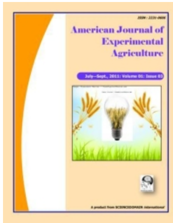

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Application of Phosphorus Fertilizer on Soybean [(*Glycine max* L. (Merril)] Inoculated with Rhizobium and its Economic Implication to Farmers

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Authors' contributions

This work was carried out in collaboration between all authors. Authors BDKA and SL designed the study and author BDKA wrote the protocol. Authors VB, SL and SY wrote the first draft of the manuscript. Authors VB and YS performed the statistical analysis and author VB did the literature searches. Authors BDKA, SL and SY did proof reading, restructured and managed the analyses of the study. All authors read and approved the final manuscript.

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ABSTRACT

The experiment was conducted during the 2012 farming season on the agricultural experimental field of the University for Development Studies, Nyankpala in the Guinea Savannah agro-ecological zone. The objective of the study was to determine the influence of *Rhizobium* inoculants and phosphorus (P) at different application rates on yield and yield components of soybean and also to determine the economically optimal application rate of phosphorus for soybean production in the Guinea Savanna agro-ecological zone. Two levels of inoculation regimes {un-inoculated (-In) and inoculated (+In)} were combined with three application rates of phosphorus (as Yaralegume) and a control (0kg P/ha, 15kg P/ha, 30 kg P/ha and 45 kg P/ha). The experiment was laid in a 2 x 4 factorial arranged in a Randomized Complete Block design with three replications. Parameters measured were crop emergence, plant height, canopy spread, number and weight of nodules, number of pods and total grain yield. The results obtained indicated significant differences in all the

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parameters measured. Phosphorus application at 45kg P/ha plus *Rhizobium* inoculants recorded significantly higher grain yield than the rest of the treatments. The economic analysis of the treatments also showed that combination of inoculation of soybean seeds with 45 kg P/ha was more profitable than the application of 45kg P/ha without inoculation. The study recommends inoculation of soybean seeds with *Rhizobium* inoculants and the application of phosphorus fertilizer at 45kg P/ha.

Keywords: Inoculation; phosphorus rates; yaralegume; grain yield.

1. INTRODUCTION

Soybean {*Glycine max* L. (Merrill)} is one of the important oil grain legume crops in the world. In the international world trade market, soybean is ranked number one among the major oil crops such as rapeseed, groundnut, cotton seed, sunflower, linseed, sesame and safflower [1]. Soybean is the cheapest protein source as compared to other protein sources such as egg, fish and meat. With an average protein content of 20% on dry matter basis, soybean has the highest protein content of all field crops and is second only to groundnut in terms of oil content among the food legumes [2] and [3]. The low availability of phosphorus nutrition in soils has become the limiting factor for plant and root growth [4,5] and [6]. Phosphorus has a key role in the energy metabolism of all plant cells and particularly in nitrogen fixation as an energy requiring process [7]. Soybean can restore soil fertility by building up the soil nitrogen through biological nitrogen fixation. According to [8], the efficiency of *Rhizobium* is influenced by the availability of phosphorus in the soil as it is directly involved in growth. Phosphorus deficiency can limit nodulation by legumes. However, phosphorus fertilizer application can overcome the deficiency [9]. Availability of phosphorus in the soil influences the efficiency of *Rhizobium* that fixes atmospheric nitrogen in association with nodulating legumes as it is directly involved in biological nitrogen fixation via legume-*Rhizobium* symbiosis. This is attracting considerable research attention world-wide due to its economic viability for resource-poor farmers and environmental friendliness [10,11] and [12]. Responses to inoculation in research experiments have shown that inoculation is justified especially in soils deprived of legume cultivation for many years [13]. Inoculation of soybean with the appropriate rhizobia provides high numbers of viable and effective rhizobia to the rhizosphere to allow rapid colonization and nodulation [14] and [15]. Inoculation of soybean by *Bradyrhizobium japonicum* significantly increased nodulation and yield [16]. Nodules are strong sinks of phosphorus reaching concentrations three-fold higher than in other organs [17]. Determining the fertilizer-output relationship can provide a means to proper fertilizer management by selecting economically optimal rates of fertilizer application that have direct implications on crop profitability. Optimum fertilizer rate is determined by the farmer’s preference of marginal net return. In northern Ghana, where the largest production of soybean occurs in the country, the average yield is about 2.5 tonnes/ha [18] as compared to that of USA which is 4.6 tonnes/ha [19]. The low yields can be attributed to soils which are inherently poor and deficient in organic matter and other vital nutrients such as phosphorus and nitrogen. Available phosphorus is found to be as low as 6.0mg/kg soil [20]. The objective of this study was therefore to assess the effect of phosphorus at different application rates and *Rhizobium* inoculants on the growth and yield of soybean and also to determine the economically optimal rate of phosphorus fertilizer application for soybean production in the Guinea Savanna agro-ecological zone.

2. MATERIALS AND METHODS

2.1 Site Description

The experiment was conducted on the experimental field of the University for Development Studies, Nyankpala (09º24'15.9''N; 01º00'12.1''W) in the Guinea Savannah ecological zone during the 2012 cropping season. The study area has an Alfisol soil under the United State Development Agency system of classification and an FAO system. The soil is moderately drained sandy-loam and brown, free from concretions, very shallow with a hard pan underneath the top few centimetres. It is developed from the Voltaian sandstone and classified as Nyankpala Series (Plinthic Acrisol). The area experiences a unimodal annual rainfall of 1000 mm-1200 mm from April to November (Fig. 1). The temperature distribution is uniform with mean monthly minimum and maximum values of 21ºC and 34.1ºC, respectively and a relative humidity of 53%-80% [21].

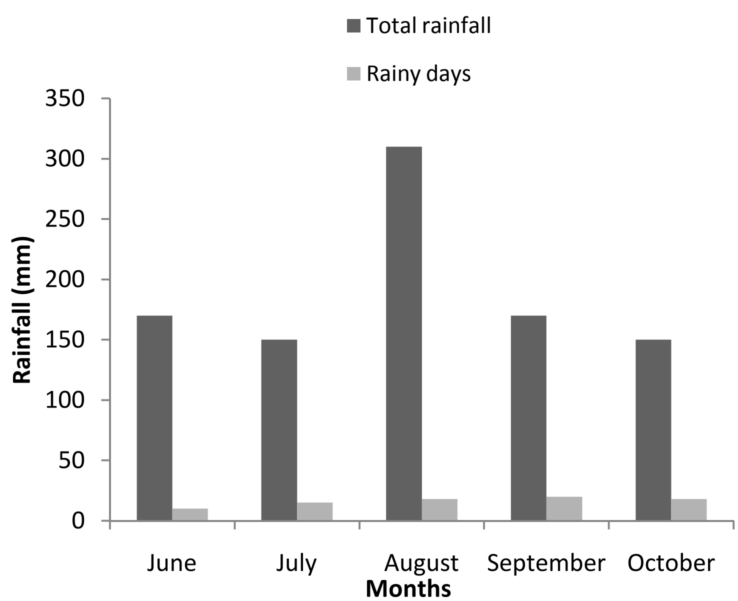

Fig. 1. Total rainfall and number of rainy days from June to October, 2012

2.2 Experimental Design

A 2 x 4 factorial experiment consisting of two inoculation regimes and four application rates of phosphorus fertilizer were laid out in a Randomized Complete Block design with three replications. The P treatments were 0kg P/ha, 15kg P/ha, 30kg P/ha and 45kg P/ha from Yaralegume fertilizer with or without inoculants. The complete treatment combinations were un-inoculated soybean seeds at 0kg P/ha, inoculated soybean seeds at 0kg P/ha, un-inoculated soybean seeds at 15kg P/ha, inoculated soybean seeds at 15kg P/ha, un-inoculated soybean seeds at 30kg P/ha, inoculated soybean seeds at 30kg P/ha, un-inoculated soybean seeds at 45kg P/ha and inoculated soybean seeds at 45kg P/ha. Phosphorus was applied two weeks after sowing by burying it in a trench dug about 5 cm away from the plant. The plot size was 2.5m x 2.5m.

2.3 Seed Acquisition and Sowing

An improved soybean variety, Jenguma whose seed was obtained from CSIR-Savanna Agricultural Research Institute, Nyankpala was used as the test crop. It is a variety with a very high shattering resistance and a maturity period of 115 days. It has a potential yield of 2.0 t/ha and is very rich in protein and oil with a ratio of 2: 1. Jenguma has a protein content of 0.57% (dry weight basis) and a fat/oil content of 0.39% (dry weight basis). For the inoculated treatments, the seeds of Jenguma were inoculated with commercial *Rhizobium* inoculants, *Legumefix* at the rate of 5 g of inoculants to 1 kg seed [22] before sowing. The soybean seeds were put in a plastic pail and moistened with ordinary tap water and then stirred uniformly with a wooden spatula. The inoculants were added to the moistened seeds in the container and again stirred gently and uniformly until the seeds were evenly coated. The seeds were then spread on a sheet of canvas material under a shade to air-dry for at least one hour to allow the inoculants to adequately adhere to the surface of the seeds. The sowing was done early in the morning to avoid exposing the inoculants to the direct rays of the sun which might affect the quality of the inoculants. Sowing was done on ridges at three seeds per hill at a distance of 50cm between ridges and 10 cm within ridges. In order to avoid contamination of the un-inoculated treatments with the inoculants that might get stuck to the hand during sowing, the un-inoculated seeds were sown before the inoculated ones. The plants were allowed to grow to maturity under rain-fed conditions while the necessary management practices like weeding were observed.

2.4 Data Collection

Data were measured on the following crop variables

2.4.1 Crop establishment

Percent crop establishment was determined three weeks after sowing by counting the emerged plants in the four inner ridges and dividing the number by the expected number of plants (i.e. number of seeds sown per the four hills) multiplied by 100.

2.4.2 Plant height

Plant heights were measured in the third, sixth and ninth weeks after planting (3 WAP, 6 WAP and 9 WAP). A meter rule was used to take the height of each of eight plants randomly selected from the four inner ridges (two plants per ridge) and tagged. Measurement of the selected plants was done from the base of the plant (ground level) to the top of the main stem. The readings from each plot were averaged and recorded.

2.4.3 Canopy spread

Canopy spread of the eight plants that were selectively tagged for height measurements were also measured from the last leaf on one side of the plant to the last leaf on the other side of the same plant using a measuring tape. This measurement was done at the same times and intervals that the plant heights were measured and averaged.

2.4.4 Shoot biomass and nodulation

For the assessment of shoot biomass and nodulation, the eight plants which had been tagged for plant height measurements were sampled at full pod stage (R4 stage) by gently pulling them out of the ground after carefully loosening the soil around the plants with a cutlass before pulling them out gently with the hand making sure to collect the few nodules that got detached from the roots in the process. The shoots from each plot were then separated from the root system, bulked and weighed on a digital scale after which they were air-dried for one day followed by oven-drying at 80°C for 48 hours (to a constant weight) and the weights recorded. The nodules were detached from the roots, counted, weighed and then oven-dried at 70ºC for 48 hours and their weights also recorded.

2.4.5 Number of pods and grain yield

At harvest, all the pods from the plants of the two innermost ridges of each plot were harvested manually and counted after which they were sun-dried in the glass house for 24 hours followed by oven-drying at 80ºC for 48 hours and weighed on a digital scale. The dried pods were threshed and winnowed to separate the grains from the husk and the former weighed to obtain the grain yield.

2.4.6 Economic analysis

Partial budget analyses were carried out on all the treatments to determine their respective economic viabilities.

2.5 Data Analysis

Data were subjected to a two-way analyses of variance (ANOVA) using the computer statistical package Genstat (2008 Edition) and treatment means were compared using the least significance difference (LSD) at 5% probability level.

3. RESULTS AND DISCUSSION

3.1 Percent Crop Establishment

Crop establishment was seen to be significantly better in inoculated plots than in un-inoculated plots and this was observed irrespective of inoculation regime though the effects due to higher P application rates were more pronounced in inoculated treatments (Table 1). There was therefore an interaction effect between P fertilizer application rate and *Rhizobium* inoculation resulting in the highest percent crop establishment being observed in treatments with joint applications of 45kg P/ha and *Rhizobium* inoculants. This observation confirms findings by [23] who intimated that increased plant establishment from seeds appears to be a result of improved soil productivity due to bacterial activity and available nutrients. Increases in whole plant growth in response to phosphorus supply have been reported in soybean [24], cowpea [25] and groundnut [26]. With *Rhizobium* inoculation showing a better crop establishment than without inoculation in the 0kg P/ha treatment, the improved establishment could be attributed to rhizobial activity and perhaps also to a vigorous germination and growth of the seeds used.

Table 1. Effect of phosphorus fertilizer application at different rates and *Rhizobium* inoculant on plant establishment

Treatment	Mean
0 kgP/ha + un-inoculant	48.0b
0 kgP/ha + Inoculant	58.0b
15 kgP/ha + un-inoculant	53.2b
15 kgP/ha + Inoculant	70.2b
30 kgP/ha + un-inoculant	61.2b
30 kgP/ha + Inoculant	80.2ab
45 kgP/ha + un-inoculant	67.8b
45 kgP/ha + Inoculant	97.0ab
LSD (5%)	27.41
CV%	27.8

3.2 Plant Height

The application of phosphorus fertilizer and *Rhizobium* inoculants impacted on the growth of soybean when compared to the non-phosphorus and non-*Rhizobium* treatments (Table 2). As expected, the plants grew taller with time within a fertilizer application regime, especially when inoculated (Table 2). Irrespective of growth stage, plants fertilized with 45kg P/ha and inoculated grew tallest (51.8 cm). The current study confirms other research findings by [27] and [28] that increased levels of phosphorus significantly increased plant height. Also, [29] observed that *Rhizobium* inoculation increased plant height. [30] reported incidences of increased plant height due to interactions between phosphorus fertilizer application and *Rhizobium* inoculants whereas [31] observed that over-supply of phosphorus resulted in decreases in plant growth, nodulation and acetylene reduction in soybean.

Table 2. Effect of phosphorus fertilizer application at different rates and *Rhizobium* inoculants on plant height (cm)

Treatment	3WAP	6WAP	9WAP
0 kgP/ha + un-inoculant	9.39b	14.73b	30.18b
0 kgP/ha + Inoculant	12.38b	26.49ab	39.68ab
15 kgP/ha + un-inoculant	12.42b	18.64b	35.20ab
15 kgP/ha + Inoculant	15.18ab	28.97ab	43.87ab
30 kgP/ha + un-inoculant	15.70ab	22.96ab	39.69ab
30 kgP/ha + Inoculant	20.71ab	30.55ab	47.97a
45 kgP/ha + un-inoculant	20.11ab	27.49ab	44.69ab
45 kgP/ha + Inoculant	24.37a	32.88ab	51.80a
LSD (5%)	3.127	3.395	2.781
CV (%)	13.1	9.1	4.5

3.3 Canopy Spread

Phosphorus application rate, *Rhizobium* inoculation and their interaction significantly affected canopy spread of soybean plants (Table 3). Phosphorus application rate of 45kg P/ha with *Rhizobium* inoculation recorded the highest canopy spread at 3, 6 and 9 WAP compared to the spreads at 15kgP/ha and 30kgP/ha 9 WAP. The above results are in line with the findings of [32] that application of phosphorus significantly increased most of the soybean growth parameters.

Table 3. Effect of phosphorus fertilizer application at different rates and *Rhizobium* inoculant on canopy spread

Treatment	3WAP	6WAP	9WAP
0 kgP/ha + un-inoculant	9.12b	18.53b	26.23
0 kgP/ha + Inoculant	12.68ab	29.57a	37.28a
15 kgP/ha + un-inoculant	12.12b	24.39ab	31.50ab
15 P_20_5kg/ha + Inoculant	15.73ab	34.20ab	43.99ab
30 kgP/ha +un-inoculant	16.34ab	32.51ab	39.58ab
30 kgP/ha + Inoculant	19.44ab	39.65ab	49.25a
45 kgP/ha +un-inoculant	20.43ab	39.96ab	45.08ab
45 kgP/ha + Inoculant	24.12a	45.84a	56.58a
LSD (5%)	3.12	3.78	4.27
CV (%)	13.1	7.8	7.1

3.4 Shoot Biomass

Shoot biomass per plot was significantly influenced by *Rhizobium* inoculation and increasing fertilizer rates (Fig. 2). The highest shoot biomass was obtained in inoculated plants fertilized with 45 kg P/ha whilst plants that received no P application with or without inoculation produced the lowest shoots biomass. Across the P application rates, inoculation increased soybean shoot dry weight by a significant average of 30% over the un-inoculated plants (Fig. 2). Shoot biomass increased with increasing application of phosphorus + *Rhizobium* inoculants. Phosphorus at 45kg P/ha + *Rhizobium* inoculants recorded the highest shoot biomass per plot as compared to 15kg P/ha + *Rhizobium* inoculants which recorded the least with regards to phosphorus and *Rhizobium* inoculants. With the sole fertilizer treatments, shoot biomass increased with increasing phosphorus rates with 45kg P/ha recording the highest. At low phosphorus application, the straws yield was lower than treatments that received the highest amount. In an earlier work, the authors reported of similar increases in shoot biomass of soybean as a result of increased rates of P from different fertilizer sources [33]. The significant increase in shoot biomass due to increased P application rates in the current study also agrees with [34] who reported of a 20.7% increase in biomass yield due to phosphorus application.

3.5 Nodulation

Nodule number was significantly higher in inoculated plants and increased P application rates (Fig. 3). Nodule formation in inoculated plants increased by 28%, 39% and 56% by applying 15, 30 and 45kg P/ha, respectively compared to nodulation in the unfertilized plants. Inoculation effect was greatest (80%) in the unfertilized treatments compared to 64%, 32% and 30% increases in the 15, 30 and 45kg P/ha treatments, respectively (Fig. 3). This suggests that *Rhizobium* inoculation influenced nodulation more positively than P fertilizer. [35] demonstrated from pot studies that nodulation and N_2 fixation of promiscuous soybean may be increased by inoculation with effective *Bradyrhizobia*. [36] attributed the increase in nodulation to the competitive ability of *Bradyrhizobium* used, a result which was confirmed by [37].

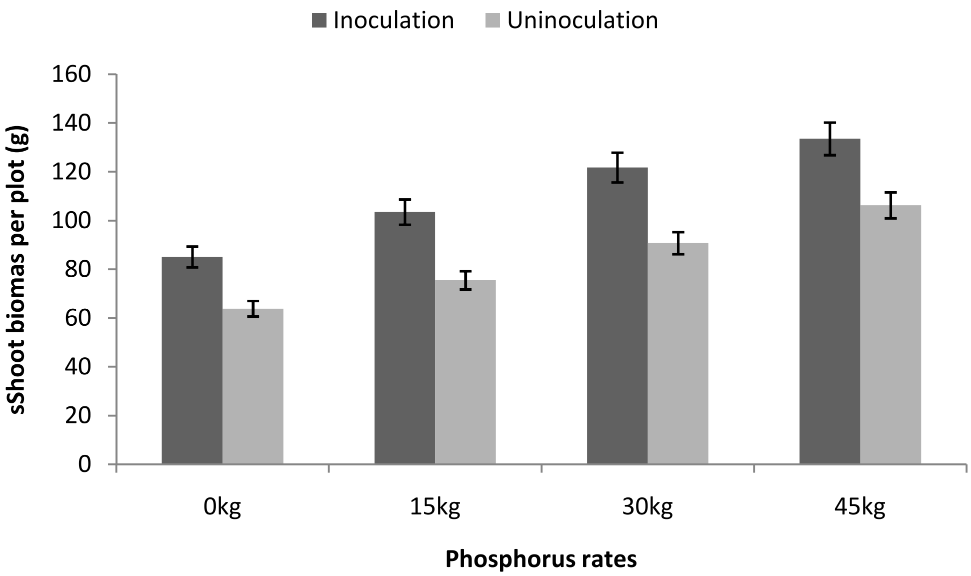

Fig. 2. Influence of *Rhizobium* inoculation and phosphorus fertilizer application rate on shoot dry biomass of soybean at full pod stage. *Bars represent standard errors*

3.6 Nodule Biomass

Nodule biomass production was enhanced significantly by inoculating soybean with *Rhizobium* inoculants whether the crop was fertilized with phosphorus or not (Fig. 4). The effect of inoculation was, however, greater in the presence of P and also when higher rates of P were applied but the highest percent increase (105%) in biomass due to inoculation occurred with P rate of 30kg/ha. The other increases were 43%, 78% and 88% for 0 kg P, 15 kg P and 45 kg P per hectare, respectively. Fig. 4 reveals that in un-inoculated plants the highest biomass of 1.6g/plant was obtained at 45kg P/ha application rate but a co-application of inoculants and only 15kg P/ha was able to produce the same nodulation effect. This means that with respect to nodule biomass (which is an index of biological N fixation if all nodules are active), application of 250g of inoculants (inoculation rate used in this study was equivalent to 250g inoculants/ha) could make savings equivalent to 30kg P (i. e. 381.7kg Yaralegume) in this study. The positive effect of *Rhizobium* inoculation on nodulation has been confirmed by [38] who recorded a significant increase in nodulation by native soil *Rhizobium* population in single inoculations conducted on a legume. Phosphorus is also known to initiate nodules formation, increase the number of nodule primordial and is essential for the development and functioning of formed nodules [39] and [40]. Several researches have reported that the supply of phosphorus plays important roles in the establishment, growth and function of nodules [32,41] and [42]. Both Figs. 3 and 4 showed that the interactive application of phosphorus and *Rhizobium* inoculants had a greater impact on nodulation than either treatment alone.

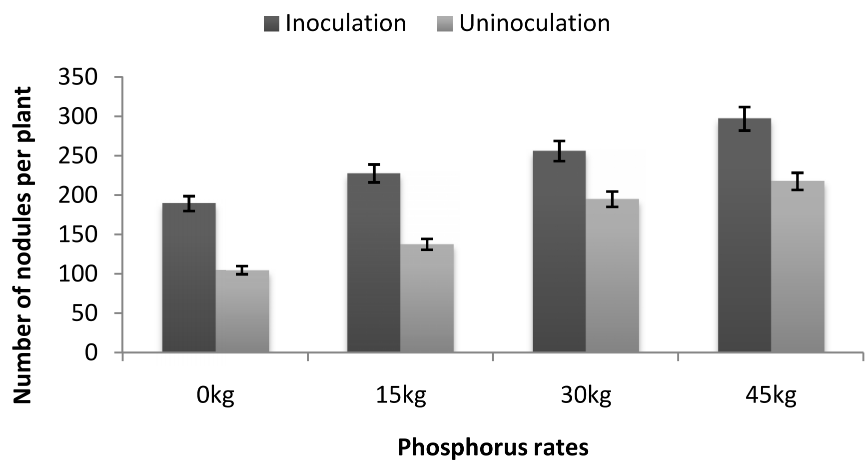

Fig. 3. Influence of *Rhizobium* inoculation and phosphorus fertilizer application rate on number of nodules per plant at full pod stage of soybean. *Bars represent standard errors*

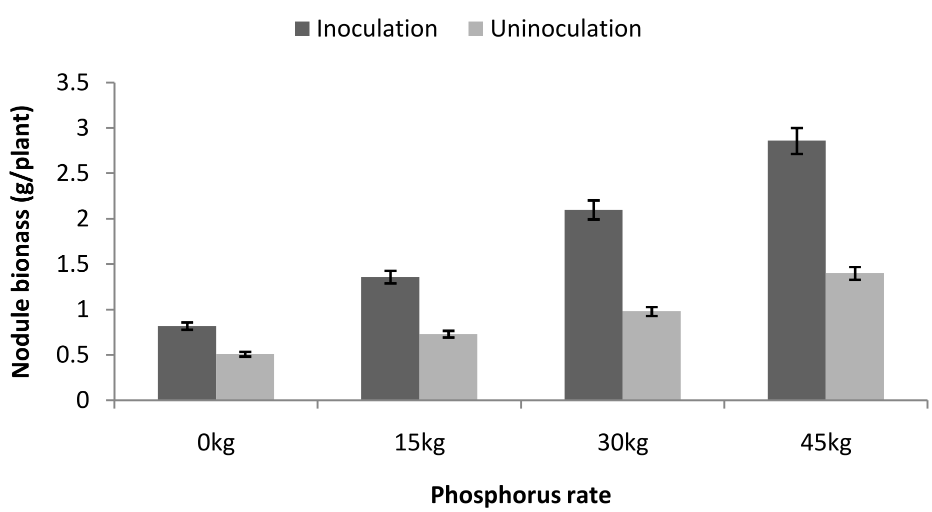

Fig. 4. Influence of *Rhizobium* inoculation and phosphorus fertilizer application rate on nodule biomass of soybean at full pod stage. *Bars represent standard errors*

3.7 Pod Production

The number and weight of pods produced by soybean in response to applications with P fertilizer and *Rhizobium inoculants* are shown in Table 4. *Rhizobium* inoculation remarkably increased both pod number and pod weight. Whereas the increases due to inoculation were observed at all the P application rates in the former (Table 4), there was no effect of inoculation on pod weight at 15 kg P/ha rate. Also, whether plants were inoculated or not, pod production generally increased with increasing rates of P application which agrees with [43] and [28] who reported high numbers of pods per plant in response to high doses of phosphorus. [44] Reported that a mixed inoculation improved the productivity of soybean when compared to the control treatment. Increased numbers of pods per plant in response to inoculation were also reported by [45] and [29]. The increases in pod weight at the different increasing rates of P plus *Rhizobium* inoculation may have been due to enhanced stimulation of pod filling in such treatments as confirmed by [29] when they reported of significant high numbers of seeds per pod when 100kg P was applied in contrast to minimum numbers of seeds where no P was applied

Table 4. Effect of phosphorus fertilizer application at different rates and *Rhizobium* inoculants on number of pod

Treatment	Mean
0 kgP/ha + un-inoculant	24.0b
0 kgP/ha + Inoculant	41.8a
15 kgP/ha + un-inoculant	32.8b
15 P_20_5kg/ha + Inoculant	43.8a
30 kgP/ha +un-inoculant	42.2a
30 kgP/ha + Inoculant	62.2a
45 kgP/ha +un-inoculant	54.8a
45 kgP/ha + Inoculant	71.8a
LSD (5%)	13.24
CV (%)	19.0

3.8 Pod Weight

There were significant differences among the various phosphorus rates, *Rhizobium* inoculants and the interaction between phosphorus rates and *Rhizobium* inoculants on pod weight (Table 5). Different rates of phosphorus fertilizer plus *Rhizobium* inoculants stimulated pod filling and thereby improved the pod weight as the phosphorus level progressively increased. Phosphorus at 45kg P ha^{-1}+ *Rhizobium* inoculants recorded the highest pod weight as compared to phosphorus at 15 kg P/ha which recorded the least. The current study agrees with the findings of [46] and [29] who also recorded significant high numbers of seeds per pod produced when 100kg P ha^{-} was applied and minimum numbers of seeds when no phosphorus was applied. Similar results were obtained by [47] who reported of significant effects of phosphorus rates on harvest index of soybeans.

Table 5. Effect of phosphorus fertilizer application at different rates and *Rhizobium* inoculants on pod weight

Treatment	Mean
0 kgP/ha + un-inoculant	6.15b
0 kgP/ha + Inoculant	7.93b
15 kgP/ha + un-inoculant	10.40ab
15 P_20_5kg/ha + Inoculant	10.34ab
30 kgP/ha +un-inoculant	10.62ab
30 kgP/ha + Inoculant	13.53ab
45 kgP/ha +un-inoculant	14.53ab
45 kgP/ha + Inoculant	18.50a
LSD (5%)	3.001
CV (%)	17.7

3.9 Total Grain Yield

Similar to pod production, grain yield of soybean was significantly influenced by varied phosphorus rates and *Rhizobium* inoculation (Fig. 5). The grain yield increased significantly at every higher rate of P application from 0 to 45 kg/ha with or without inoculation. Phosphorus application at 45kg P/ha plus *Rhizobium* inoculants recorded the highest grain yield of 1955kg/ha compared to 897kg grain per hectare in the unfertilized inoculated treatment which constitutes a yield increase of 118% (Fig. 5). However, though inoculation enhanced grain yield at every P application rate, within the P application regimes *Rhizobium* inoculation caused the highest percent grain yield increase (25%) at 15kg P/ha. Also, these results are in agreement with [48] who concluded that phosphorus and inoculation induced a pronounced effect on grain yield. [45] Also reported significant increases in grain yield with *Rhizobium* inoculation.

3.10 Economic Analysis

Information on costs and benefits of treatments is a prerequisite for adoption of technical innovation by farmers [49]. The studies assess the economic benefits of the treatments to help develop recommendation from the agronomic data. This enhances selection of the right combination of resources by farmers in the study area. The results in this study indicated that the inoculated treatments resulted in higher net benefits than the un-inoculated treatments for all P fertilizer treatments (Table 6). The implications are that farmers will be better off inoculating soybeans seeds before planting as it will improve incomes of farmers through increased grain yields. The partial budget analysis showed that the application of 45 kg P/ha for both inoculated and un-inoculated treatments yielded higher net benefits than all the treatments. The control (no fertilizer) treatment also produced the lowest net benefit for both the inoculated and un-inoculated treatments. This implies that farmers would be better off inoculating their soybean in combination with application of 45kg P/ha as these increase soybean yields and thus increase farmers' income.

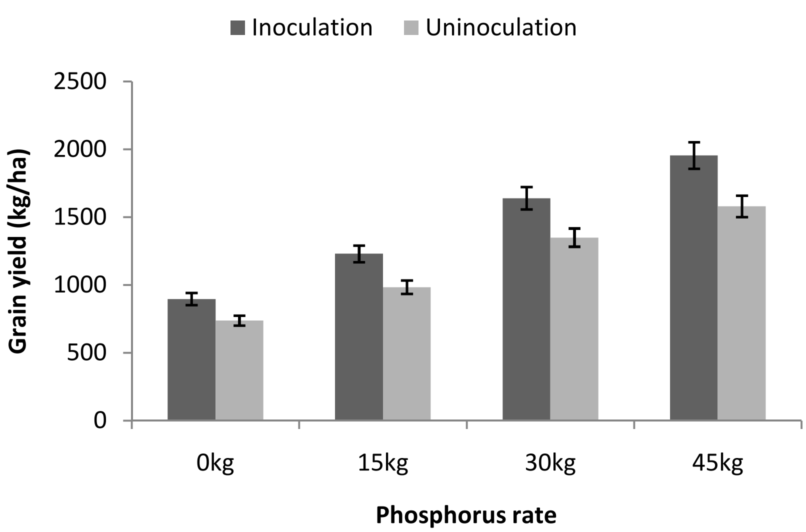

Fig. 5. Influence of *Rhizobium inoculation* and phosphorus fertilizer application rates on grain yield of soybean. *Bars represent standard errors*

Table 6. Partial budget for inoculated and un-inoculated soybean seeds at four different treatments

Item	Treatment							
	Inoculated				Un-inoculated			
	15 kg P/ha	30 kg P/ha	45kg P/ha	0 kg P/ha	15 kg P/ha	30 kg P/ha	45 kg P/ha	0 kg P/ha
Average yield (kg/ha)	1230	1640	1955	897	984	1350	1580	738
Adjusted yield (kg/ha)[1]	1107	1476	1759	807	885	1215	1422	664
Gross field benefit (¢)[2]	2656	3542	4222	1937	2125	2916	3412	1594
Cost of Yaralegume (¢/ha)	16	33	48	0	16	33	48	0
Cost of inoculation (¢/ha)	15	15	15	15	0	0	0	0
Total cost that vary (¢)	31	48	63	15	16	33	48	0
Net benefit (¢)	2625	3494	4159	1922	2109	2883	3364	1594

[1]Average yield adjusted 10% downwards; Farm gate price of soybean as at December 2012= GH¢2.4 per kg; Price of 50 kg of Yaralegume as at December, 2012 = GH¢50.00 and price of inoculants = GH¢15.00/ha

4. CONCLUSION AND RECOMMENDATION

Growth and development parameters of the soybean measured increased with increasing rates of phosphorus fertilizer coupled with *Rhizobium* inoculation. Generally, plants that received phosphorus fertilizer performed better than plants that were not fertilized as well as than plants that received inoculation only. However, the positive effects of P fertilizer application on growth and grain yield of soybean in this study were significantly boosted in the presence of *Rhizobium* inoculants. The growth and grain yield enhancements observed in this investigation may be attributed to an increased symbiotic relationship of rhizobia (bacteria) with the roots of leguminous crops. This reflected in increased nodulation resulting in the possible fixation of atmospheric nitrogen into the roots of soybean which was favoured by increased P nutrition. From the results of the economic analysis conducted, this study therefore recommends that farmers inoculate their soybean seeds with *Rhizobium* and apply phosphorus fertilizer at 45kg P/ha to maximize their grain yield and their farm income.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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