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Comparative Assessment of Phosphorus Fertilization and Rhizobia Inoculation on Soybean Production in the Guinea Savanna Zone of Ghana

Sam Ebenezer Kofi*
Faculty of Agriculture, University for Development Studies, Ghana

Kugbe Xorse Joseph
Faculty of Agriculture, University for Development Studies, Ghana

Adu-Gyamfi Raphael
Faculty of Agriculture, University for Development Studies, Ghana

Odoom Asooming Daniel
Faculty of Agriculture, University for Development Studies, Ghana

Laryea Obodia Kenneth
Faculty of Agriculture, University for Development Studies, Ghana

Asodewine Peter
Faculty of Agriculture, University for Development Studies, Ghana

Abstract

In the Guinea savannah zone of northern Ghana, the soils are reported to be declining for agricultural productivity. In these farming communities that depend on soybean production for their livelihoods, resource-poor farmers are not able to afford purchases of high cost inorganic phosphatic fertilizers to enhance the crop's production. The need arises to identify efficient practices and strategies and research into alternative means of enhancing soybean production to improve food security. This Randomized Complete Block Design as an experimental tool was employed to carry out a research in the Guinea savanna zone of Ghana (Tolon District) to assess the agronomic and economic productivity of rhizobia inoculation use in soybean production. Treatments used for the experiment were sole soybean production, soybean + recommended phosphorus (P) fertilize rate, soybean + inoculums, and soybean + P + inoculum. A planting distance of 60*10cm was used during planting. Each treatment was replicated three times. Growth and yield data were collected on plant height, nodule number and dry weight, shoot dry weight, pods number and dry weight, grain yield, 100 seed weight and nodule effectiveness. The results revealed the existence of significant difference in grain yield between treatments ($p = 0.011$). Soybean + inoculation + P gave the highest yield of 3.6 t/ha followed by soybean + inoculation (3.17 t/ha), soybean + P (2.97 t/ha) and soybean only (2.6 t/ha) respectively. Significant difference was also observed for number of pods between treatments ($p= 0.01$), with soybean + inoculation + phosphorus recording the highest followed by soybean + inoculation, soybean + phosphorus and soybean-only treatment respectively. However, use of sole inoculation in soybean production was associated with the least production cost, high revenue generation and high benefit/cost ratio. As rhizobia inoculation of soybean produced higher yields and is comparatively cheaper than phosphorus application, inoculation is suggested for the resource poor farmer in Northern Ghana.

Keywords: Soybean; Comparative; Phosphorus; Fertilization; Inoculation.

1. Introduction

Soya bean (*Glycine max* (L.) Merrill) is an important global legume crop that cultivates in the tropical, subtropical and temperate climates. According to Dugje, *et al.* [1], soybean contains more protein than any of the common vegetable or legume food in Africa. Edible oil can also be derived from soya bean and its also considered as a promising pulse crop proposed for the alleviation of acute shortage of protein and oil worldwide [2]. In the guinea savanna zone of Ghana, promotion of the nutritional and economic values of the crop is being done by the Ministry of Food and Agriculture, and this has resulted in rapid expansion in production [3]. Across this region, the crop has become a major source of high quality and cheap protein for the resource-poor and rural households, necessitating the need to improve upon the crops production to satisfy the ever increasing consumption.

Application of phosphatic fertilizers to soybean fields improves the crops' performance [2]. Inadequate soil P has been observed to restrict the plant's root growth, nodulation, yield, as well as the process involved in photosynthesis, and other activities which directly influence N fixation by the crop [4-6]. For this reason, phosphorus application to soy fields is strongly recommended in P-deficient soils [2]. While P fertilization can increase the yield of soybean, farmers across northern Ghana are resource-poor and mostly lack the means for the purchase of P

*Corresponding Author

fertilizers. In situations that farmers can afford the P fertilizers, lack of means to transport the bulky fertilizer to the farm-fields also hinder fertilizer application and adds to the cost of production. Decreasing cost of production while increasing yield is therefore a solution to sustained soybean production in this resource-poor savannah region.

Over the years, the practice of inoculation or coating of soybean seeds with rhizobia before planting has been reported [7]. Numerous studies have shown the existence of synergistic effect of rhizobial inoculation and phosphorous application on growth and yield of the crop [8]. Though such P-nutrition and rhizobia-inoculation technologies have been developed, the current yield of about 1.5 t/ha across the Guineas savanna zone of Ghana is still below the achievable yield of 4.6 t/ha [9]. It has been proposed, that a combined application of phosphatic fertilizer and rhizobia inoculation will increase the yield and yield parameters of the crop [2]. Across this region, such data is limited to support the claim. In this research therefore, we aimed to evaluate and compare the impact of P-fertilization and rhizobia inoculation on the productivity of soybean to inform productive decision for smallholder resource-poor farmers in the guinea savanna zone of Ghana.

2. Materials and Methods

2.1. Study Area

The research was carried out in Nyankpala from July to October 2013. Nyankpala is located about 16 km west of Tamale and lies on latitudes N 09°24' 15.9" and longitude W 01°00' 12.1' of the interior Guinea Savanna agro-ecological zone of Ghana. Rainfall across the region is unimodal and starts from April – May; builds up slowly to a height in August-September before declining sharply in October-November. The total precipitation is about 1,100 mm per annum, with a range of 800 mm to about 1,500 mm. Average ambient temperatures are high year round (about 28°C) but the harmattan months of December and January are characterized by minimum temperatures that may fall to 13°C at night. Geologically, the area consists of proterozoic rocks which differ in lithology and degree of metamorphism. Granite and metamorphic rocks are the main rock types and include biotite schists, biotite-hornblande gneisses, garnet-hornblende and garnet-biotite gneisses and schists. Others include: Albite-chlorite, sericite-quartz schists with interbedded acid tuffs, manganiferous phyllites and sandstones. The soil consists of laterites and are mostly Savannah Ochrosols and Luvisols/Lixisols (World Reference Base for Soil Resource; ISSS/ISRIC/FAO 1998).

2.2. Experimental Design and Treatments

Randomized Complete Block design was used for the experiment and replicated 3 times. Each plot measured 10 m X 10 m with 1 m alley between replications and 0.5 m alley within reps or between plots. Total field size measured 41.5 m X 32 m. The treatments used were: Soybean only, Soybean + inoculums + P, Soybean + inoculum, and Soybean + P.

2.3. Seed Inoculation

Inoculation of seeds was done using slurry method outlined by Woomer, *et al.* [10]. The seeds of the Jenguma soybean variety, weighing 1 kg were used. Inoculation was done, using water as adherent. The seeds and inoculum were placed in a bowl and mixed judiciously until seeds were covered with black film of inoculants. The treated seeds were allowed to dry for a few minutes after which they were planted. The inoculation was done at the rate of 5 g of legume fix inoculant per 1 kg of seed.

2.4. Land Preparation and Planting

Prior to planting, the land was ploughed and harrowed using a tractor. Planting was done at a planting distance of 60 X 10 cm.

2.5. Cultural Practices

2.5.1. Fertilizer Application

About 60 kg/ha of triple superphosphate was applied to plots that received phosphorus treatments, 5 days before planting. After application, the fertilizer was incorporated into the soil manually with the use of a hoe as would have been done by the resource-poor farmers in the area.

2.5.2. Weeding

Weeding was done on the 2nd, 4th and 6th weeks after planting to control weeds.

2.6. Data Collection

2.6.1. Number of Nodules Per Plant and Nodule Dry Weight

Ten plants from the two middle rows were randomly selected and gently dug out at 8 weeks after planting. The plants were then washed through a fine sieve with water to remove soil particles and organic debris. The number of nodules on each plant was then determined and the average nodule number per plant calculated. The nodules were oven dried at 65°C for 72 hours. The dry nodules were then weighed and nodule dry weight recorded.

2.6.2. Determination of Shoot Dry Weight

Ten plants were randomly selected from each plot and cut at the ground level for shoot dry matter determination at 8 WAP. An electronic balance was used to measure the total fresh shoot weight. After weighing, the materials were then wrapped in brown envelopes and oven dried at 65^{o}C for 72 hours. Shoot dry weight was then recorded after weighing.

2.6.3. Pod Number per Plant and Pod Yield

In order to attain the number of pods from the net harvest area, ten plants were indiscriminately selected by picking every 5th plant in the two inner rows. The pods were counted. Pods from teach plot were then added weighed to get pod weight in grams. This was then extrapolated to obtain total pod yield on a per hectare basis.

2.6.4. Grain Yield and Mean Hundred Seed Weight

Electronic balance was used to weigh the grains n per plot basis after threshing the harvested pods in the harvest area and converted to yield per ha. Hundred seeds from each treatment were unsystematically selected and weighed. This was replicated three times and 100-seed weight determined by finding the average.

2.7. Statistical Analysis

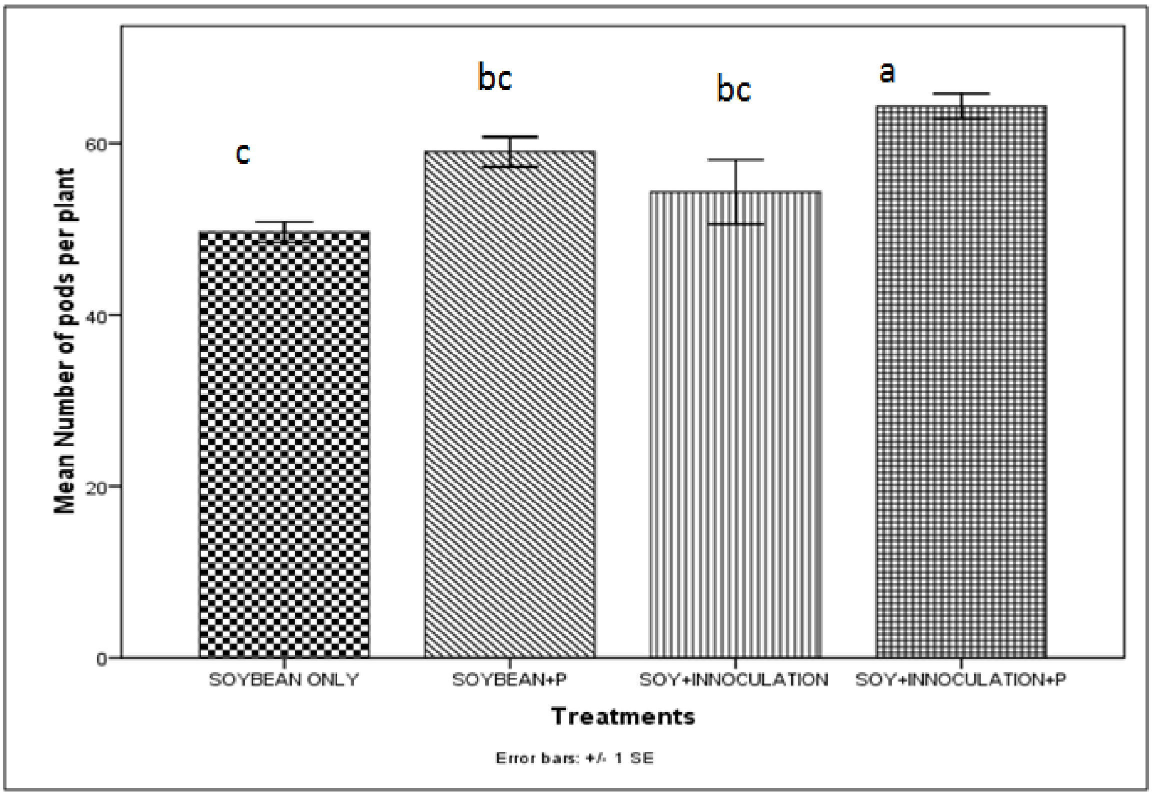
Data collected were subjected to statistical analysis using the SPSS statistical package. The analysis of variance procedure was followed to determine differences in means among treatments. Treatment means were matched using the Duncan's multiple range tests at 5 % level of significance.

3. Results and Discussion

3.1. Impact of Inoculation and Phosphorus Fertilization on Number of Pods of Soybean in the Guinea Savanna Zone

The treatments significantly affected the number of pods formed (*p = 0.01*). Inoculation plus phosphorus application recorded the highest pod number (Figure 1). Application of phosphorus as a sole treatment resulted in an increase in pod number than sole inoculation. The result also shows that application of either phosphorus or inoculum and in combination enhances podding more than sowing soybean alone.

Figure-1. Effects of phosphorus fertilization and rhizobia inoculation on number of pods of soybean grown in the Guinea savanna zone of Ghana. Bars represent the standard error of mean



3.2. Impact of Inoculation and Phosphorus Fertilization on Hundred Seed Weight, Seed Number per Pod and Grain Yield in Soybean Production in the Guinea Savanna Zone of Ghana

No significant differences were observed between the various treatments for the mean seed weight and number of seeds per pod (Figure 3 and 4). However, inoculated seeds recorded the higher hundred seed weight than seeds that were not inoculated (Figure 3). Hundred (100) seed weight (Figure 3), number of seeds per pod (Figure 4), and number of pods per plant (Figure 1) are significant yield contributing constituents.

Figure-2. Effects of phosphorus fertilization and rhizobia inoculation on grain yield of soybean grown in the Guinea savanna zone of Ghana. Bars represent the standard error of mean

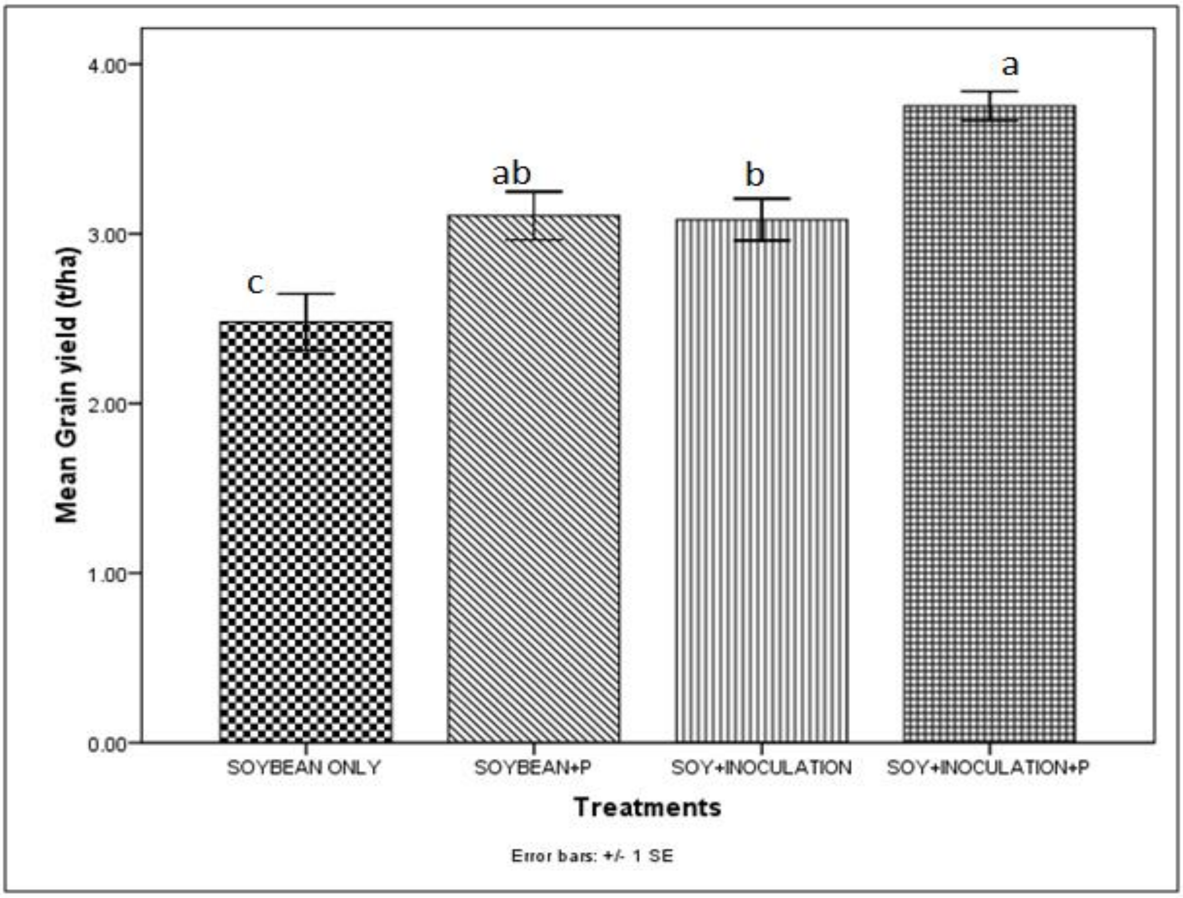


Figure-3. Effects of phosphorus fertilization and rhizobia inoculation on mean 100 seed weight of soybean grown in the Guinea savanna zone of Ghana. Bars represent the standard error of mean

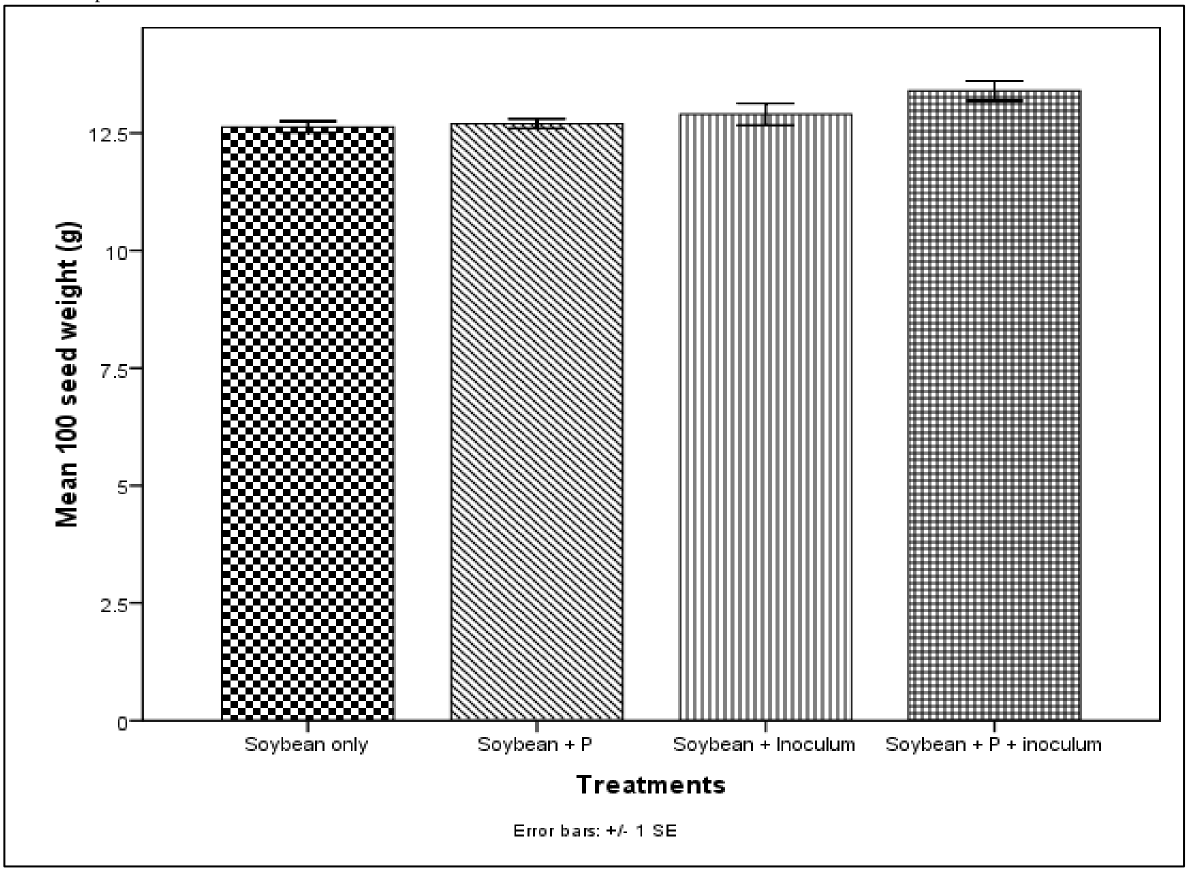
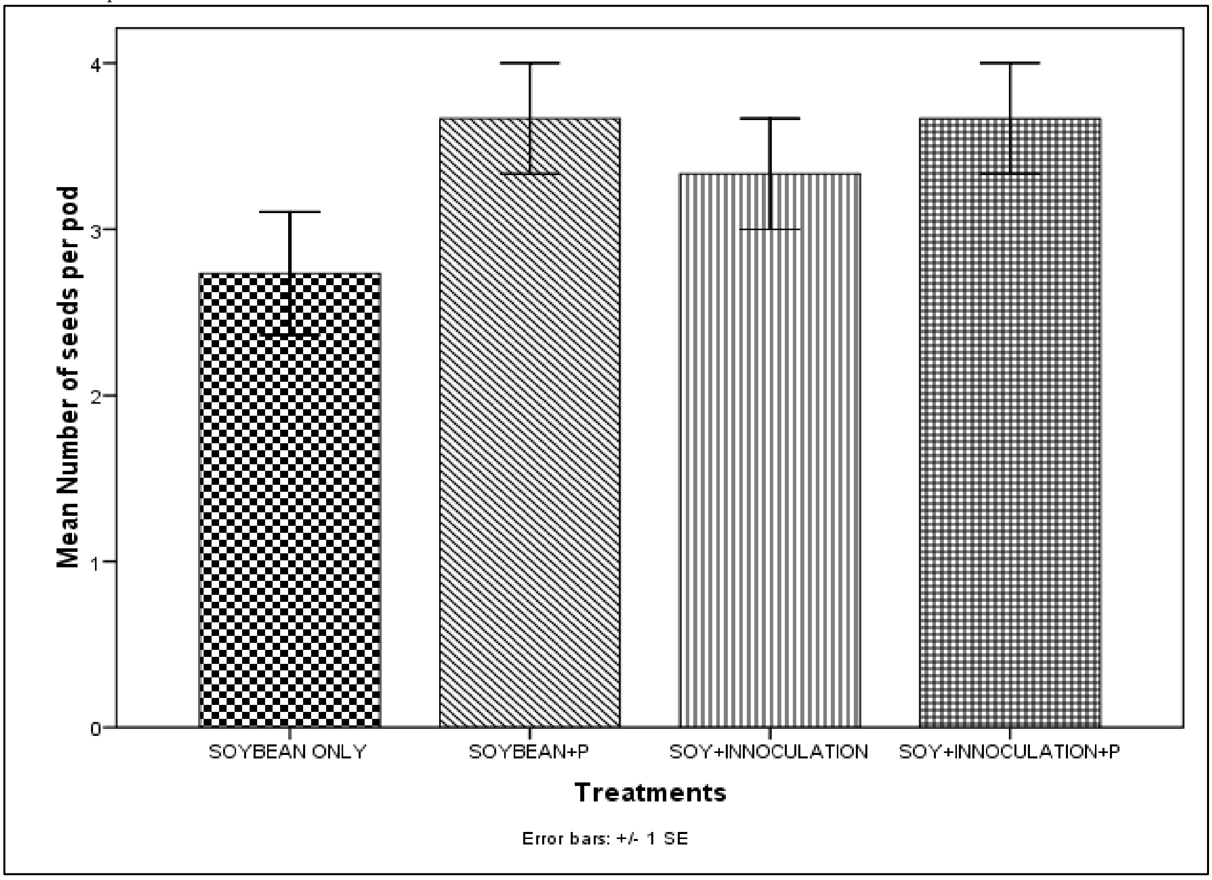


Figure-4. Effects of phosphorus fertilization and rhizobia inoculation on mean number of seeds of soybean grown in the Guinea savanna zone of Ghana. Bars represent the standard error of mean



3.3. Impact of Inoculation and Phosphorus Fertilization on Nodule Effectiveness, Nodule Number and Nodule Dry Weight of Soybean Grown In the Guinea Savanna Zone of Ghana

The results of this experiment showed substantial difference in nodule effectiveness among the treatments (*p = 0.037*). The application of both inoculant and phosphorus to soybean production significantly increased nodule effectiveness compared to the untreated control (Figure 5). However, sole application of either inoculum or phosphorus fertilizer did not significantly differ from the combined treatment (Figure 5).

Figure-5. Effects of phosphorus fertilization and rhizobia inoculation on nodule effectiveness of soybean grown in the Guinea savanna zone of Ghana. Bars represent the standard error of mean

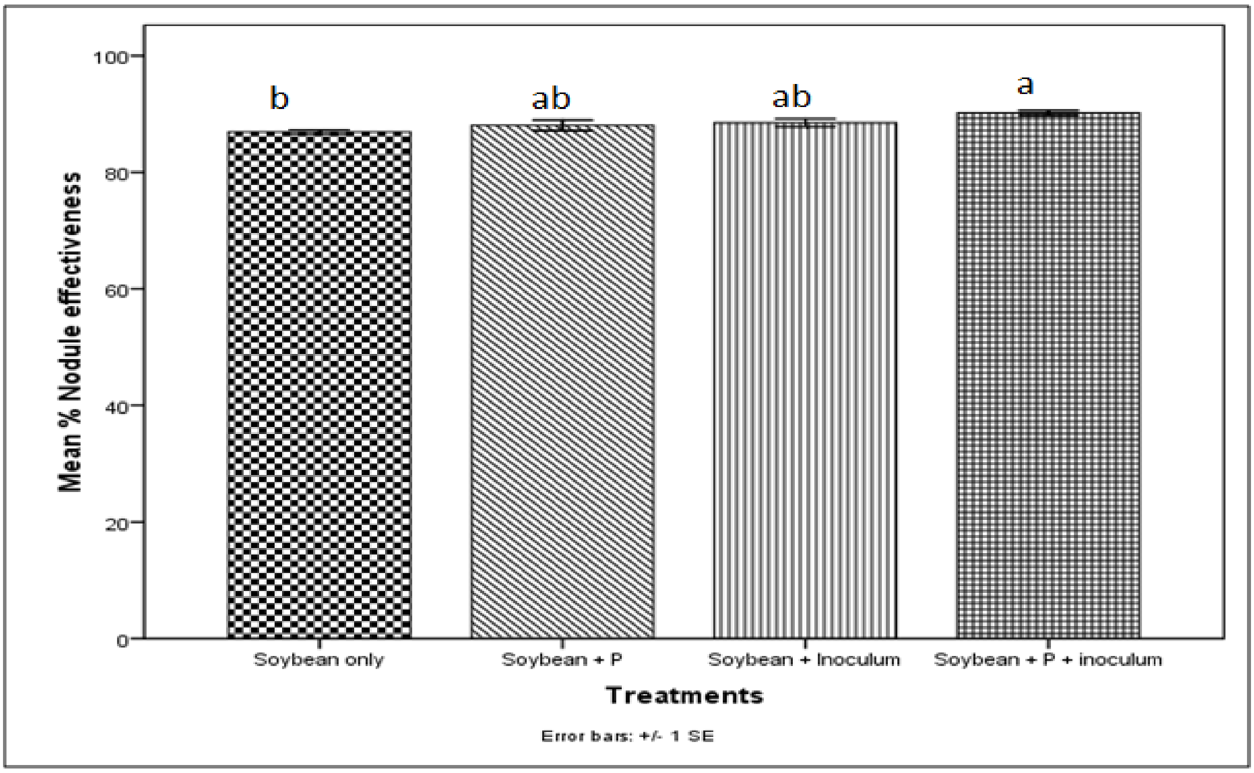


Figure-6. Effects of phosphorus fertilization and rhizobia inoculation on nodule number in Nyankpala in the Guinea savanna zone of Ghana. Bars represent the standard error of mean

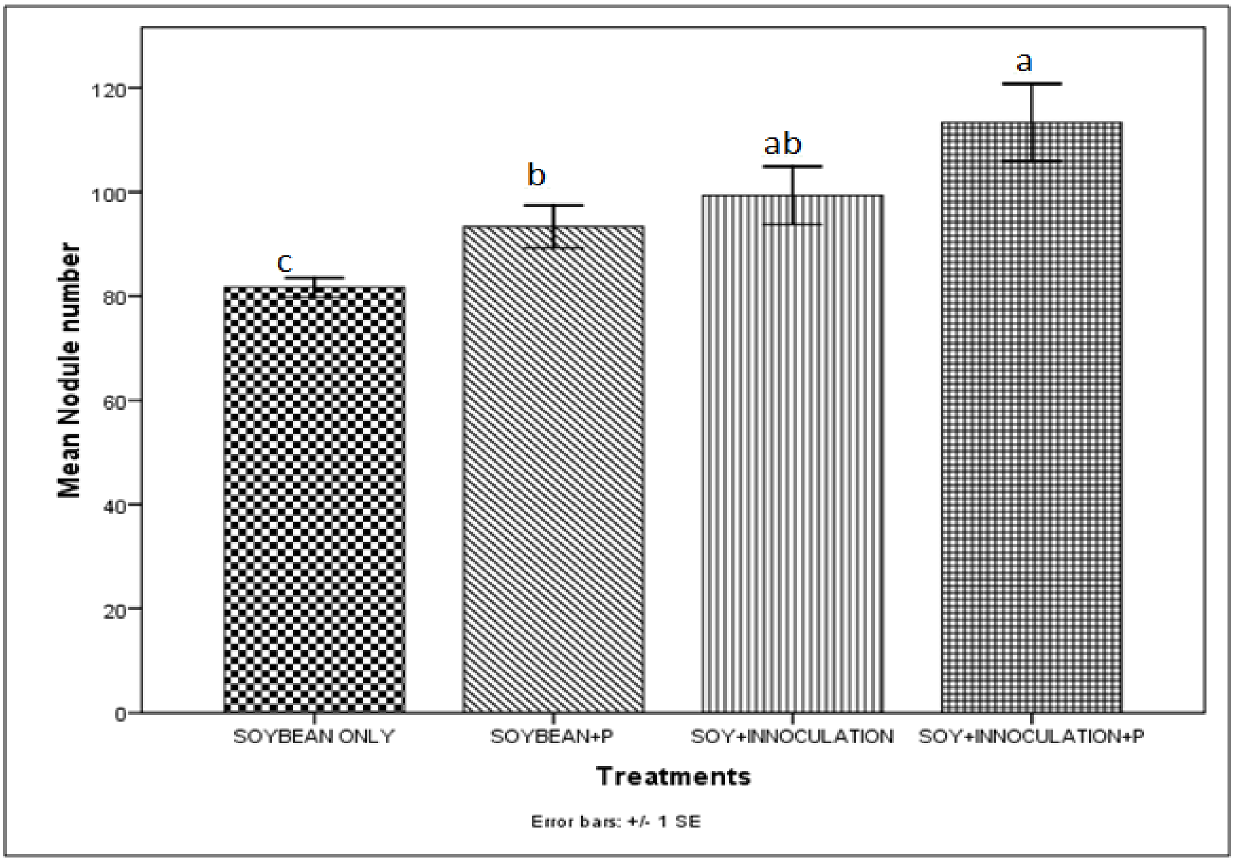
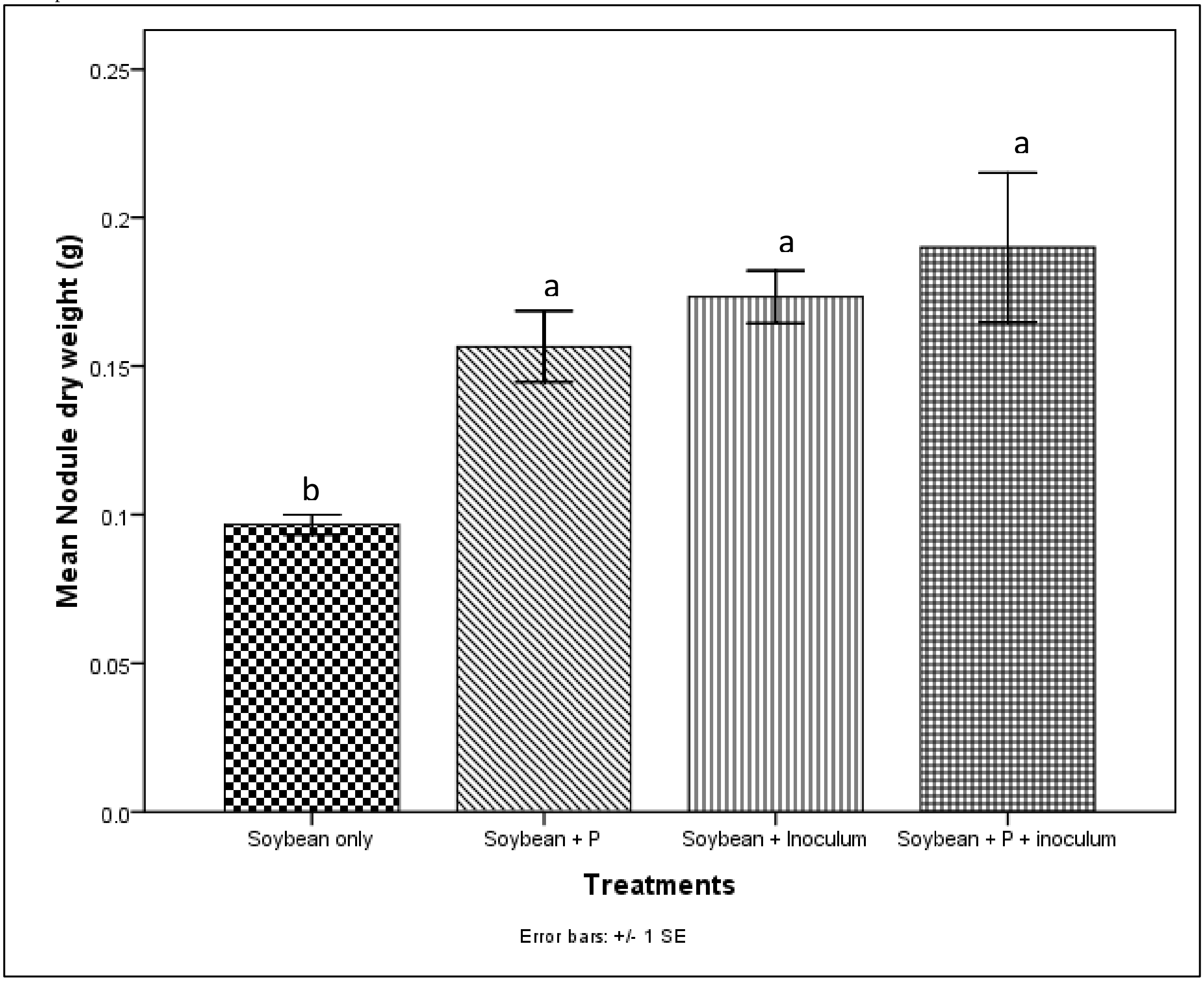


Figure-7. Effects of phosphorus fertilization and rhizobia inoculation on nodule dry weight in Nyankpala in the Guinea savanna zone of Ghana. Bars represent the standard error of mean



3.4. Impact of Inoculation and P Fertilization on Days To 50% Flowering, Days To 100% Flowering and Pod Shattering of Soybean

Similarity (No significant difference, p>0.05) in days to 50% flowering and days to 100% flowering of soybean under the various treatments (Table 1) was observed.

Table-1. Effect of phosphorus fertilization and rhizobium inoculation on pod shattering, days to 50 % and 100% flowering of soybean at Nyankpala in the Guinea Savanna zone of Ghana

Treatment	Pod shattering (%)	Days to 50% flowering	Days to 100% flowering
SOY+INOCULATION	43.5	42.3	46
SOY+INOCULATION+P	47.8	42.3	46
SOYBEAN ONLY	41.8	42.3	46
SOYBEAN+P	46.0	42.0	47
LSD (0.05)	11.2	0.6	1
CV (%)	3.6	1.6	1.1

3.5. Benefit/Cost Analysis of Use of Inoculants and Phosphorus Fertilizers for Soybean Production in Northern Ghana

From the results on comparative analyses of the economic productivity of soybean production techniques (Table 2), rhizobia inoculation gave the highest benefit: cost ratio, followed by the soybean + phosphorus fertilizer application and soybean + phosphorus + inoculums respectively. The control treatment (sole soybean) gave the least benefit cost ratio.

From the results on comparative analyses of soybean production treatments, the application of phosphorus and inoculation inured to the benefit of soybean production. According to Adegeye and Dittoh [11], the higher the benefit: cost ratio, the higher the gain derived from the use of the given production system.

Table-2. Benefit and Cost analyses of soybean production base on inoculation and phosphorus application technologies in the Northern savanna region of Ghana

Technology	Cost of production (GHS) per ha	Benefit (GHS) per ha	Benefit/cost ratio
Inoculated soybean with P application (SIP)	2016	11840	5.9
Inoculated soybean (SI)	1639	10016	6.1
Soybean with P application (SP)	1890	10208	5.4
Sole soybean (S)	1489	7936	5.3

4. Discussion

The treatments significantly affected the number of pods formed (*p = 0.01*). Inoculation plus phosphorus application recorded the highest pod number (Figure 1). Application of phosphorus as a sole treatment resulted in an increase in pod number than sole inoculation. Also the application of either phosphorus or inoculum and in combination enhances podding more than sowing soybean alone. The high number of pods in the soybean + inoculants + P treatment may have contributed to the observed high yield in that treatment (Figure 2). This confirms the report by Bekere and Hailemariam [4], that soybean seed yield can be increased by inoculation and phosphorus application. No significant differences were observed between the various treatments for the mean seed weight and number of seeds per pod (Figure 3 and 4). However, inoculated seeds recorded the higher hundred seed weight than seeds that were not inoculated (Figure 3). Hundred (100) seed weight (Figure 3), number of seeds per pod (Figure 4), and number of pods per plant (Figure 1) are significant yield contributing constituents. These reflect the degree of seed growth which eventually reflects the final yield of a crop [4]. Since number of seeds per pod and hundred seed weight, as yield determining factors did not significantly differ for the various treatments, but had positive correlation with yield, the observed difference in grain yield is attributed to the differences in the mean number of pods per plant. The high number of pods recorded in the inoculants + P treatment contributed to the observed high yield (Figure 2). This observation is in line with the work by [12], and Jain and Trivedi [13], who reported that hundred (100) seed weight, seed number per pod, pod number per plant are important yield contributing components.

The substantial difference in nodule effectiveness among the treatments (*p = 0.037*) observed was due to the application of both inoculant and phosphorus to soybean production (Figure 5). However, sole application of either inoculum or phosphorus fertilizer did not significantly differ from the combined treatment (Figure 5). The observed significant difference in nodule number (Figure 6), effectiveness (Figure 5) and dry weight (Figure 7) among the different treatments could be attributed to the impact of phosphorus and rhizobium on nodule initiation and development. Phosphorous is known to initiate nodule formation, increase number of nodule primordial and is essential for the development and functioning of nodules [14, 15]. Inoculating soybean with the appropriate strain of Bradyrhizobia is also known to increases the number of nodules formed [16]. Inoculated seeds resulted in higher nodule numbers than un-inoculated seeds. (Figure 6) Since phosphorus is considered as one of the major factors that lead to nodule formation and effectiveness, a combined treatment of P and inoculation may explain the observed high effectiveness in nodule number, effectiveness and dry weight. The observed trend in this experiment confirms the findings of [17] who also observed that the combined treatment of inoculation and P fertilization had synergistic effects on nodule dry weight. This observation may go to confirm the report of Singleton and Bohlool [18], that, in addition to enhancing nodule formation, deficiency of phosphorus in legume markedly affects the development of effective nodules and the nodule leghaemoglobin content. The findings in this study however, contradict those of Bekere, *et al.* [19], and Bekere and Hailemariam [4]. The above mentioned authors observed that phosphorus application without inoculation did not influence nodule dry weight.

The observed similarity in days to 50% flowering and days to 100% flowering of soybean under the various treatments (Table 1) are in contrast with observations made by Tomar, *et al.* [20], and Rani [21], who reported that, P application has positive impact on these parameters. The observation is also in contrast with that of Hernández [22], who noted an increase in the parameters upon soybean inoculation. The similarity in days to flowering and shattering of pods however, confirms the report of Mahamood, *et al.* [2], that certain parameters such as days to flowering and pod shattering are genetic attributes of varieties: and might not be influenced by environmental factors.

From the results on comparative analyses of soybean production treatments, the application of phosphorus and inoculation inured to the benefit of soybean production. According to Adegeye and Dittoh [11], the higher the benefit: cost ratio, the higher the gain derived from the use of a given production system. In that sense therefore, use of sole inoculant in soybean production stands to benefit resource-poor farmers in the Guinea savannah zone of northern Ghana.

5. Conclusion

The experiment shows that, inoculation of soybean seeds with P leads to increase in almost all yield and growth parameters of soybean. Resource poor farmers in Africa can also opt for only inoculation if affording P fertilizers becomes a problem since its economically beneficial. It is recommended that soybeans producers should inoculate seeds and also apply or fertilize their soil with P to increase soybean production.

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