academicresearchJournals

Vol. 3(10), pp. 281-288, October 2015
DOI: 10.14662/ARJASR2015.057

ISSN: 2360-7874
http://www.academicresearchjournals.org/ARJASR/Index.htm

Academic Research Journal of Agricultural Science and Research

Full Length Research

Response of Soybean [*Glycine max* (L.) Merrill] to Phosphorus Fertilizer Rates in Ferralsols

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Accepted 29 August 2015

A field experiment was conducted during cropping season of 2012-2013 in Angónia District, central Mozambique, to evaluate the response of soybean [Glycine max (L.) Merrill] to rates of Phosphorus fertilizers. The study was laid out as randomized complete block design with four replications. The treatments consisted of P rates of 0, 20, 40 and 60 kg P2O5 ha-1 as Single super phosphate (SSP), with 16% P2O5 content. The results showed that the plant height, the height to the 1st pod, number of pods, biomass yield, weight of 100 seeds, grain yield, number of nodules and weight of nodules were significantly affected by the treatments. The highest plant height was observed at rate of 60kg P2O5 ha-1 (76.40 cm; p=0.0015). The highest height to the insertion of 1st pod was observed with application of 20kg P2O5 ha-1 (19.35 cm; p=0.0323). The treatment of 40 kg P2O5 ha-1 presented significantly higher number of pods per plant (44.68 pods plant-1; p=0.0101). The highest weight of 100 seeds was observed with 60 kg P2O5 ha-1 (13.71 grams; p=0.0318). The highest biomass and grain yields were observed with the rate of 60 kg ha-1 P2O5 (8.92 t ha-1; p=0.0078; and4.29 t ha-1; p=0.0089, respectively). The highest number of nodules (41.35 nodules; p<0.0001) and the highest nodule weight (521.70 grams nodules; p=0.0003) were observed with the rate of 60 kg ha-1 P2O5. Thus, it should be recommended for soybean fertilization in Ferralsols under Angónia's agro-ecological conditions.

Keywords: Soybean [Glycine max (L.) Merrill], Grain Yields, Phosphorus rates, Ferralsols

INTRODUCTION

Soybean [*Glycine max* (L.) Merrill] is the world's leading source of protein and oil. It has the highest protein content of all food crops and is second only to groundnut in terms of oil content among grain leguminous crop (Ikeogu and Nwofia, 2013). It also contributes to the improvement of soil fertility through biological nitrogen fixation (Sanginga *et al.,* 2002). The spread of soybean crop from its native land of origin has been mainly due to its adaptability and predominant use as a food crop for human nutrition, source of protein for animals, medicinal plant and lately as an industrial crop (Ikeogu and Nwofia, 2013).

Nevertheless, the crop is relative new under traditional cropping systems of Sub-Saharan Africa (Sanginga *et al.,* 2002). In the Angónia Plateau of central Mozambique, the soybean production is increasingly being practiced by smallholder farmers, but the yields are still lower than the reported yields in the Sub-Saharan Africa region. Some of the highlighted constraints in the current attempts for the successful incorporation of soybean crop in to the cropping system of these zones are soil related constraints such as low pH, nutrient deficiencies (phosphorus, nitrogen, potassium, molybdenum and sulphur), and toxic levels of some metals like aluminium iron, and manganese (Ikeogu and Nwofia, 2013; Rubaihayo *et al.,* 2000), and agronomy related constraints such as luck of improved varieties (Ikeogu and Nwofia, 2013).

Soybean, like all other nitrogen fixing leguminous crops, requires P for its proper growth and N fixation, soybean's effective contribution on soil fertility improvement can be inhibited due to P deficiency (Giller and Cadish 1995). Legumes are especially sensible to low P availability because the biological nitrogen fixation requires high levels of P. The P deficiency can limit the nodules formation while the P fertilization can overcome the deficiency (Carsky *et al.,* 2001). Soils that fix P can severely affect the yields of crops and the P fixation in the soils increases with the time of contact between soluble phosphates and soil particles. Most of legume crops develop poorly under low soil fertility conditions; especially where the acid conditions of the soils makes free oxides of Fe and Al to react with soil P forming insoluble compounds, thus not allowing its availability in the soil (Bationo *et al.,* 2011).

Recent studies conducted in similar agroecological regions as Angónia Plateau revelled positive response and lack of response of soybean varieties to moderate P application of 30 kg P_2O_5 ha^{-1} and inoculation with rhizobia was also noted (N2 Africa, 2011). Compared to the control treatment (0kg ha^{-1} P and without application of inoculants), the grain yield in soils with moderate fertility increased from 0.8 t ha^{-1} to 1.5 t ha^{-1} with inoculants application and then to 2 t ha^{-1} when inoculants and P where applied. However, there was no clear response of P and inoculants application in acidic soils, similar to ones of Angónia Plateau. In this region, apart from the soils being acidic, information about the response of soybean crop to phosphorus fertilizer rates is lacking. Thereby, this study is intending to evaluate the response of soybean crop to different levels of phosphorus fertilizer.

MATERIALS AND METHODS

Study area

The experiment was carried out at N'tengo-Umondzi research station in Angónia district (Figure 1), Tete province of Central Mozambique, which occupies an area of 3,277 km^2 and population of 330,378 habitants. The experimental site lies within S14˚32.205' E034˚09.664' and at the altitude of 1655 m above the sea level. Table 1 shows the soil characteristics of the experimental site. The district is covered by humid temperate climate strongly influenced by altitude. It shows a wide variation of rainfall, 725 mm to 1149 mm, with most of the rainfall (about 90%) going from late November to early April. The standard temperature is conditioned by altitude, which ranges from 700 m to 1655 m, with an average temperature of 20.9°C. The topography is dominantly very undulating to dissected, and that occurs piecemeal being geographically located in the complex areas of Marávia-Angónia (Government of Mozambique, 2005). Rainfall and Temperature data for the cropping seasons of 2012/2013 in which the experiment was conducted are presented in Figure 2 and Figure 3.

Experimental design and management

Before planting, soil samples from the experimental sites were collected at 0 to 15 cm depth for analysis of organic carbon, total nitrogen using standard methods (Okalebo *et al.,* 2002), extractable P, Ca, Mg, K, Na using Mehlich-1 (M1) extraction method, where P and Mg^{2+} were determined colourimetrically in a spectrophotometer and Ca^{2+}, and K^+ were determined using flame photometer. The experiment was established at N'tengo-Umondzi Research Station (Angónia district) in a Randomized Complete Block Design with four replications and plots measuring 9mx2m (18m^2) with four treatments, 0 kg P_2O_5 ha^{-1}, 20 kg P_2O_5 ha^{-1}, 40 kg P_2O_5 ha^{-1}, and 60 kg P_2O_5 ha^{-1} as Single Super Phosphates (Table 2). Before planting, the land was ploughed to a depth of 25 cm using manual hoe. The test crop was Soybean [*Glycine max* (L.) Merrill] variety TGX-1740-2F, planted in a spacing of 50cmx10cm on December 13th, 2012. The fertilizer was applied in rows at planting time accordingly to the treatments.

Soybean harvest and yields

Soybean grain and stover was harvested at maturity from a net area of each treatment demarcated after leaving out two rows on each side of the plot and the first two and the last two plants on each row to minimize the edge effect. The entire plants on the plots was harvested by cutting at the ground level and weighted to represent the total fresh weight. Soybean pods were manually separated from the stover, sun-dried, and packed in sacks before threshing. After threshing, moisture content of the grains was determined using a moisture meter and grain yield adjusted to 12 percent moisture content using the following formula. Similarly, yields and harvest index were calculated using the following formulas:

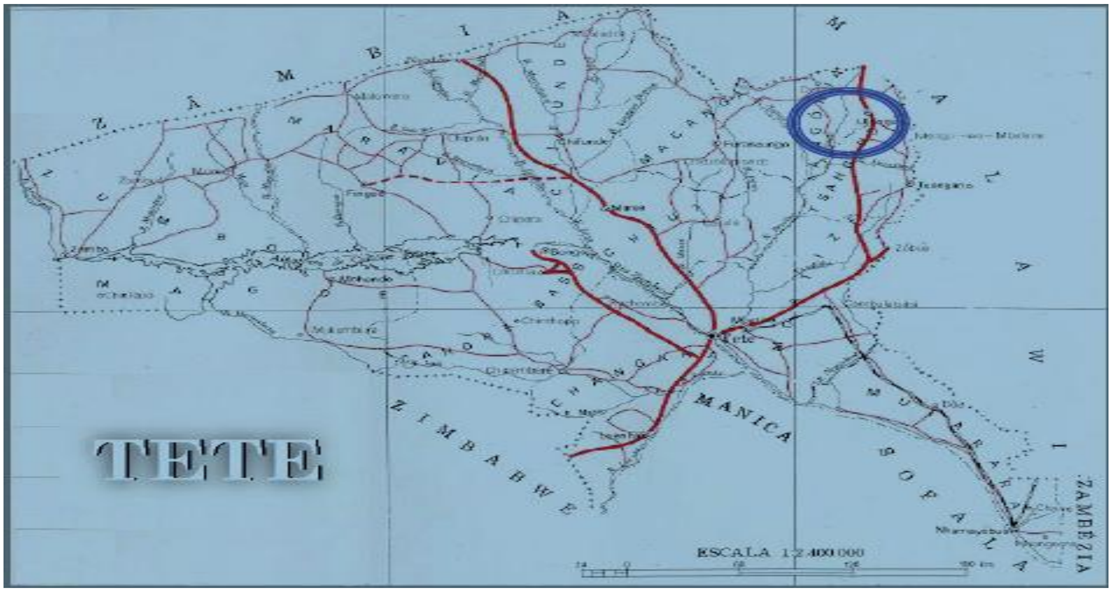

Figure 1: Map of the experimental site.

Table 1: Soil characteristics at experimental site

Soil parameter	Experimental site
pH in water (1:2.5)	5.78
pH in KCl	4.71
Available N (mg kg^{-1})	14.44
Available P (mg kg^{-1})	4.84
Exchangeable K (mg kg^{-1})	186.10
Exchangeable Ca (mg kg^{-1})	614.06
Exchangeable Mg (mg kg^{-1})	140.81
Exchangeable Na (mg kg^{-1})	8.41
Total soil organic Carbon (%)	1.12
Organic Matter (%)	1.93
Soil density (g/cm^3)	1.26

$$Adjusted\ yield = measured\ yield * \frac{(100 - sample\ moisture\ content)}{(100 - standard\ moisture\ content)} \quad (1)$$

$$Yield\ (t/ha) = 10 * \frac{Dry\ weight\ (kg/m^2)}{Net\ area\ (m^2)} \quad (2)$$

$$Harvest\ Index\ (HI)(\%) = \frac{Grain\ yield\ (t/ha)}{Total\ biomass\ yield\ (t/ha)} * 100 \quad (3)$$

Data analysis

Data of soybean yields and growth parameters were subjected to analysis of variance using SAS version 9.0 to test for significant differences between different treatments, the yields were subjected to *t-student* test at 95 percent of significance level ($p < 0.05$).

RESULTS AND DISCUSSION

Effects of P fertilizer rates on soybean growth parameters

Based on the table 3, it was noted that the P fertilization

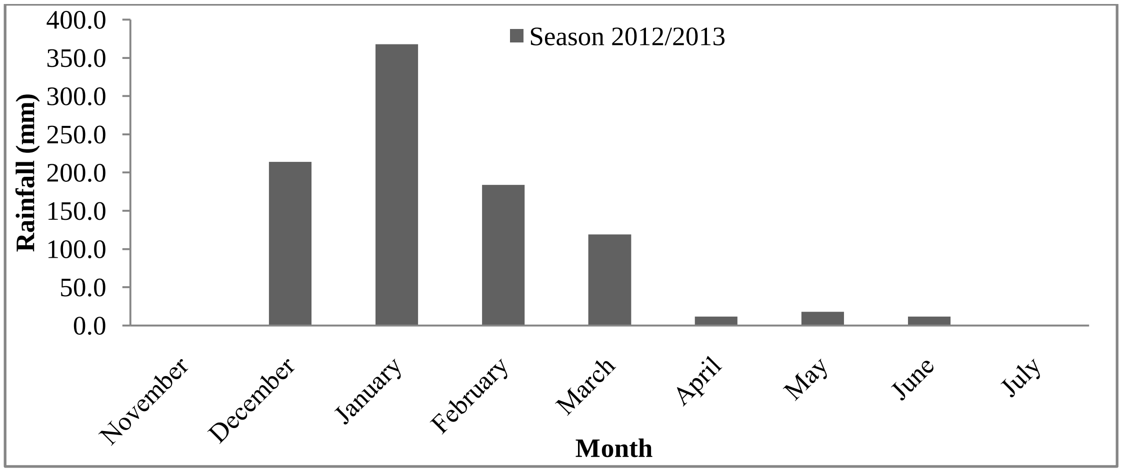

Figure 2: Rainfall amount in 2012/2013 at N'tengo-Umodzi site, Mozambique

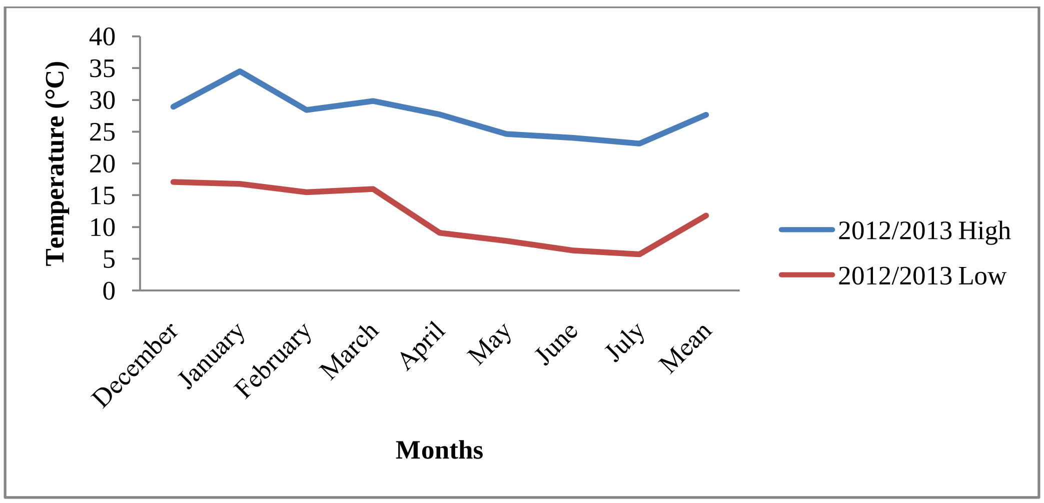

Figure 3: Temperature in 2012/13 at N'tengo-Umodzi site, Mozambique

Table 2: Treatment description

Treatment		Abbreviation	Description of treatments
1.	Control – 0kg	P0	0 kg ha^{-1} P_2O_5
2.	Single Super Phosphate – 20kg	P20	20 kg ha^{-1} P_2O_5
3.	Single Super Phosphate – 40kg	P40	40 kg ha^{-1} P_2O_5
4.	Single Super Phosphate – 60kg	P60	60 kg ha^{-1} P_2O_5

Table 3: Effects of P fertilizer rates on plant height and height to the insertion of 1st pod

Traetment	Plant height (cm)	Height to the insertion of 1st pod (cm)
0 kg ha^{-1} P_2O_5	43.30	12.65
20 kg ha^{-1} P_2O_5	56.90	19.35
40 kg ha^{-1} P_2O_5	73.60	18.85
60 kg ha^{-1} P_2O_5	76.40	18.85
p-value	0.0015**	0.0323*
$LSD_{(0.05)}$	13.99	5.84

* Significant at $p \leq 0.05$; **significant at $p \leq 0.001$.

rates affected significantly both the plant height (p=0.0015) and the height to the insertion of 1st pod (p=0.0323). The highest plant height was observed at rate of 60kg P_2O_5 ha^{-1} (76.40 cm; p=0.0015) which was significantly different to the control (43.30 cm; p=0.0015); the level of 20kg P_2O_5 ha^{-1} was not significantly different to the control treatment. Contrary, the highest height to the insertion of 1st pod was observed with application of 20kg P_2O_5 ha^{-1} (19.35 cm; p=0.0323) which was significantly different to the control treatment (12.65 cm; p=0.0323).

Similarly, to the results reported in this study, in Brazil Martins and Pitelli (2000) found that the plant height increased with application of 30 kg ha^{-1} de P_2O_5. In Nigeria Chiezey and Odunze (2009), reported increase in plant height and leaf area index after application of 39.6 kg P_2O_5 ha^{-1}. In Iran Mahamood *et al*. (2013), reported linear and significative increase of plant height with increases of P levels up to 90 kg P_2O_5 ha^{-1}. The application of P has important role in vegetative growth (Fatima *et al*., 2007). Other researchers reported increase in plant height due to application of different rates of P fertilizer (Piri *et al.,* 2012; Mahamood *et al.,* 2009; Israel, 1987). Contrarily, Segatelli (2004) did not find significant differences in plant height after applying 36 kg P_2O_5 ha^{-1} as single super phosphate.

Differently to the results gotten in this study, *et al*. (2010) and Valadão Júnior *et al*. (2008) did not find significant differences in the height to the insertion of 1st pod due to the variation of rates of single super phosphate. Shigihara and Hamawaki (2005), considered that adequate heights vary between 10 and 15 cm, and varieties with height to the insertion of 1st pod higher than 15 to 20 cm makes easy the harvesting process and results in less losses. The height to the insertion of 1st pod can be a particular characteristic of the variety, therefore, if the planting is done in regions with short days, the plant height shorter and the pods development tend be close to the ground (Shigihara and Hamawaki, 2005).

Effects of P fertilizer rates on yield parameters

The results showed that the number of pods per plant was significantly affected by the treatment (p=0.0101) (Table 4). The treatment of 40 kg P_2O_5 ha^{-1} presented significantly higher number of pods per plant (44.68 pods $plant^{-1}$; p=0.0101) compared to all other treatments, except the 60 kg P_2O_5 ha^{-1}. Similarly, in South Africa Mokoena *et al*. (2012) found that the number of pods per plant was significantly affected by the levels of P applied. In Brazil Segatelli (2004), reported significant differences in number of pods per plant after the application of 36 kg ha^{-1} P_2O_5. In Kenya Mugendi *et al*. (2010), reported significative increase in number of pods with application of 50 kg ha^{-1} P_2O_5. In Iran Mohmoodi *et al.* (2013) found significant differences in number of pods with variation in P levels.

The number of seeds per pod was not significantly affected by the treatments (p=0.2343). Nevertheless, the 60 kg P_2O_5 ha^{-1} treatment observed numerically the highest number of seeds per pod (2.39 seeds pod^{-1}; p=0.2343) in relation to all other treatments; whereas, the control treatment observed the lowest number of seeds per plant with 2.13 seeds pod^{-1} (p=0.2343). Guareschi *et al*. (2011) also did not find significant differences in number of seeds per pod after varying P rates.

The weight of 100 seeds was significantly affected by the treatments (p=0.0318). The treatment control (0 kg P_2O_5 ha^{-1}) observed significantly the lowest weight of 100 seeds (12.29 grams; p=0.0318) in relation to the other treatments, excepting the treatment of 20 kg P_2O_5 ha^{-1}. The highest weight of 100 seeds was observed with 60 kg P_2O_5 ha^{-1} (13.71 grams; p=0.0318) (Table 4). In India Devi *et al.* (2012) also found significant differences in weight of 100 seeds when varying the levels of P fertilizer. Simarly, increase in weight of 100 seeds with variation on P fertilizer was reported by Anchal *et al.* (1997), Chauhan *et al.* (1992), Singh and Hiremath (1990), and Kar *et al*. (1989). To improve growth and development of plants due to supply P can be increased with the supply of assimilates to the seed, which finally gained more weight (Devi *et al*., 2012).

Effects of P fertilizer rates on biomass and grain yields

The biomass yield was significantly influenced by the treatments (p=0.0078). The highest biomass yield was observed with the rate of 60 kg ha^{-1} P_2O_5 (8.92 t ha^{-1}; p=0.0078) which was significantly different from the control treatment and the rate of 20 kg ha^{-1} P_2O_5 (Table 5). Similarly, in India Devi *et al.* (2012) reported significant differences in biomass yield when varied the levels of Phosphorus. In Nigeria, Chiezey and Odunze (2009) reported significant increases in biomass yield after varying the levels of P. In RSA, Mabapa *et al.* (2010) observed increase in above ground biomass after applying 60 kg ha^{-1} P_2O_5.

Still according to the Table 5, the treatments influenced significantly the grain yields; and the rate of 60 kg ha^{-1} P_2O_5 observed the highest yield (4.29 t ha^{-1}; p=0.0089) than all other treatments. Similar results were also reported by several researchers (Kamara *et al*.; 2011; Mugendi *et al*., 2010; Mahamood *et al*., 2009; Chiezey and Odunze, 2009; Kamara *et al*., 2008; Kamara *et al*., 2007).

Table 4: Effects of P fertilizer rates in nr of pods, number of seeds per pod, and weight of 100 seeds

Treatment	Nr of pods plant^{-1}	Nr of seeds pod^{-1}	Weight of 100 seeds (gr)
0 kg ha^{-1} P_2O_5	23.73	2.13	12.29
20 kg ha^{-1} P_2O_5	25.23	2.24	12.94
40 kg ha^{-1} P_2O_5	44.68	2.16	13.39
60 kg ha^{-1} P_2O_5	41.63	2.39	13.71
p-value	0.0101**	0.2343ns	0.0318*
$LSD_{(0.05)}$	13.17	0.2833	0.9186

ns – Not significant; * significant at $p \leq 0.05$; **significant at $p \leq 0.001$.

Table 5: Effects of P fertilizer rates on biomass and grain yields

Traetment	Biomass yield (kg ha^{-1})	Grain yield (kg ha^{-1})
0 kg ha^{-1} P_2O_5	3.81	2.00
20 kg ha^{-1} P_2O_5	6.09	2.45
40 kg ha^{-1} P_2O_5	7.41	2.97
60 kg ha^{-1} P_2O_5	8.92	4.29
p-value	0.0078**	0.0089**
$LSD_{(0.05)}$	2.5162	1.18

**Significant at $p \leq 0.001$.

Table 6: Effects of P fertilizer rates on nr of nodules and nodule weight

Traetment	Nr of nodules	Nodule weight (grams)
0 kg ha^{-1} P_2O_5	8.55	202.40
20 kg ha^{-1} P_2O_5	13.45	222.15
40 kg ha^{-1} P_2O_5	22.10	353.10
60 kg ha^{-1} P_2O_5	41.35	521.70
p-value	<0.0001***	0.0003**
$LSD_{(0.05)}$	8.83	106.62

**Significant at $p \leq 0.001$; ***significant at $p \leq 0.0001$;

Effects of P fertilizer rates on biological nitrogen fixation N_2

Both the number of nodules and the weight of nodules were significantly affected by the treatments (p<0.0001 e p=0.0003, respectively). The highest number of nodules (41.35 nodules; p<0.0001) was observed with the rate of 60 kg ha^{-1} P_2O_5, which was significantly different than other treatments (Table 6). The highest nodule weight nodule (521.70 grams nodules; p=0.0003) was observed with the rate of 60 kg ha^{-1} P_2O_5, which was significantly higher than the other treatment (Table 6). Similarly, the effects of P fertilizer in improvement of biological nitrogen fixation have been several reported in other studies. For instance, in Kenya Mugendi *et al*. (2010) observed increase in nodule weight with the increase in doses P fertilization. In Nigeria, Amba *et al*., (2011), Chiezey and Odunze (2009), and Ogoke *et al.,* (2004) reported increases in number of nodules after varying levels of P fertilizer.

CONCLUSIONS

From the results of this experiment it can be concluded that the treatment influenced significantly all the evaluated parameters. The application of 60 kg P_2O_5 ha^{-1} showed significantly higher plant height, higher height to the insertion of 1st pod, higher 100 seeds weight, higher biomass and grain yields, higher nodules number, and higher nodule weight.

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