

Full Length Research Paper

Yield response and economic benefits of groundnut to phosphorus fertilization and inoculant rates in Northern Ghana

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Groundnut (*Arachis hypogea* L.) is a major source of dietary protein, cultivated for both human and animal consumption. However, in West Africa, the yields are low, renewing the interest to evaluate groundnut response to P fertilizer (P) and rhizobium inoculant (IR) application. A study was conducted on the experimental field of the University for Development Studies, Nyankpala in the Northern region of Ghana to evaluate the interactive effect of three P rates (0, 30 and 60 kg P₂O₅/ha) and three IR rates (0, 3 and 6 g/kg seed) on groundnut yield and to assess the economic viability of these technologies to farmers. The study was conducted using a 3 × 3 factorial laid out in a randomized complete block design with three replications. Nodule count and pod number per plant were significantly affected by P fertilizer rates (PR) and rhizobium inoculant rates (IR) interaction. The effects of PR and IR significantly increased grain yield of groundnut, with 60 kg P₂O₅/ha and 6g inoculant/kg seed recording the highest grain yield of 2708.3 and 2376.6 kg/ha respectively. Correlation analysis suggested that major determinants of groundnut grain yield were nodule count, effective nodule count, pod number and pod weight. Gross benefits were higher in treatment with P fertilizer and/or inoculant application. Estimated B/C ratios also indicated that, compared to the control, all the treatments are attractive. Therefore, cultivating groundnut by using P fertilizer and/or inoculant may provide the most economically viable and low-risk options for increasing groundnut yield in northern Ghana.

Key words: Phosphorus, rhizobium inoculant, gross benefit, groundnut, grain yield.

INTRODUCTION

Groundnut (*Arachis hypogea* L.) is a major grain legume in the world, cultivated for both human and animal consumption (Dapaah et al., 2014). Its seed is a major source of protein (12-30%) and oil (36-54%) for both rural and urban settlers in Sub-Saharan Africa (Naab et al.,

2009). According to the Food and Agriculture Organization (FAO) estimate for 2018, 28.5 million hectares of peanut were harvested worldwide of which West African sub-region harvested 7.1 million ha (www.FAOSTAT.org). Despite its importance, the average yield of groundnut in

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West Africa is estimated to be 1.1 t/ha. Several biophysical and socio-economic factors; including low and declining soil fertility, high cost and/or unavailability of inputs (seed, fertilizer, inoculant) and use of low yielding varieties are often cited as the major causes of the low yield of groundnut.

Low and declining soil fertility, especially phosphorus (P) deficiency, in smallholder groundnut farms has been described as the fundamental biophysical factor responsible for the declining yield in Sub-Saharan Africa (Naab et al., 2009). Although groundnut can fix their own nitrogen, they often need P for enhanced seed formation (Asiedu et al., 2000). Some authors (Naab et al. 2005; Kamanga 2010) have reported a significant yield response of groundnut to P application. Despite, these benefits, results from various studies on the optimum application rate of P to enhance groundnut yield proves to be inconsistent. For instance, studies by Mouri et al. (2018) reported higher yields with P rate at 60 kg P₂O₅/ha while Taruvinga (2014) found no significant effect when P rate was increased beyond 45 kg P₂O₅/ha. Therefore, this has renewed the interest for further studies.

Inoculation using *Rhizobia* strains has been identified as one of the most successful strategies employed to enhance symbiotic N-fixation by legume (Amba et al., 2013). It has been reported that, leguminous plant with symbiotic nitrogen fixing bacteria are able to fix about 15 - 210 kg/ha of nitrogen per season (Dakora and Keya, 1997). Thus, the inoculation of peanut with appropriate rate of rhizobium inoculant can be a beneficial strategy to improve peanut productivity. However, peanut response to inoculation has been inconsistent (Sharma et al., 2011), as survival and effective functioning of rhizobia population are reduced by high soil temperature, salt, soil acidity and nutrient deficiency (Zahran, 1999). Therefore, the full potential of the symbiotic system may be realized by increasing the number of effective rhizobia. Consequently, Deaker et al. (2004) demonstrated that, increasing number of effective rhizobia per seed application of inoculants improves nodulation and yield.

Previous studies on groundnut with P rate and rhizobium inoculant application only covered information on yield components and yield with little or no data on their economic viability. The objective of this study was therefore to evaluate the interactive effect of phosphorus and rhizobium inoculant rates on the performance of groundnut and assess the economic viability of P and inoculant application to guide farmer's adoption.

MATERIALS AND METHODS

Study site description

Field experiment was conducted during the 2018 cropping season at the University for Development Studies experimental field at Nyankpala in the Northern Region of Ghana, located at latitude 9.40980° N; longitude 0.98654° W at altitude 183 m above sea level. The area experiences a unimodal annual rainfall of 800 to

1200 mm which occurs from May to October. The mean monthly minimum and maximum temperature ranges between 21 and 34.1°C respectively.

Experimental design and treatment

The study was a 3 × 3 factorial experiment laid in a randomized complete block design with three replications. The treatments included three P application rates (0, 30 and 60 kg P₂O₅/ha) and three rhizobium inoculation rates (0, 3 and 6 g/kg seed). The unapplied treatment plots (0 kg P₂O₅/ha and 0 g/kg seed) served as the control treatments for P rate and rhizobium inoculant rate respectively.

Agronomic procedures

Each treatment plot consisted of six rows of 4 m in length, 0.40 m inter-row spacing and 0.2 m intra-row spacing. The groundnut variety: Nkatie SARI, an erect bunch habit with 110 days maturity duration and resistant to early and late leafspot infections was used in the study. Commercial rhizobium inoculant product: Nodumax (strain USDA 110) was obtained from Savannah Agricultural Research Institute, Tamale, Ghana for the experiment.

Seed inoculation was performed just before planting by weighing 1 kg of seed into a plastic container and adding 10 ml of dissolved gum Arabic solution as sticker. The seeds and gum Arabic solution were mixed thoroughly and 10 g of Nodumax inoculant was applied to the seed and mixed thoroughly to ensure that all the seed were effectively covered with the inoculant. The groundnut was then planted at 1 seed/hill. Weed was controlled manually at 3 and 6 weeks after sowing (WAS) to avoid weeds build up to critical infestations levels as suggested by Priya et al. (2013).

Data collection

Growth, yield components and yield

Plant height and nodulation assessment were determined 8 weeks after sowing. For nodulation assessment, 5 plants outside the two centre rows were randomly uprooted from each plot. The roots were carefully washed with water inside a bowl to loosen adhering soil. The nodules were then removed, counted and dissected to determine nodule number and effective nodule number. At physiological maturity, 5 plants from the two centre rows of each plot were randomly selected for pod weight and count. The total weight and average number of pods were then calculated for each plot. The grain yield was measured from the two centre rows of each plot (3.2 m²). The pods were stripped, sun dried and shelled to measure grain yield.

Economic benefits

Data on cost of production and price of the grain after harvest were collected to estimate the total income of the output. The total cost of production constituted cost of land preparation, seed, fertilizer, inoculant and labour. Price of groundnut seed, P fertilizer and inoculant were as purchased in the study area. Cost of ploughing and harrowing were as charge by operators in the area while labour payment was valued at the daily wage rate of hired farm labourers. Grain yield price was determined by the market price at the nearest market (Tamale) during harvest (2018). The profit or marginal net return (MNR) was computed for each treatment as follows:

Table 1. Plant height, nodulation, yield components and yield as affected by phosphorus and rhizobium inoculation rates in northern Ghana.

Treatment	Plant height (cm) at 8 WAP	Nodule No. 5 plants ⁻¹	Effective nodules No. 5 plants ⁻¹	Pod No. 5 plants ⁻¹	Pod wt. (kg ha ⁻¹)	Grain yield (kg ha ⁻¹)
Phosphorus rate (PR) (kg/ha)						
0	14.2 ^b	22 ^c	19 ^c	26 ^c	2500.0 ^c	1215.3 ^b
30	14.6 ^a	25 ^b	22 ^b	32 ^b	7395.8 ^b	2361.1 ^a
60	14.4 ^{ab}	38 ^a	25 ^a	37 ^a	9652.8 ^a	2708.3 ^a
s.e	0.15	0.20	0.83	0.63	852.60	374.1
<i>p</i> -value	*	***	***	***	***	***
Rhizobium inoculation rate (IR) (kg/ha)						
0	14.3 ^b	24 ^c	17. ^c	28 ^c	5694.4 ^b	1770.8 ^a
3	14.4 ^b	27 ^b	23 ^b	31 ^b	6458.3 ^b	2137.3 ^{ab}
6	14.6 ^a	34 ^a	27 ^a	35 ^a	7395.8 ^a	2376.6 ^a
s.e	0.15	0.20	0.83	0.63	852.60	374.1
<i>p</i> -value	**	***	***	***	*	*
PR x IR						
<i>p</i> -value	ns	***	*	***	ns	ns

†s.e, standard error, †ns, $p > 0.05$, * $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$.

$$\text{MNR} = Y \times P - \text{TVC} \quad (1)$$

Where Y is grain yield of groundnut (kg/ha), P is selling price of groundnut grain at harvest and TVC is the cost of inputs related to the treatment. The marginal rate of return (MRR) for each treatment was calculated as follows:

$$\text{MRR} = \text{MNR}/\text{TVC} \quad (2)$$

Data analysis

The General Linear Model of the Statistix 10 Analytical Package (2013) for windows was used to analyse data on growth, yield components and yield. Duncan Multiple Range Test was used to separate treatment means of significance level at 5% probability level. However, the economic benefit of groundnut production was not statistically analysed. Correlation analysis was performed to determine relationship among growth, nodulation, podding capacity and grain yield. Parameters with

correlation values of 0.50 and above were considered to be best fitted and less than 0.50 considered non-best fit. Linear regression was used to determine predictive equations among correlated variables.

RESULTS

Growth, yield components and yield

The PR x IR interaction was not significant on plant height at 8 WAS, however, the effects of PR and IR did influence plant height significantly, such that plant height at 30 kg P₂O₅/ha and inoculant at 6 g/kg seed increased significantly compared with their respective control (Table 1). Nodule count was significantly affected by PR x IR application rates. P rate at 60 kg P₂O₅/ha and inoculant rate at 6 g/kg seed combined to give

higher ($P < 0.001$) nodule count than the control (Figure 1). Conversely, effective nodule number was influenced by the effects of PR and IR with P rate at 60 kg P₂O₅/ha and inoculant rate at 6 g/kg seed recording the highest number than their respective controls (Table 1). The PR x IR interaction was significant on pod number, likewise the effects of PR and IR. Pod number of P at 60 kg P₂O₅/ha combined with inoculation at 6 g/kg seed increased significantly compared with the control (Figure 2). The weight of pods produced by groundnut in response to application rates of P and inoculant are shown in Table 1. Statistically, the lowest pod weight was observed under the control of both PR and IR. The PR x IR interaction was not significant on grain yield, however the effects of PR and IR affected grain yield significantly. Groundnut grain yields of P at 60 kg

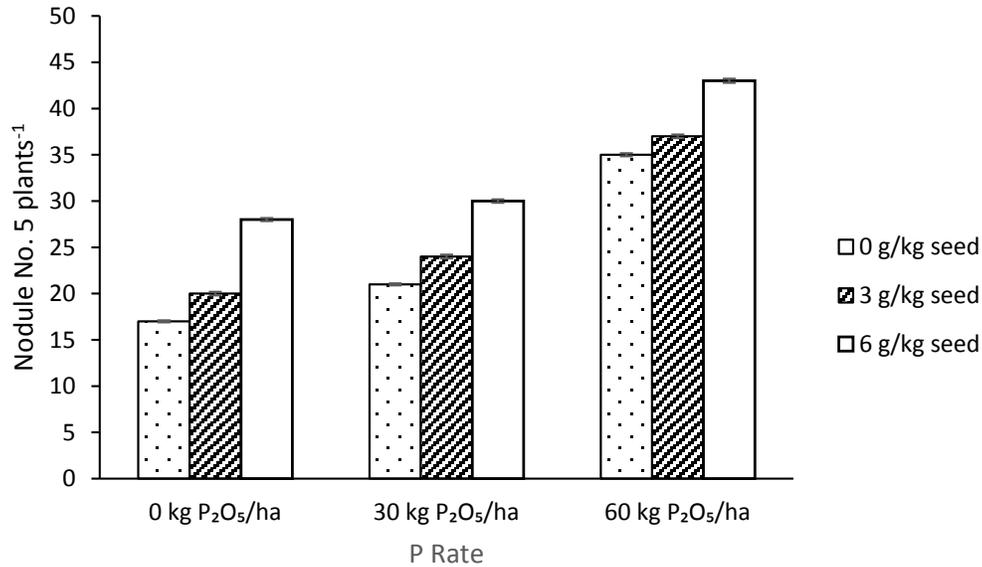


Figure 1. Nodule number as affected by phosphorus and rhizobium inoculation rates in northern Ghana. Error bars represent standard error of mean.

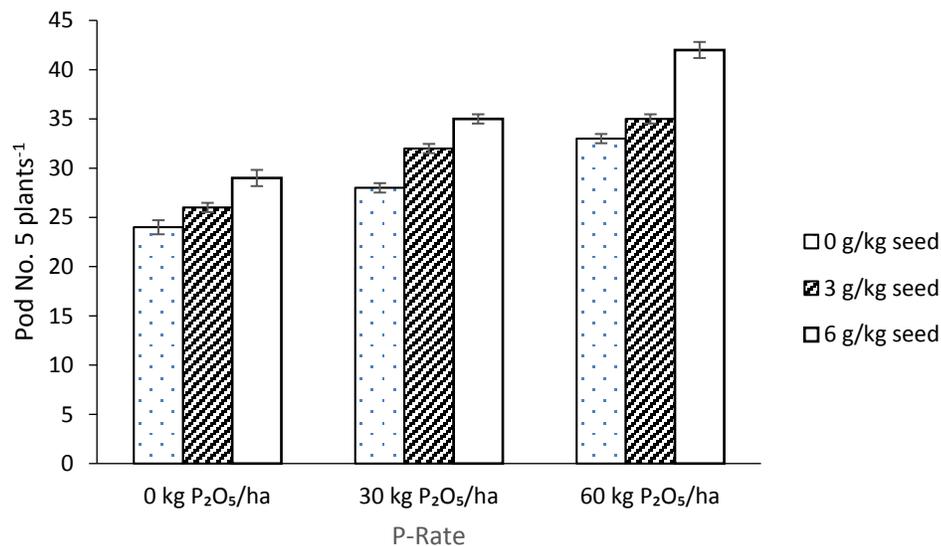


Figure 2. Pod number as affected by phosphorus and rhizobium inoculation rates in northern Ghana. Error bars represent standard error of mean.

P₂O₅/ha and inoculation at 6 g/kg seed increased significantly compared with their respective controls (Table 1). Groundnut grain yield (GGY) was positively correlated with nodule count (NC), effective nodule count pod number (PN) and pod weight (PW). This indicates that when NC, ENN, PN and PW increase GGY also increases. This relationship could be predicted from the general linear regression model:

$$Y_{GGY} = -2275.03 + 25.72_{NC} + 121.73_{ENC} + 168.00_{PN} + 0.26_{PW}, r^2 = 0.75 \quad (3)$$

Economic benefits

Table 2 depicts the total variable cost, gross benefits, net benefits and benefit: cost (B/C) ratio for groundnut

Table 2. Total variable cost, gross benefit, net benefit and benefit:cost (B/C) ratio of groundnut production as affected by the application of phosphorus rates and rhizobium inoculant rates in northern Ghana.

Trait	P0			P30			P60		
	I0	I3	I6	I0	I3	I6	I0	I3	I6
Production cost (US\$/ha)									
Ploughing	45.25	45.25	45.25	45.25	45.25	45.25	45.25	45.25	45.25
Harrowing	22.62	22.62	22.62	22.62	22.62	22.62	22.62	22.62	22.62
Seed	20.36	20.36	20.36	20.36	20.36	20.36	20.36	20.36	20.36
P fertilizer	0	0	0	41.18	41.18	41.18	82.35	82.35	82.35
Inoculant	0	3.62	7.23	0	3.62	7.23	0	3.62	7.23
Planting	66.18	66.18	66.18	66.18	66.18	66.18	66.18	66.18	66.18
Fertilizer application	0	0	0	30.54	30.54	30.54	30.54	30.54	30.54
Inoculant application	0	10.18	10.18	0	10.18	10.18	0	10.18	10.18
Weeding	33.93	33.93	33.93	33.93	33.93	33.93	33.93	33.93	33.93
Harvesting	33.93	33.93	33.93	33.93	33.93	33.93	33.93	33.93	33.93
Shelling and Bagging	17.26	43.35	60.24	75.96	75.96	82.87	82.87	93.23	93.23
Transportation	2.60	6.52	9.06	11.43	11.43	12.47	12.47	14.02	14.02
Total variable cost	242.13	285.94	308.98	381.38	395.18	406.73	430.49	456.21	459.82
Output/revenue									
Average grain yield (kg/ha)	520.8	1307.7	1817.3	2291.7	2291.7	2500	2500	2812.5	2812.5
Adjusted grain yield*	468.72	1176.93	1635.57	2062.53	2062.53	2250	2250	2531.25	2531.25
Gross benefit (US\$/ha)	339.34	852.08	1184.12	1493.23	1493.23	1628.96	1628.96	1832.58	1832.58
Net benefit (US\$/ha)	97.22	566.14	875.14	1111.85	1098.05	1222.23	1198.47	1376.37	1372.76
Benefit:cost ratio	0.4	2.0	2.8	2.9	2.8	3.0	2.8	3.0	3.0

†Average yield adjusted 10% downward; market price of groundnut at the nearest market (Tamale market) as at December 2018 = US\$ 0.72/kg.

‡P0, P rate at 0 kg P₂O₅/ha; P30, P rate at 30 kg P₂O₅/ha; P60, P rate at 60 kg P₂O₅/ha; I0, Inoculant rate at 0 g/kg seed; I3, Inoculant rate at 3 g/kg seed; I6, Inoculant rate at 6 g/kg seed.

production for the different technologies. The cost of producing groundnut by applying P alone at either 30 or 60 kg P₂O₅/ha was 57.5% (USD 381/ha) and 77.8% (432 USD/ha) higher respectively than the control (249 USD/ha). Similarly, applying inoculant alone at either 3 or 6 g/kg seed increased the production cost by 18% (331 USD/ha) and 28.5% (320 USD/ha) respectively above the control. Substituting 30 kg P₂O₅/ha with 60 kg P₂O₅/ha increased the

production cost by 12.9% while replacing 3 g/kg seed with 6 g/kg seed inoculant raised the production cost by 8.1%. However, increasing rate of P from 30 to 60 kg P₂O₅ and inoculant from 3 to 6 g/kg seed, which added to the cost of production, did not significantly enhance grain yield. The application of 60 kg P₂O₅/ha with inoculant at 3 or 6 g/kg seed yielded higher net benefit than all the treatments. Furthermore, compared to the control, the B/C ratios for the

other treatments were all greater than 1.

DISCUSSION

The significant effect of P and rhizobium inoculant on plant height could possibly be attributed to the stimulation of vegetative growth by the application of P and inoculant. The increase in vegetative growth in response to phosphorus and inoculant

application has been reported by several authors (Kwari, 2005; Hasan and Sahid, 2016).

Nodulation plays important role in nitrogen (N) fixation by leguminous crop. In this study, the significant interaction effect of PR x IR on nodule count could possibly be due to the effectiveness of the P fertilizer rate in providing energy source (ATP) for rhizobium to enhance its nodule formation activity. This result concurs with earlier reports that P applied in combination with rhizobium inoculant increases nodule number per plant (Badar et al., 2015). Similarly, the number of effective nodules was significantly influenced by PR and IR effects. This finding indicates that the ability of peanut to nodulate and further produce effective nodules can also be influenced by the application of either P fertilizer rates or rhizobium inoculant rates.

The significant effect of PR x IR interaction on pod number could be attributed to the synergistic effect of PR and IR on pod formation. The increase in pod number with PR and IR application supports earlier reports that integrated application of P fertilizer and rhizobium inoculant result in improved soil productivity because of the supply of P for improved N fixation by the bacteria. Conversely, in spite of the increased number of pods, pod weight was not significantly affected by PR x IR interaction. The failure of higher pod number to translate into pod weight could be due to poor pod filling, encountered as a result of drought during the pod filling stage. Pod filling in legumes tends to be ineffective under extreme drought conditions (Schulz and Thelen, 2008).

Although the interactive effect of PR x IR was not significant on grain yield, the effects of PR and IR significantly contributed to grain yield. This result suggests that the use of either P fertilizer or rhizobium inoculant is very important for groundnut production. This finding is in agreement with earlier observations made by Ikenganyia et al. (2017) that phosphorus and rhizobium inoculant impact positively on grain yield.

The expected profitability of a technology is a prerequisite for adoption by smallholder farmers (Morris et al., 1999). This study has revealed that groundnut production can be very profitable with the application of P fertilizer and/or rhizobium inoculant. Accordingly, gross benefits were much higher in treatments with P fertilizer and/or rhizobium inoculant than the control. Similar economic benefits with P and inoculant application have been reported by several authors (Naab et al., 2009; Ahiabor et al., 2014). Although the application of inoculant alone increased grain yield and gross benefits per hectare relative to its' control, these were nevertheless lower when compared with P fertilizer alone or its combination with rhizobium inoculant. This result indicates that phosphorus is the main deficient factor for groundnut production in the study area. This finding corroborates study by Adjei-Nsiah et al. (2018). The estimated B/C ratios for plots with P fertilizer and rhizobium inoculant applications, shows the attractiveness of the treatments. A farmer could adopt the combined

application of P fertilizer at 30 kg P₂O₅/ha and inoculant at 6 g/kg seed, as it gives a high return to investment at a relatively lower production cost and higher net benefit. However, according to Morris et al. (1999), in reality the uptake of agricultural technology is more likely to proceed erratically as individual farmers learn to adapt the technology to their own socio-economic circumstances. Therefore, depending on resource availability (P fertilizer and inoculant), small-scale groundnut farmers with low resource endowment could either adopt the application of P alone at either 30 kg P₂O₅/ha or inoculation alone at 6 g/kg seed while those with more resource endowment could use P fertilizer at 60 kgP₂O₅/ha alone or in combination with rhizobium inoculant at either 3 or 6 g/kg seed.

Conclusion

Results show that P fertilizer rates combined with rhizobium inoculant rates has a significant influence on nodule number and pod number. P rate at 60 kgP₂O₅/ha and rhizobium inoculant rate at 6 g/kg seed combined to promote the best nodule and pod number. The application of either P fertilizer or inoculant affected groundnut grain yield significantly. Higher grain yields were observed in groundnut sown with either 60 kg P₂O₅/ha or 6 g/kg seed. Gross and net benefits were all higher in treatment with P fertilizer and/or inoculant application. Estimated B/C ratios also indicated that, compared to the control, all the treatments are attractive. Therefore, cultivating groundnut by using P fertilizer and/or inoculant may provide economically viable and low-risk options for increasing groundnut yield in northern Ghana.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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