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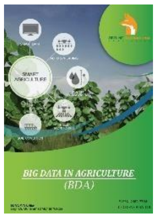

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RESEARCH ARTICLE

OPTIMIZATION OF ROCK PHOSPHATE USE AND EFFECT ON SOYBEAN GRAIN YIELD AND YIELD COMPONENTS ON AN *ANDOSOL* AND *ACRISOL* OF CAMEROON

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ABSTRACT

Modulation of rock phosphate fertilizer dose in soybean cultivation is crucial for maximizing plant growth and grain yield while ensuring efficient use of resources and environmental sustainability. This study evaluated rock phosphate (RP) dose to produce soybean on Leptic *Andosol* in Foumbot and *Acrisol* in Mbalmayo, respectively in the West and Centre regions of Cameroon. This split-plot experiment consisted of five fertilizer rates (control-no input and four Phosphorus (P) rates of 0, 30, 60 and 90 kg P /ha respectively) and two soybean varieties (TGX 1910-14 F and TGX 2001-24 DM) laid out in randomized complete block design with each treatment replicated three times. Plots containing the different P rates also had N (25 kg / ha) and K (40 kg / ha) straight fertilizers. Analysis of variance showed that fertilizer application significantly increased ($P < 0.01$) the number of pods and seeds, aboveground dry weight, and grain yield of the soybean varieties at both locations. There was an outright grain yield and economic benefit because of fertilizer application which increased with addition of phosphorus in the fertilizer mixtures. The grain yield response to phosphorus fertilizer was fitted to quadratic and square root models. The two models predicted maximum yields which were close to the experimental maximums recorded at P rates of 30 kg / ha (TGX 2001-24 DM: 5.04 and 4.89 t / ha) and 60 kg / ha (TGX 1910-14 F: 4.72 and 4.38 t / ha) at Foumbot and Mbalmayo respectively. The average optimum P fertilizer recommendations for soybean estimated by square root model (29.41 kg P/ ha) was considerably lower than that given by the quadratic equation (45.61 kg P/ ha) for both sites but only slightly lower the experimental dose of 30 kg P/ ha. Taking into account the yield and cost benefit analysis of the soybean seeds, fertilization with 30 kg P/ ha can be recommended.

KEYWORDS

Phosphorus, quadratic model, soil, soybean varieties, square root model.

1. INTRODUCTION

Soybeans (Glycine max) are versatile legumes that hold significant agricultural and economic importance globally. They are cultivated across continents, finding particular prominence in Africa due to their nutritional value and adaptability to diverse climates. Soybeans are rich in protein (around 36-56%), essential amino acids, healthy fats, fiber, vitamins (B-complex), and minerals (iron, calcium) (Anupam and Suprodip, 2019). This makes them a valuable source of nutrition, especially in regions where protein deficiency is a concern. Soybeans are processed into various food products and animal feed (Mabapa et al., 2010). They account for 58 % of world oil seed production and are used in the production of biodiesel, biodegradable plastics, and as renewable source of oil for various industrial applications (Board, 2013; Mabapa et al., 2010).

Soybean cultivation in Africa has seen growth due to its potential to improve food security, provide income opportunities for farmers, and contribute to sustainable agricultural practices (Kolapo, 2011; Kiwia et al., 2022). Many African countries are promoting soybean cultivation through extension services, training, and access to improved seeds. However, its production in Africa is still very low and the demand far exceeds the supply and annual imports are valued at 1.2 billion US dollar (Sinclair et al., 2014; Kiwia et al., 2022; Sileshi and Gebeyehu, 2020). Soybean seed yield in Cameroon stands at 1.37 t / ha which is low compared to the world average yield (2.48 t / ha) despite the presence of improved soybean varieties that could yield up to 5 t / ha (Takahashi et al., 1994; Giller et al., 2011).

The impact of soil fertility on soybean production is profound and directly influences yield, quality, and overall agricultural sustainability (Singh et al., 2003). Soybeans, like all crops, require a range of nutrients for optimal growth (Bagarama et al.). Today, low soil fertility is recognized as a fundamental biophysical cause for declining food security among small-farm households in sub-Saharan Africa and represent huge obstacles to securing needed harvest (Bello et al. 2018; Sanchez et al. 1997; Sanginga and Woomer 2010). Thus, managing soil fertility has become a major issue because of soil degradation (Nanganoa et al. 2019; Fritzpatrick, 1986).

In Cameroon poor soil fertility and low application of external inputs are the most important reasons for the low yield (Ngome et al., 2013). To improve soil fertility and optimize crop productivity, farmers often apply different fertilizers and rates (Nanganoa et al., 2019; Nottidge et al., 2005; Saha et al., 2008; Hepperly et al., 2009; Ngosong et al., 2019). The present level of chemical fertilizer use in Cameroon stands at 7 to 10 kg / ha, which is still considered very low relative to the above 150 kg / ha of other countries in Asia and Europe (Lekeanju et al., 2016). As a result, soil degradation processes have intensified with soil nutrient mining as the most usual form of soil degradation (Nanganoa et al., 2019; Vanlauwe et al., 2015). According to soil survey in selected localities of the different agro-ecological zones of Cameroon, it was reported that, soils were consistently low in nitrogen, phosphorus, sulphur, and zinc (Nanganoa et al., 2020). Hence, smallholder farmers who might attempt to grow crops without or with marginal fertilizer application would not be able to produce enough even to feed their own families.

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Legumes, such as soybeans play a key role in enhancing soil fertility through the action of microorganisms (Kebede, 2021; Nanganoa et al., 2019). They have the ability to form symbiotic relationships with nitrogen-fixing bacteria to convert atmospheric nitrogen into a form that the plant can use for growth (Kebede, 2020). However, even with nitrogen fixation, soybeans benefit from soils with adequate initial nitrogen levels and other nutrients for optimal performance. When soybeans are grown with good management, they can fix up to 300 kg / ha of nitrogen (N), which contributes N to cereal crops grown in rotation (Salvagiotti et al., 2008). This can be sufficient to replace the basal N fertilizer needed for maize crops (Giller et al., 2011).

Studies have shown that, low P availability in soils is one of the most obvious abiotic factors that limits the growth and productivity of soybean (Mabapa et al., 2010; Qin et al., 2022). Phosphorus is essential for various physiological processes in soybeans, including root development, flowering, and seed formation and is crucial in N fixation (Carsky et al., 2000; Giller et al., 2011). Rock deposits from which most chemical phosphorus fertilizers originate are finite and so food security will inevitably be threatened when this valuable resource becomes scarce. Besides, there is expected depletion of high-quality rock phosphate which is the major source of P-fertilizers by the year 2050 (Vance et al., 2003).

The direct application of rock phosphate has been found to be suitable for acidic soils as low pH helps to solubilize the RP and increase the available form of P to plants (Ditta et al., 2018). Therefore, studies aimed at determining the optimum P rate of RP in acid soils are crucial to avoid resources waste, guarantee agronomic effectiveness and safeguard the ecological environment. The objective of this study was to (i) evaluate the effect of different rates of rock phosphate fertilizer on soybean yield and yield components, and (ii) evaluate site-specific fertilizer recommendation rates for P using crop response models.

2. Materials and Methods

2.1 Study locations

On-station experiments were conducted at the experimental fields of the Institute of Agricultural Research for Development (IRAD) in Foumbot and Mbalmayo. Foumbot (05°30′-05°42′ N, 10°34′-10°43′ E) is located in the Noun Division, West Region of Cameroon. The area is found in the Western Highlands agro-ecological zone (AEZ 3) characterized by Leptic Andosol according to the world Referential Base (FAO-ISRIC 2006) and subjected to a mountainous tropical climate with a dry season of four months (mid-November to mid-March) and a rainy season of eight months (mid-March to mid-November). Total average annual rainfall is 1782 mm and the mean annual temperature is 22°C (Azinwi et al., 2019). Mbalmayo (3°51′ N, 11°27′ E) is located in the Nyong and So'o Division of the Centre Region of Cameroon. The area is found in the humid forest agro-ecological zone (AEZ 5), characterized by Acrisol, a bimodal rainfall pattern, with four seasons: long rainy season from September to November, long dry season from December to February, short rainy season from March to June, and short dry season from July to August (FAO-ISRIC 2006). The average daily temperature and rainfall was estimated at 20 to 29°C and 1,700 mm respectively (Temegne et al., 2019). Figure 1 shows the data on temperature and rainfall during the experimental period of both sites.

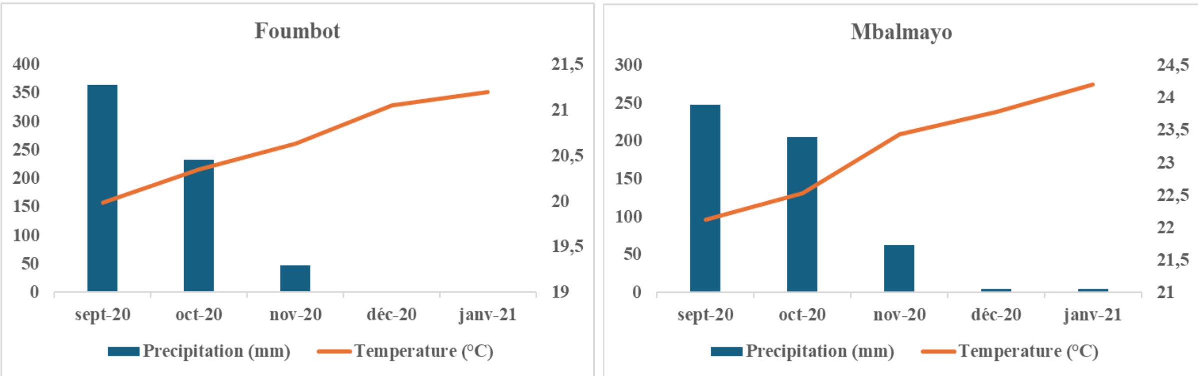

Figure 1: Total monthly rainfall and monthly means temperature from September 2020 to January 2021.

2.2 Soil analysis

Before planting, soil samples per experimental site were randomly collected in a zigzag pattern at a depth of 0–15 cm with an auger and thoroughly mixed to form a composite sample. The samples were air dried, sieved through a 2 mm sieve and subjected to physical and chemical analysis following standard methods. Soil pH was determined in the ratio of 1:2.5 soil–water suspensions using a digital pH meter. Available phosphorus was determined by Bray II method and total nitrogen by the Kjeldahl digestion method (Van Reeuwijk, 1992; Bremner and Mulvaney, 1982). Soil exchangeable bases were determined after extraction with 1 N ammonium acetate (NH4OAc) solution at pH 7. Calcium and Magnesium were analysed by the EDTA titration method, while potassium was analysed by flame photometer (Rowell, 2014). Sulphur, Boron, and Zinc were determined after extraction with Mehlich-3 solution (Mehlich, 1984). Particle size distribution was determined using the Bouyoucos (hydrometer) method and textural class assigned according to the USDA textural triangle (Van Reeuwijk, 1992).

2.3 Experimental design

The experiments were laid out in a split plot design with 2 soybean varieties as main plot, 4 rates of phosphorus (0, 30, 60, 90 kg P/ha) with each receiving 25 kg N / ha and 40 kg K / ha as straight fertilizers and control-no input as sub plots giving rise to 5 treatments at each site. Each treatment was replicated 3 times; therefore, each site had 30 experimental units (sub plots) in total. Each experimental unit was 5 m^2 (2.5 m x 2 m) in size. Sub plots within replicates were separated by 1 m alley and 1.5 m separated replicates from each other, while 2m buffer surrounded the entire experimental site. The sites were manually cleared.

2.4 Crop management

2.4.1 Planting

TGX 1910-14 F and TGX 2001-24 DM soybean varieties were used for this experiment. Planting was done at a depth of 4 – 5 cm on the 5th and 14th of September 2020 at Foumbot and Mbalmayo respectively. The plant spacing was 40 cm inter-row and 20 cm in-row. In the season before the experiment, maize was planted on both sites. The field sites were regularly monitored for weed emergence and weeded during the experimental period. The experiment was conducted under rainfed condition but was supplemented with irrigation after the second decade of November.

2.5 Fertilization

Phosphorus was applied at planting in form of rock phosphate (P=27 %) at the rates of; 0, 0, 30, 60 and 90 kg P /ha per sub plot. The plots (excluding the control plots) were amended with K applied in form of Potassium sulphate (K_2SO_4) at the rate of 40 kg K / ha two weeks after sowing (2 WAS). Nitrogen was applied in form of urea 2 WAS at the rate of 25 kg N /ha (Table 1).

Table 1: Fertilizer application rates for the different treatments

Treatment	Quantity of nutrient added (kg/ha)		
	N	P	K
T0	0	0	0
T1	25	0	40
T2	25	30	40
T3	25	60	40
T4	25	90	40

2.6 Plant sample collection, measurements and calculations

Soybean plants were sampled for grain yield and yield components at maturity. The area sampled from each experimental unit was 0.96 m^2 randomly selected while excluding the two-border rows. The plant biomass of the sampled area was cut at ground level. and the fresh weight recorded (Córdova et al., 2020). A subsample of ten plants was taken from each plot, partitioned into seeds, pods, and stem (including petioles) and weighed; oven-dried at 65 ◦C until constant weight. Total aboveground dry weight (ADW) of samples was reported per-area basis (g / m^2) as the sum of all plant organs dry weight. No leaf weights were collected due to leaf senescence. The number of pods and grains per plant were counted. Final soybean grain yield was reported in t / ha adjusted to 13 % moisture.

2.7 Calculations and data analysis

Data analyses were performed using SPSS version 23 software (IBM, 2015). First, the data was subjected to Analysis of Variance (ANOVA) for determining the effects using a Split-plot design and Tukey's HSD test ($P < 0.05$) was used to separate the means. A simple economic analysis of return to fertilizer cost was calculated as the net return above fertilizer cost (Córdova et al., 2020). Economic net return = (Y_{yield} × market price) − (additional fertilizer × fertilizer price). The fertilizers use benefits over the control were obtained by subtracting returns made from the control from returns of each fertilizer treatment and these are the actual returns after paying the costs for fertilizers. Statistical analysis was also done by excluding the control-no input plots to determine the measured grain yield response to different P rates. P fertilizer use benefit over fertilizer treatment without additional phosphorus were obtained by subtracting returns made from each P fertilizer treatment from fertilizer treatments without P. The phosphorus data were also subjected to two fertilizer response models (quadratic and square root models) to evaluate the optimum P fertilizer recommendation for soybean in the two locations.

The quadratic model is as follows:

$$Y_{yield}(P_{rate}) = a + bP_{rate} + cP_{rate}^2 \quad (1)$$

And the square root model is:

$$Y_{yield}(P_{rate}) = a + bP_{rate} + cP_{rate}^{1/2} \quad (2)$$

where Y_{yield} is the grain yield in kg / ha, P_{rate} is the P fertilizer rate in kg P/ ha, and a (intercept), b (linear coefficient) and c (coefficient of the equation) are parameters estimates obtained using the SPSS procedure for Windows (Pinochet et al., 2018). Coefficients of determination (R^2 values) for the models were determined by use of regression analyses. For the quadratic and square root models (Eq. (1) and (2), predicted maximum yields and optimum P rate were obtained by equating the first derivatives of the response equations to zero and solving for P_{rate} and Y_{yield}.

The average market price of soybean in the economic capital of Cameroon - Douala in 2021 was 0.92 USD (550 FCFA) kg−1 grain, and the prices of fertilizers; urea, potassium sulphate and rock phosphate were 17.500 (29.41 USD), 30.000 (50.42 USD) and 18.000 FCFA (30.25 USD) per 50 kg bag, respectively (1 USD = 595 FCFA).

3. Results and Discussion

3.1 Soil characteristics of the experimental sites

Texturally, the soils at both sites (Foumbot and Mbalmayo) were sandy loam having moderately and strongly acidic pHs respectively (Table 2). The soil pH at the site in Foumbot was in the acceptable pH range for soybean (5.2 – 8.2) growth while that at Mbalmayo was just a tenth unit below (Table 2) (Sys et al., 1993). However, no correction measures for pH were undertaken. According to the guidelines for tropical soils elaborated by Landon, 1991, the Foumbot site had high postasium, calcium and magnesium; medium nitrogen; and low phosphorus. The Mbalmayo site had high potassium, magnesium, medium calcium, and low nitrogen and phosphorus. Sulphur, Boron, and Zinc were low at both experimental sites (Table 2). With these observations, strong responses are likely for P application at Foumbot and Mbalmayo sites while low response are likely for K application at both sites. However, the added K_2SO_4 was to maintain the K pool and increase the low S content in the soils.

Table 2: Soil physical and chemical properties for the selected sites

Soil property	Foumbot	Mbalmayo
Clay (%)	13.5	20.0
Silt (%)	21.0	8.0
Sand (%)	65.5	72.0
Soil texture	Sandy loam	Sandy loam
pH (H_2O)	6,0	5.1
Tot N (%)	0.31	0.19
Av. P (mg/kg)	4.00	3.07
Exch. K (meq /100 g)	1.09	0.89
Exch. Ca (meq /100 g)	8.58	2.69
Exch. Mg (meq /100 g)	2.43	0.78
S (mg/kg)	6.8	11.2
B (mg/kg)	0.23	0.21
Zn (mg/kg)	2.10	1,07

3.2 Fertilizer effect on pod, seed, total aboveground dry weight, and grain performance

Fertilizer application, varieties and their interaction had a significant influence on number of pods and seeds, total aboveground dry weight (ADW) and grain yield ($P < 0.01$) at both locations (Table 3). Like this result, a group of researchers reported significant effects of soybean genotypes and fertilizer sources on grain yield and yield components though their interaction effects were not significant (Nget et al., 2022). In other study, author reported a significant varietal effect on grain yield and a significant interaction effect on variety and fertilizer (Adeyeye et al., 2017). The differences among soybean varieties for grain yield and its components might be related to their intrinsic characteristics (Nget et al., 2022). Nevertheless, the soybeans response to fertilizer and variety did not vary over location (Table 3), therefore, separate analysis for each location was done.

Table 3: Analysis of variance for yield and yield components of soybean as influenced by fertilizer rates, variety and the interaction effect in two locations

Sources of variation	df	F probability (P = 0.05)			
		Number of pods/plants	Number of seeds/plants	Total dry weight (g/m^2)	Grain yield (t/ha)
Variety (V)	1	< 0.001	< 0.001	0.005	0.001
Fertilizer treatment (F)	4	< 0.001	< 0.001	< 0.001	< 0.001
Location (L)	1	0.099	0.030	< 0.001	0.013
V x F	4	< 0.001	< 0.001	< 0.001	0.002
V x L	1	0.788	0.829	0.566	0.516
F x L	4	0.316	0.186	0.097	0.201
V x F x L	4	0.316	0.405	0.181	0.117
Error	40	-	-	-	-
Total	60	-	-	-	-

Pod number per plant was in the range of 38.00 to 77.67 at the Foumbot site and 41.00 to 72.33 at the Mbalmayo site. The lowest pod number per plant was observed in T0 – no input of TGX 1910-14 F variety at both sites which was not significantly different from T0 – no input of TGX 2001-24 DM variety and the interaction T1 * TGX 2001-24 DM at both sites (Figure 1a & b). The highest pod number was recorded by T2 * TGX 1910- 14 F interaction at both sites (Figure 1a and b) and was not significantly different from T3 * TGX 1910- 14 F, T4 * TGX 1910- 14 F interactions at both sites and T2 * TGX 2001 -24 DM in Mbalmayo (Figure 1b). It has been established according to Buttery that, application of P fertilizer stimulates node and pod formation in legumes (Buttery, 1969). Other studies have shown that the significant increase in pod load in various legume plants were due to increased P application (Turuko and Mohammed, 2014).

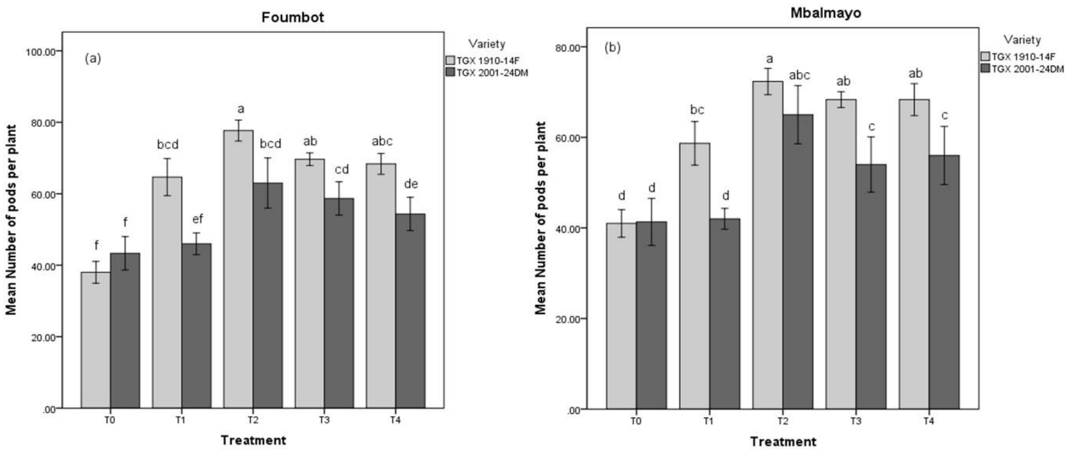

Figure 2: Number of pods per plant as affected by the interaction of fertilizer rates and soybean varieties. Different letters indicate that the means are significantly different (P < 0.05) (T0: control-no input; T1: 25 kg N/ha, 0 kg P/ha, 40 kg K/ha; T2: 25 kg N/ha, 30 kg P/ha, 40 kg K/ha; T3: 25 kg N/ha, 60 kg P/ha, 40 kg K/ha; T4: 25 kg N/ha, 90 kg P/ha, 40 kg K/ha)

The effect of fertilizer on the number of seeds per plant was significant at both locations (P< 0.001) with all treatments significantly higher than the control (T0) of both varieties at Foumbot. In Mbalmayo, the interaction of T1 * TGX 2001-24 DM (125.33) was not significantly higher than T0 of both varieties (118.67 for TGX1910-14 F and 119.00 for TGX 2001-24 DM) (Figure 2a & b). Although T2 * TGX1910-14 F had the highest number of seeds per plant (208) compared to T0, its number of seeds per plant was not significantly different from T1 * TGX1910-14 F (182), T2 * TGX 2001-24 DM (195.33), T3 * TGX1910-14 F (203), T3 * TGX 2001-24 DM (181.67), and T4 * TGX1910-14 F (192.67) in Mbalmayo (Figure 2b). In Foumbot, T2 * TGX1910-14 F was significantly higher (226.67) than all the other treatments (Figure 2a).

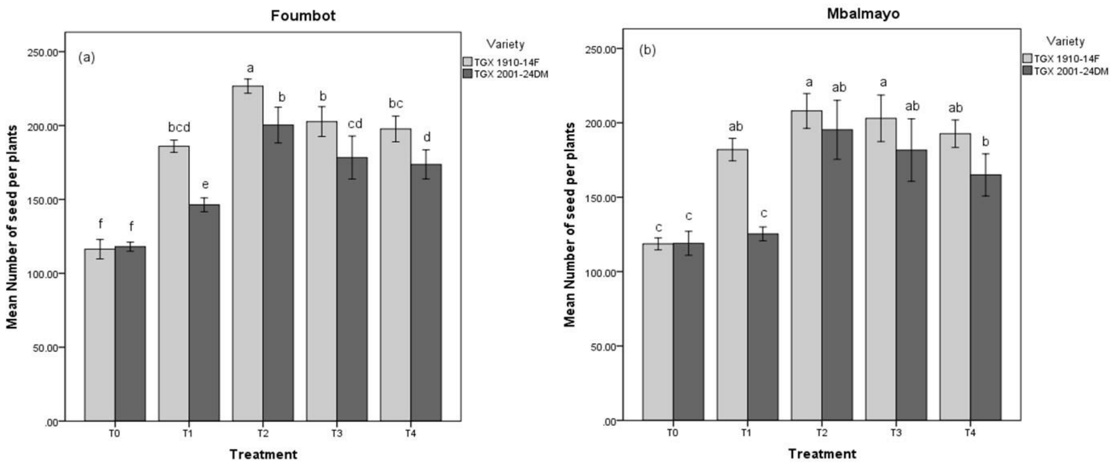

Figure 3: Number of seeds per plant as affected by the interaction of fertilizer rates and soybean varieties. Different letters indicate that the means are significantly different (P < 0.05) (T0: control-no input; T1: 25 kg N/ha, 0 kg P/ha, 40 kg K/ha; T2: 25 kg N/ha, 30 kg P/ha, 40 kg K/ha; T3: 25 kg N/ha, 60 kg P/ha, 40 kg K/ha; T4: 25 kg N/ha, 90 kg P/ha, 40 kg K/ha)

For the total aboveground dry weight of biomass, fertilizer application had a strong significant effect (P < 0.001) at each site. The highest significant effect was registered in T2 of TGX 1910-14 F variety and in T3 of the TGX 2001-24 DM variety (Figure 3a & b). However, T2 * TGX 1910-14 F (1448 and 1333 g/m^2) was not significantly different from T3 * TGX 2001-24 DM (1399 and 1293 g/m^2) at Foumbot and Mbalmayo respectively (Figure 3a & b). The significant effect of the interactions of fertilizers and varieties on yield components could have resulted from variation in uptake and utilization of nutrients (especially P) by the crop varieties (Mabapa et al., 2010).

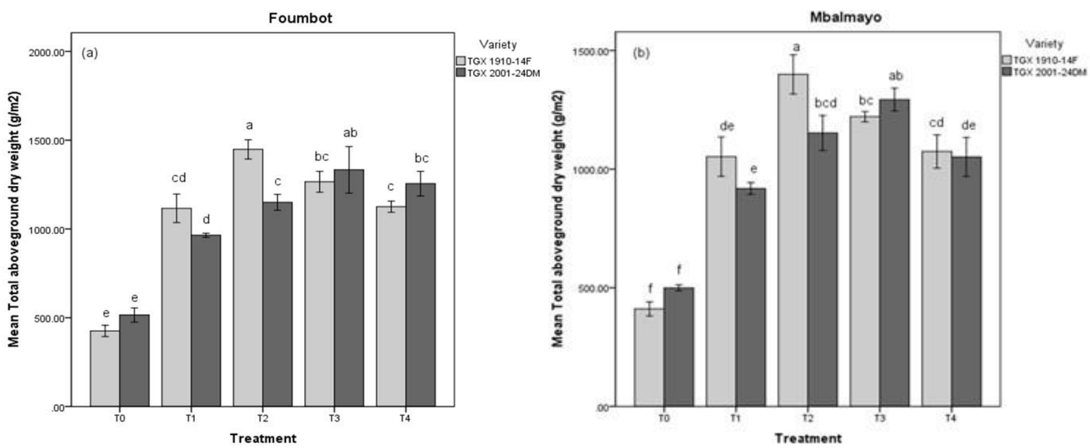

Figure 4: Total aboveground dry weight as affected by the interaction of fertilizer rates and soybean varieties. Different letters indicate that the means are significantly different (P < 0.05) (T0: control-no input; T1: 25 kg N/ha, 0 kg P/ha, 40 kg K/ha; T2: 25 kg N/ha, 30 kg P/ha, 40 kg K/ha; T3: 25 kg N/ha, 60 kg P/ha, 40 kg K/ha; T4: 25 kg N/ha, 90 kg P/ha, 40 kg K/ha)

Grain yields ranged from 1.72 to 4.72 t / ha and 2.36 to 5.04 t / ha for TGX 1910-14 F and TGX 2001-24 DM varieties respectively at Foumbot site (Figure 4a) and from 1.69 to 4.38 t / ha and 2.23 to 4.89 t/ha for TGX 1910-14 F and TGX 2001-24 DM varieties respectively at Mbalmayo (Figure 4b). The lowest grain yield values were recorded in the control plots (T0) while the highest was observed in the T2 * TGX 2001-24 DM interaction on both locations but was not statistically different from T2 * x TGX 1910-14 F; T3 * TGX 1910-14 F; T3 * TGX 2001-24DM and T4 * TGX 2001-24DM at Foumbot (Figure 4a) and T1 * TGX 1910-14 F; T3 * TGX 1910-14 F and T3 * TGX 2001-24 DM at Mbalmayo (Figure 4b).

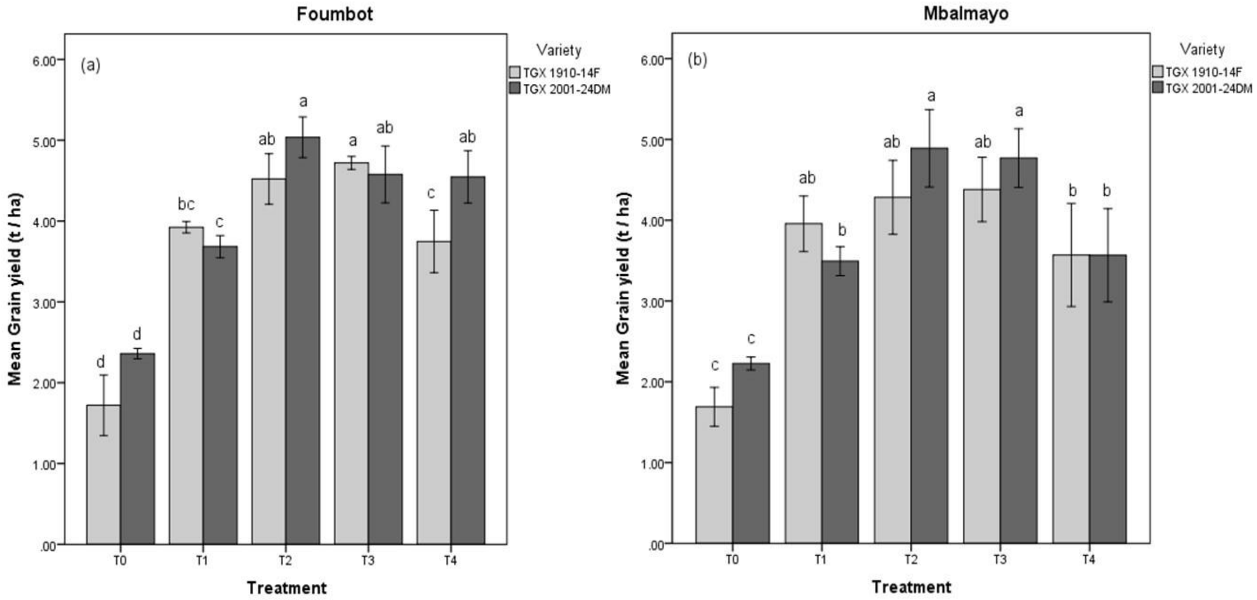

Figure 5: Grain yield as affected by the interaction of fertilizer rates and soybean varieties. Different letters indicate that the means are significantly different (P < 0.05) (T0: control-no input; T1: 25 kg N/ha, 0 kg P/ha, 40 kg K/ha; T2: 25 kg N/ha, 30 kg P/ha, 40 kg K/ha; T3: 25 kg N/ha, 60 kg P/ha, 40 kg K/ha; T4: 25 kg N/ha, 90 kg P/ha, 40 kg K/ha)

Generally, the yields were higher for TGX 2001 – 24 DM compared to TGX 1910 – 14 F variety. This might be due to the differences in the absorption and use efficiency of nutrients between the two varieties (Meng et al., 2014; Wang et al., 2021). Soybean yield was better in Foumbot compared to Mbalmayo (Figure 4a and b). The higher yield in Foumbot can be attributed to its inherent soil physicochemical properties of this andosol (Table 2). In addition, phosphorus in the fertilizer mixtures had an outstanding influence on the number of pods per plant, number of seeds per plant, total aboveground dry weight of biomass and grain yield as compared to fertilizer treatment without P (Figure 1 – 6). This is a strong indication that in these soils with low P contents, RP might have supplied a considerable amount of extractable P. According to a study, acid soils favour the solubility of rock phosphate (Hammond et al., 1986; Utomo, 1995). Furthermore, these results showed variability that exists in P requirements for soybean depending on the P rate. At P rate of 90 kg /ha (T4), majority of the yield and yield attributes declined which indicated that P fertilizer application at this rate could be excessive. This might have resulted to limited absorption of micronutrients. If P concentration is high in the soil, it is known to "lock" and reduce the absorption and utilization of micronutrients through P to micronutrients interactions (Mousavi, 2011; Murphy et al., 1981). Thus, resulting to P-induced micronutrients deficiency which leads to low yields. Some researcher also demonstrated that there is no continuous increase in maize yield when P application rates go beyond moderate dose (60 – 120 kg / ha) (Jiang et al., 2019). In other study, authors observed similar trends who found that maize grain yield increased with increasing P fertilizer and then moved slowly to a plateau (Deng et al., 2014).

3.3 Cost-benefit analysis

The fertilizer treatments considered increased the overall financial returns, compared to the profit gained with no fertilizer use (Table 4). The highest net income was recorded in T2 * TGX 2001-24DM in both Foumbot and Mbalmayo. Statistically, the net income was not significantly different (P > 0.05) from T2 * TGX 1910-14 F; T3 * TGX 1910-14 F; and T3 * TGX 2001-24DM for both sites and from T1 * TGX 1910-14 F of the field in Mbalmayo. However, the lowest fertilizer use benefit was observed in T1 * TGX 2001-24DM in Foumbot and was not statistically different from T3 * TGX 2001-24DM; T4 * TGX 2001-24DM and T4 * TGX 1910-14 F. The lowest fertilizer use benefit in Mbalmayo site was recorded in T4 * TGX 2001-24DM (Table 4) and was not significantly different from T1 * TGX 2001-24DM and T4 * TGX 1910-14 F (Table 4). Phosphorus use benefit was realized at P rates of 30 and 60 kg/ha in both experimental sites and at 90 kg / ha rate for the TGX 2001-24DM variety in Foumbot (Table 4). The rest of the fertilizer mixtures with P rate of 90 kg/ha were not profitable. Therefore above 60 kg, P application will have very little benefit to the farmers.

3.4 Evaluation of soybean yield response to phosphorus

Figure 5a & b show curves of grain yield against P application rate for each site. Yield increased initially to a peak and then decreased with increase in P application. To describe the response of soybean to phosphorus fertilizer, two mathematical models (Quadratic and the square root models) were used. The regression analysis showed that the coefficient of determination (R^2) varied from 0.354 - 0.820 (Table 4). These two models seem to fit the yield data equally thus, limitation of using R^2 to select any of the model is illustrated. According to Cerrato and Blackmer, R^2 is inappropriate for assessing the performance of nonlinear models or for comparisons among linear, quadratic, and nonlinear models (Cerrato and Blackmer, 1990; Sileshi, 2021). The optimum P fertilizer rates for soybean yield predicted by the models varied between sites and ranged from 18.39 - 54.18 kg P /ha (Table 4) with the square root model registering lower average optimum P rate (29.41 kg P/ ha) which range from 18.39 - 34.33 – kg P / ha compared to the quadratic model (45.61 kg P/ ha) which range from 39.30 – 54.18 kg P / ha (Table 4) with significant polynomial functions (P < 0.05) except for the quadratic and square root models of TGX 1910-14 F in Mbalmayo (P > 0.05). However, a range between 10 to 65 kg P / ha has been reported to give positive remarkable results in legumes yield and yield attributes (Kumar and Sreekumaran, 1992; Rath et al., 2000). Other studies have found that the quadratic model leads to overestimation of fertilizer recommendations derived from responses to fertilizer (Cerrato and Blackmer, 1987). It is therefore suggested that the square root model be given serious attention in response analysis to avoid excess use of P fertilizers than the actual need. The models also showed similar range of predicted optimum grain yield of 4.41 – 5.00 kg / ha and 4.48 – 5.06 kg / ha for the quadratic and square root models respectively (Table 4). These values were also like the experimental maximums recorded at P rates of 30 kg / ha (TGX 2001-24 DM: 5.04 and 4.89 t / ha) and 60 kg / ha (TGX 1910-14 F: 4.72 and 4.38 t / ha) at Mbalmayo and Foumbot respectively.

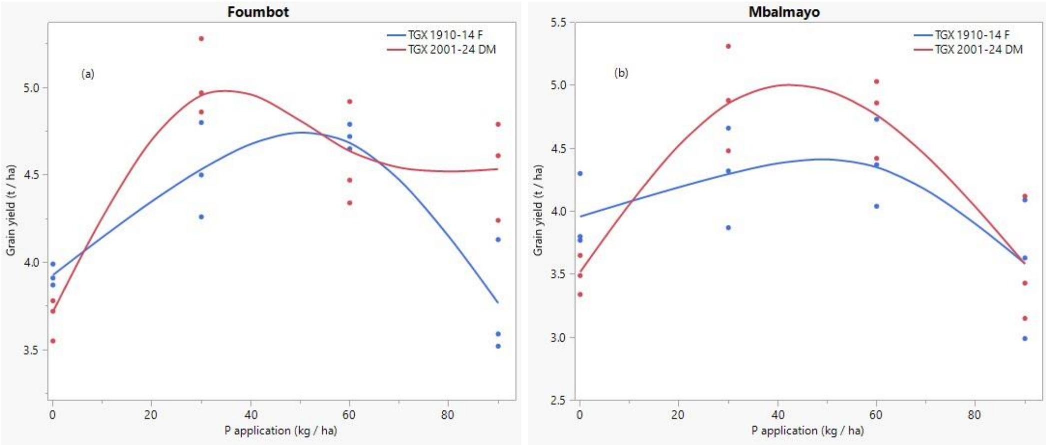

Figure 6: Relationship between P application rate and grain yield

Table 4: Cost benefit analysis of soybean with respect to fertilizer application on acid soils in Foumbot and Mbalmayo experimental fields

Treatment	Cost of fertilizer applied US$	Grain market price US$ /kg	Gross income US$/ha		Net income US$/ha		Fertilizer use benefits US$ /kg		Phosphorus use benefits US$ /kg	
			TGX 1910-14F	TGX 2001-24DM	TGX 1910-14F	TGX 2001-24DM	TGX 1910-14F	TGX 2001-24DM	TGX 1910-14F	TGX 2001-24DM
Foumbot										
T0	0	0.92	1582.82d	2169.71d	1582.82e	2169.71e	0	0	0	0
T1	128.57		3609.28bc	3389.95c	3480.71bc	3261.38cd	1897.89abc	1091.67d	0	0
T2	282.25		4158.08ab	4633.61a	3875.83abc	4351.37a	2293.01a	2181.66ab	395.12b	1089.99a
T3	437.14		4342.59a	4209.00ab	3905.45ab	3771.86abc	2322.63a	1602.15bcd	424.74b	510.48ab
T4	590.82		3448.54c	4181.65ab	2857.72d	3590.83bc	1274.90d	1421.12cd	- 622.99c	329.45b
Mbalmayo										
T0	0	0.92	1557.06c	2048.89c	1557.06e	2048.89de	0	0	0	0
T1	128.57		3642.14ab	3212.10b	3513.57abc	3083.53bc	1956.51abc	1034.64cd	0	0
T2	282.25		3940.68ab	4502.05a	3658.43ab	4219.80a	2101.37ab	2170.91a	144.86ab	1136.27a
T3	437.14		4030.38ab	4387.64a	3593.24abc	3950.50ab	2036.18abc	1901.61abc	79.67ab	866.97a
T4	590.82		3283.25b	3278.38b	2692.43cd	2687.56cd	1135.37bcd	634.67d	- 198.87b	- 395.97b

- Different letters per column indicate that the means are significantly different (P<0.05)
- Fertilizer treatments was based on application rates used in this experiment.
- Price was based on the observed market price in the study area in 2020.
- Currency conversion was based on the exchange rate in Central Africa (1USD: 590.XFCFA).

Table 5: Statistics of regression coefficients for the quadratic and square root models of grain yield, optimum P rate and predicted optimum yield

Mathematical model	Experimental site	Variety	Optimum P rate (kg/ha)	Coefficient of determination (R^2)	F Probability (P = 0.05)	Coefficients of equations			The Predicted Optimum Yield (t/ha)
						a	b	c	
Quadratic	Foumbot	TGX 1910-14 F	43.73	0.797	0.010	3884.31	38.13	-0.436	4.72
		TGX 2001-24DM	54.18	0.631	0.011	3796.99	41.61	-0.384	4.92
	Mbalmayo	TGX 1910-14 F	39.30	0.446	0.070	3924.72	24.84	-0.316	4.41
		TGX 2001-24DM	45.23	0.820	< 0.0001	3513.67	65.50	-0.724	5.00
Square root	Foumbot	TGX 1910-14 F	22.47	0.625	0.012	3898.77	-37.29	353.53	4.74
		TGX 2001-24DM	34.33	0.794	0.001	3700.80	-35.28	413.42	4.91
	Mbalmayo	TGX 1910-14 F	18.39	0.354	0.140	3939.66	-29.39	252.04	4.48
		TGX 2001-24DM	24.05	0.780	0.001	3473.15	-66.10	648.32	5.06

4. Conclusion

From the results, it is possible to conclude that rock phosphate fertilizer had a significant effect on soybean yield and yield components in these soils. Soybean varieties responded slightly different to the P fertilizer applied. The highest pod and seed number, and total aboveground dry weight were recorded by T2 * TGX 1910- 14 F interaction at both locations while the highest grain yield and net income were obtained by T2 * TGX 2001- 24 DM interaction at both sites. The square root model better described the yield responses with average optimum P fertilizer recommendation of 29.41 kg / ha which range between 18.39 – 34.33 kg

P/ ha. These findings can be used to optimize RP fertilizer application in acid soils with the potential to increase grain yields and reduce environmental risks due to excessive P use and losses.

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