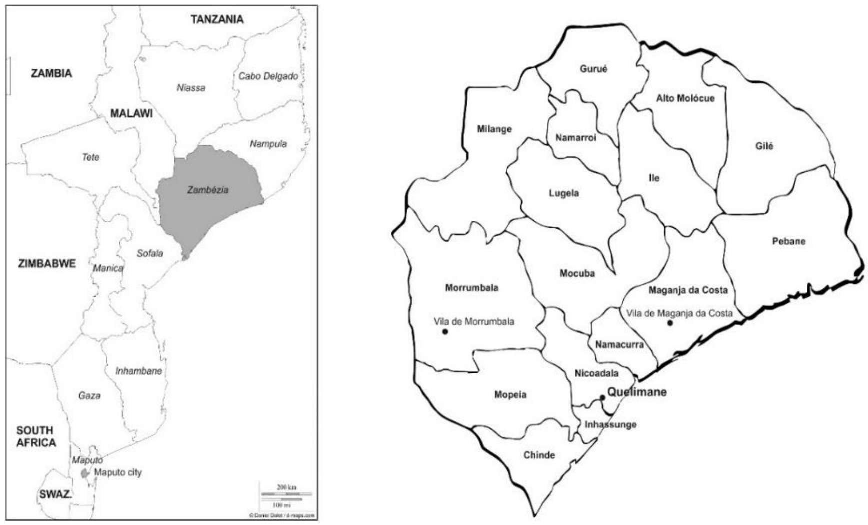

Figure 1. Location of the Gùrué District, Zambézia Province, Mozambique.

phosphate was applied were higher than expected with yields reaching almost 1200 kg ha^{-1}. A closer comparison shows that maximum yields occurred with TSP rates of 20 and 80 kg P ha^{-1} as Evate rock phosphate. Pigeon pea yields where rock phosphate was applied were surprisingly high given the low solubility of the material (3.75%) and were almost similar to yields where the soluble TSP fertilizer was applied. This relatively high effectiveness of Evate rock phosphate may be related to several factors that may have led to the relatively high availability of the Evate rock phosphate:

1. The pigeon pea growth cycle is long and in this case the crop was harvested after 220 days of growth allowing a long time for rock phosphate dissolution.
2. Pigeon pea is known for the exudation of large amounts of the organic acid, malonic acid that solubilizes otherwise unavailable forms of soil phosphorus (Otani et al., 1996).
3. Soils of the experimental site are both acidic (ranging in soil pH from 4.5 to 5.7) and low in exchangeable bases such as Ca (ranging from 0.4 to 2 $cmol_c$ kg^{-1}), which are well known factors that enhance rock phosphate dissolution (Diarra et al., 2004)

This result indicates that in these conditions, Evate rock phosphate was an effective source of the nutrient phosphorus.

Plant height and plant population were measured at given intervals but are not reported here. Field observations of pigeon pea growth during the experiment revealed zones of superior growth and plant height unrelated to treatment. In addition, grain yields on the check treatment (no P added) plot were surprisingly high (Figure 2) leading to inquiry into the experimental plot preparation. A comparison of soil measurements from individual plots indicated a large variation in soil pH as in levels of calcium, magnesium, and other nutrients (Figure 3). This analysis revealed that two of the three replications of the check plot were on plots with abnormally high soil pH. These differences were not apparent when soil was sampled by compositing by blocks, replicates, or across the entire site. In addition, variation in three variables, soil pH, soil Ca^{2+} and soil Mg^{2+} seem closely related. This variation appears to have resulted from the preparation of the experiment whereby all plant residue from the experimental area was gathered and burned in the plot center, clearly a time efficient alternative, but not optimal for the experimental objectives. A further analysis suggests that, in fact, the pigeon pea did respond to the gradient on soil pH induced by burning of plant residue from clearing (Figure 4). These results do suggest that while pigeon pea is known for its tolerance to soil acidity, it did respond to the reduction in soil acidity and less toxic extractable Al as well as increased levels of Ca^{2+} and Mg^{2+}.

Soil measurements on a per plot basis (Table 4) indicate an unfortunately wide range in pH, Ca, and Mg as mentioned previously. The levels of soil pH are clearly in the acidic range and suggest that acid tolerant plants such as pigeon pea, cassava, cowpea, and certain varieties of peanut would likely be most successful on such soils. The levels of soil P were variable, but generally low relative to typical plant requirements. Levels of soil Ca and Mg were particularly low indicating very low cation retention capacity of the soils. With such low levels sufficiency of Ca might be limiting for certain legumes (Fageria et al., 2013).

An analysis of pigeon pea aboveground biomass in relation to source and rate of applied phosphate revealed essentially the same pattern of response as did grain yield results (Figure 5). The biomass result also indicates

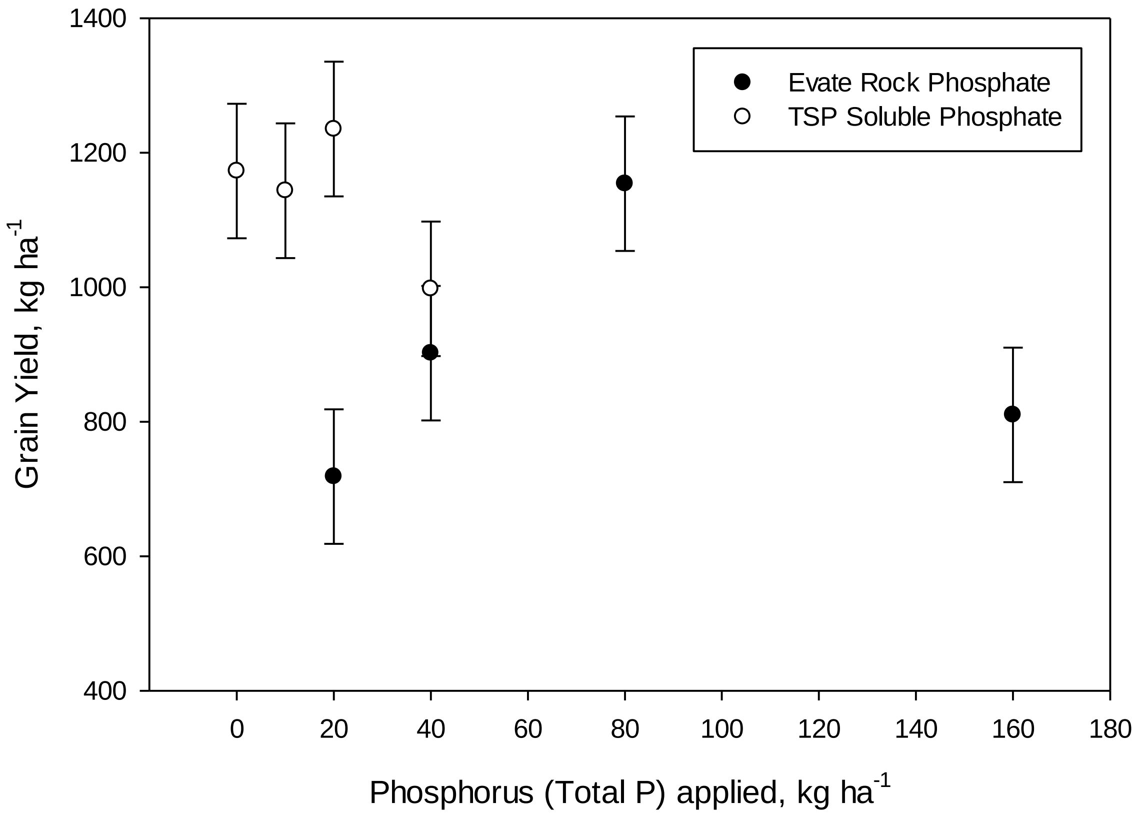

Figure 2. Grain yields of pigeon pea (*Cajanus cajan*) as influenced by rate and source of phosphate. The bars represent standard errors of treatment means.

that the Evate rock phosphate effectively supplied nutrients to this pigeon pea crop and in this acid, infertile soil.

Conclusions

A pigeon pea grain yield of 1000 kg grain ha^{-1} was obtained with an application of 80 kg ha^{-1} of total P added as Evate rock phosphate. By comparison 20 kg P ha^{-1} as TSP was needed to reach a maximum yield of pigeon pea grain. If this relationship was used to estimate relative effectiveness it is 20/80 or 25%. This research suggests that the Evate rock phosphate can be an effective amendment that can enable food grain production on the acid, infertile upland soils of Central Mozambique.

Evate rock phosphate, in this combination of soils and crops was an effective source of the often missing nutrient P for food grain production in Mozambique. This rock phosphate has an unusually high level of P (40.7% P_2O_5), however solubility is low (3.5 citric acid solubility and 0.95 neutral ammonium acetate solubility). These values are high in total P and low in solubility compared with data from Smallberger et al. (2010). The solubility of this rock phosphate can be improved by increased surface area with fine grinding, use on acid soils, and with crops of either long duration and / or that acidify their rhizosphere. Use of this potentially very important local fertilizer resource needs to be tested in other conditions and cropping systems whereby the dissolution might be initiated and largely carried out during the pigeon pea cropping period. Other research shows that subsequent crops also benefit from the P released during the pigeon pea phase of the rotation. Additional field experimentation using this rock phosphate are needed to quantify and assess its potential role in increased food crop productivity in Central Mozambique.

CONFLICTS OF INTEREST

The authors have not declared any conflict of interest.

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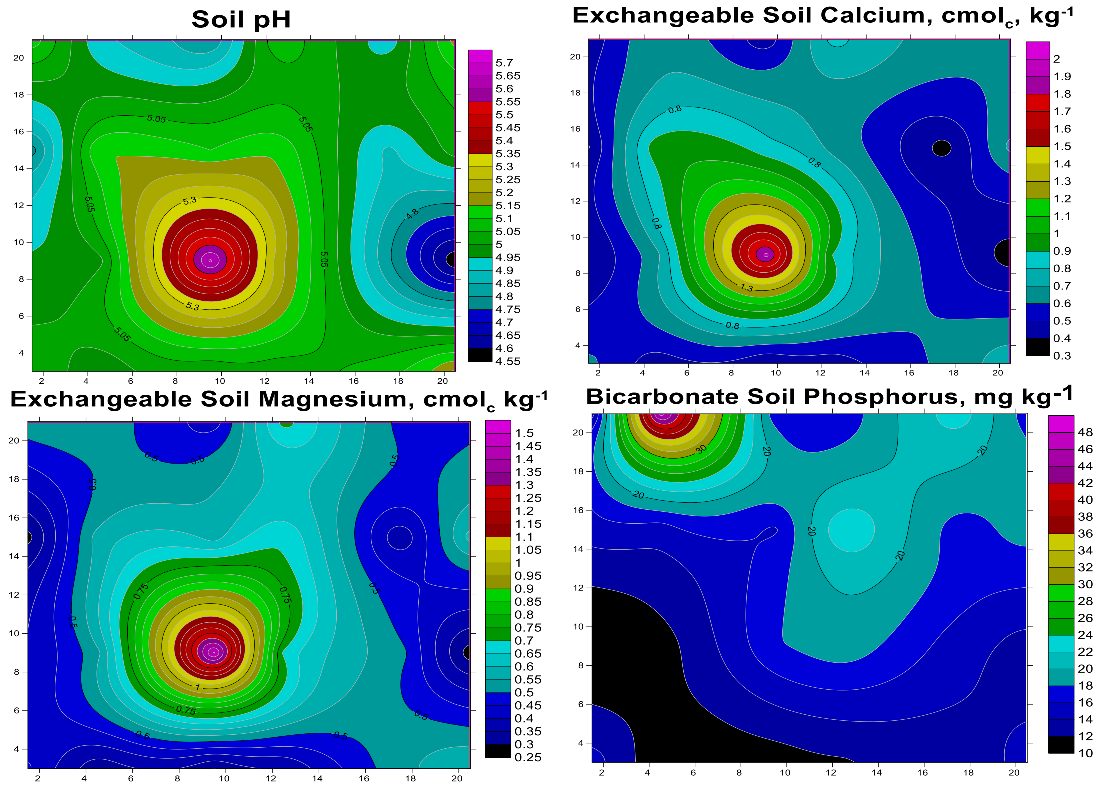

Figure 3. Variation in soil pH, exchangeable Ca^{2+}, Mg^{2+}, and P after pigeon pea harvest.

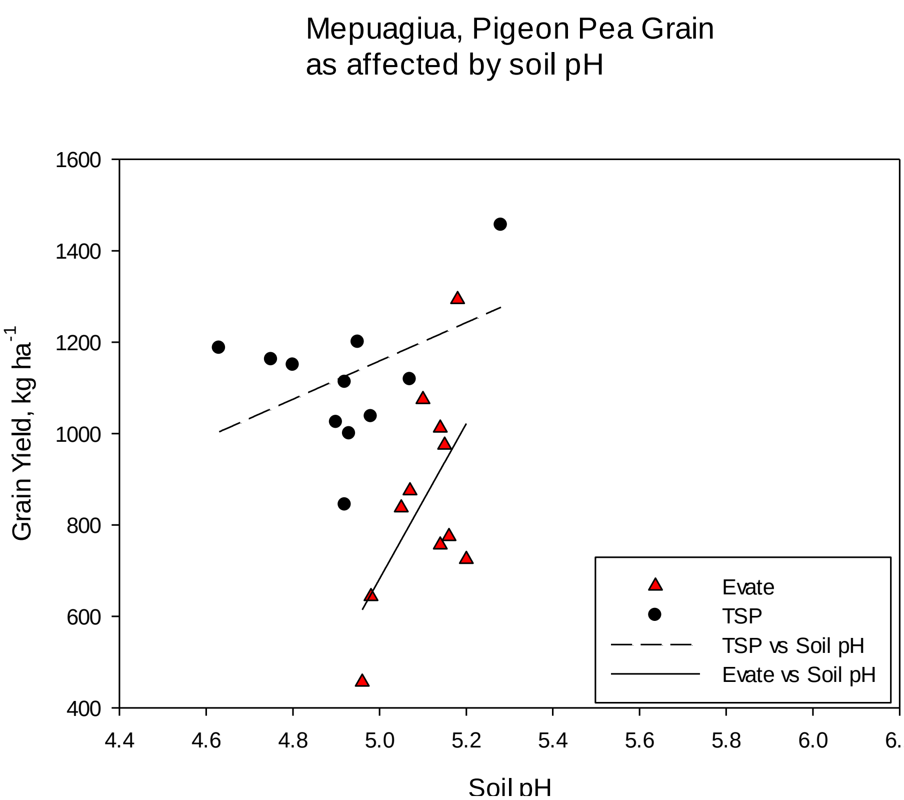

Figure 4. Relationship between grain yield and soil pH of all treatments.

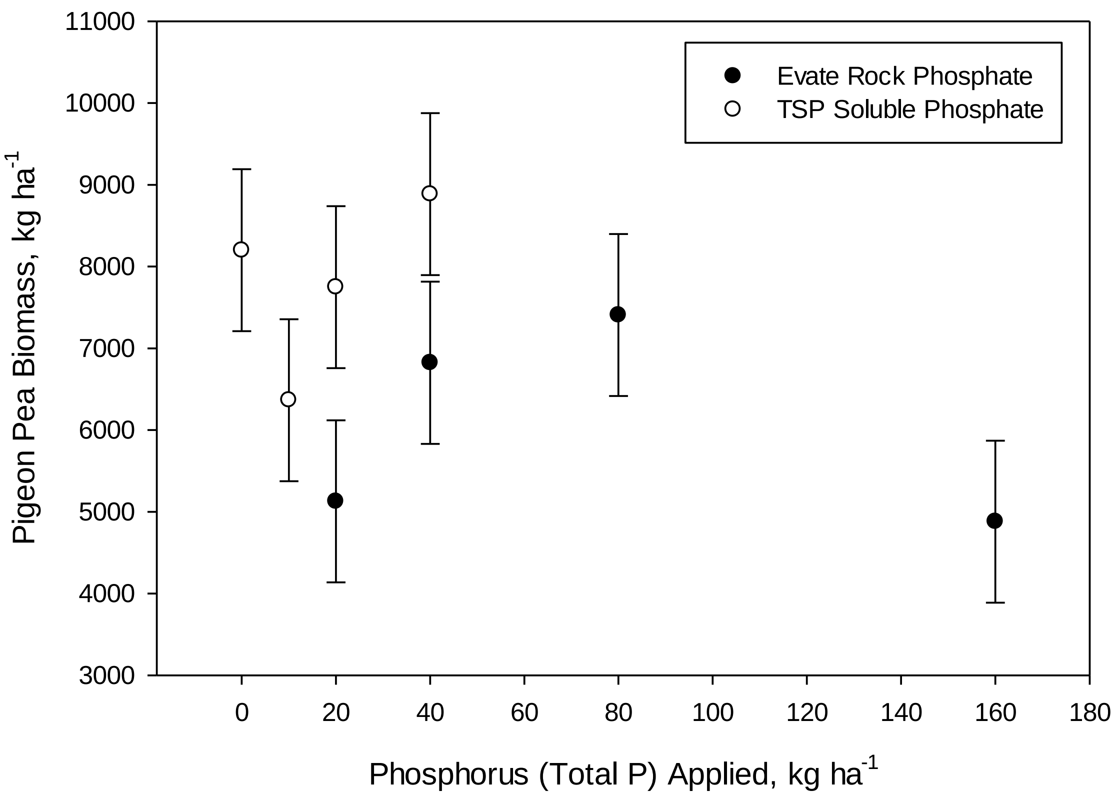

Figure 5. Pigeon pea above ground biomass in relation to source and amount of applied P.

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