Growth and yield response of soybean [*Glycine max* (L.) Merrrill] to inoculation and starter N fertilizer applications in the Tolon District of the Northern Region of Ghana

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ABSTRACT

An experiment was conducted at Nyankpala in the 2012 cropping season and repeated in the 2013 cropping season in the Tolon District of the Northern Region of Ghana. This was to ascertain the effect of N fertilizer and inoculant applications on the growth and grain yield of soybean (*Glycine max* [L.] Merrill). It was a 3 × 5 factorial experiment laid in Randomized Complete Bock Design (RCBD) with four replications. The factors were three soybean varieties (Jenguma, Quarshie and Anidaso) and four levels of N fertilizer (urea), which were 0, 15, 30 and 45 kg N ha^{-1} and inoculant. The inoculant was applied at the rate of 5 g to 1 kg of soybean seed through the slurry method that was estimated to give 10^7 of viable rhizobia cells. Planting was done on 14th and 10th July, 2012 and 2013, respectively, by drilling. Thinning was later done to two plants $hill^{-1}$ at 10 cm within rows and 50 cm between rows with an approximate plant population of 400 000 plants ha^{-1}. The N fertilizer was applied to randomly assigned plots 2 weeks after planting (2 WAP) in drills 5 cm away from the plants and covered. Growth parameters measured were plant height, leaf area, number of primary branches, nodule and shoot dry weights. Grain yield was measured from 2 m × 2 m net plot and extrapolated to kg ha^{-1}. Results showed that all the varieties nodulated following the inoculation. It also showed that there was promiscuous nodulation where inoculants were not applied. The inoculated treatment produced greater plant growth, grain yield and the amount of N fixed than the uninoculated control. Growth and yield were greatest in the 30 and 45 kg N ha^{-1} treatment compared with the other treatments. The results showed that for profitable soybean production in the study area, inoculation or 30-45 kg N ha^{-1} fertilizer should be applied.

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Introduction

Soybean [*Glycine max* (L.) Merrill] is one of the most important oil seed crops in the world and produces more oil per unit land than any other crop (Aduloju *et al*., 2009). It is also an impor-tant source of protein for both human consump-tion and for animal feed, and it is used for pharmaceutical and other industrial purposes. In Ghana, the crop is mostly produced in the savanna zones by smallholder farmers, where soils are depleted of nutrients with yields as low as 0.8 ton ha^{-1} (MiDA, 2010; Mbanya, 2011) compared with 4.6 tons ha^{-1} in the US (Richard *et al*., 1984). There is a huge gap between Ghana's soybean consumption and total production, which leads to huge imports from Brazil and the

US. This has a serious implication for the import bill of the government and the overall effect on the local currency. Ghana can increase her soybean production and reduce the import bill and even become a net exporter of soybean to other neighbouring countries, if small scale and commercial farmers improve their productivity by using improved agronomic practices (Mbanya, 2011).

Relying on the soil to meet the total soybean nitrogen needs may not be enough in some ecologies (Soulsoki & Bucham, 1978), and this makes the use of N fertilizer and /or inoculant necessary. With appropriate technologies, soybean has the potential of fixing atmospheric N_2 to levels of 360-450 kg N ha^{-1}, which will enable yields to go up to 5,600 kg ha^{-1} and provide residual N for the succeeding crops (Giller, 2001). Higher yields of 6,000 kg ha^{-1} have been recorded in Brazil and Argentina using effective inoculants (Hungria *et al.,* 2006). A study by Sanginga *et al.,* (1997) in the southern guinea savanna zone in Nigeria, using the ^{15}N isotope dilution method to assess symbiotic BNF, response to inoculation of different soybean lines showed that rhizobial inoculation increased total N and grain yield of early maturing cultivars. The ability of legumes to fix atmospheric N allows them to grow in N impoverished soils. More than 250 kg N ha^{-1} of fixed N_2 has also been measured in soybean in southern Africa with associated grain yields of 4.0 tons ha^{-1} (Giller, 2001). Several reports indicated that symbiotic N_2 fixation alone may not meet soybean N requirement during early and late phases of growth especially in very poor soils. Therefore, small amounts of N fertilizer supplied early to start the crop often promote growth and N_2 fixation in legumes (Sanginga, 2003; Okugun & Sanginga, 2003; Osborne & Riedell, 2006; Tahir *et al*., 2009).

Increased soybean production through the use of improved technologies such as the use of inoculants and fertilizer applications has been recorded in recent works in Ghana (Asei *et al*., 2015). Several workers have argued differently in respect of N fertilization of soybean as factors such as temperature, moisture and soil *p*H affect the response of soybean to N fertilizer (Bergersen *et al*., 1989; Sawyer & Barker, 2001). It has been reported that N fertilizer application to soybean improved growth, biomass and grain yield (Pikul *et al*., 2001; Umeh *et al.,* 2011). The introduction of rhizobia through inoculation technology and N fertilizer at the early stage of growth to enhance biological nitrogen fixation (BNF) and improved yield is environmentally friendly. This is, however, not common with Ghanaian farmers as inoculants are not readily available locally. Therefore, there is the need for investigations in order to come up with packages that can enhance and sustain soybean production in some parts of the Guinea savanna zone of Ghana where soybean cultivation is a business.

The objective of the experiment was to study the effect of inoculant application and determine the N fertilizer level for soybean in the area.

Materials and methods

Experimental design and treatments

Two experiments were carried out at Nyankpala in the Tolon District within the Guinea savanna zone of Ghana in the 2012 and 2013 cropping seasons. The sites were located between latitude 09°24' 15.9" N and longitude 01° 00' 12.1" W with an elevation of 182 m above mean sea level. The rainfall in the study area is unimodal and ranges between 1000 and 1200 mm annually with temperatures ranging from 26 to 39 °C.

Each field was ploughed and harrowed 2 weeks later using a disc harrow. Each of the experimental fields measured 20 m × 90 m. The experiment was a 3 × 5 factorial arranged in Randomised Complete Block Design (RCBD) with four replicates. The factors were three soybean varieties (Jenguma, Quarshie and Anidaso) and four levels of N fertilizer 0, 15, 30 and 45 kg N ha^{-1}, and rhizobia from Legume Fix (inoculant) applications of 5g 1 kg^{-1} of soybean seed. The alleys separating the replications were

2.0 m while those separating the varieties and the fertilizer levels/ inoculant were 1.5 m and 1.0 m, respectively.

Planting of experimental field and Nitrogen fertilizer application

Planting was done on 14th and 10th July 2012 and 2013, respectively, after the seeds were inoculated using the slurry method as outlined by Woomer *et al*., (1994) that is estimated to give 10^7 of viable rhizobia cells. Planting was done manually on flat by drilling and later thinned to 10 cm between plants with two plants per hill. Each plot had eight rows with 30 stands that gave an approximate plant population of 400,000 plants per hectare. Weed control was done manually using the hoe 3 weeks after planting (WAP) and hand pulling of weeds was done at 8 weeks after planting (WAP) on all replications. Phosphorus was applied at plan-ting at the rate of 30 kg P ha^{-1} to all plots to promote root development. Nitrogen fertilizer was applied as urea (46% N) at 0, 15, 30 and 45 kg N ha^{-1} to randomly assigned plots by drilling 5 cm away from the plants and buried at 2 weeks after planting to all plots except the inoculants and control plots.

Data collection

Five plants were randomly selected in the second and seventh rows in each plot and tagged. Plant heights were taken with graduated meter at 20, 40 and 60 days after planting (DAP). The average plant height of the five plants was recorded to represent the treatment during each period. Leaf area was measured non-destructively at 60 DAP. Three tagged plants in each plot were taken and measurements of three leaflets from each level (lower, middle and upper) were done according to the method of Wilhelm & Nelson (2000). The leaf area was estimated from the relationship: LA (cm^2) = (L × B) × 0.74. The mean was then calculated for each plot.

At 60 DAP, number of branches of the five tagged plants in each plot was counted and the average computed for the plot. Shoot dry weight was taken at 60 DAP where five plants were randomly taken from the second and seventh rows in each plot and cut at the ground level, placed in brown labelled envelops and oven dried at 65 °C for 72 h and the weight recorded for each plot. Nodule count was done at 60 DAP by randomly selecting five plants from the second and seventh rows. These were carefully dug with a shovel. Soil was gently removed and all nodules picked into a transparent poly sack and sent to the laboratory. The roots were gently washed under a tap over a fine sieve to remove all soil particles and dirt. These were air-dried under a fan after which the nodules were counted and means recorded. The nodules of each sample were put in brown labelled envelops and oven-dried at 65 °C for 72 h to a constant weight. The average nodule dry weight was determined for each plot.

Grain yield and Nitrogen fixation

The grain yield was determined from a net plot of 2 m × 2 m measured within the four middle rows of each plot. Plants within the net plot were harvested at ground level and put in labelled sacks and sent to the yard. Each sample was sun-dried for 1 week and the weight taken with a spring balance and recorded. The samples were then threshed and the grain also sun-dried for 1week and the weight taken. The crop residue yield was taken as the difference between the weight before threshing and the weight of the grain. The grain yield in kg from the net plot was extrapolated to kg ha^{-1}. The Total Nitrogen difference method (TND) as described by Herridge *et al., (*2008) was used to determine the amount of N fixed, using maize as a reference crop. Both legume and non-legume were harvested for N determination. Nitrogen fixed was calculated using the formula: N fixed (kg N ha^{-1}) = Total N in legume – Total N in reference crop.

The N derived from the atmosphere was calculated using the formula:

$$\%\ NDFA = \frac{\text{Total N in legume} - \text{Total N in reference crop}}{\text{Total N in legume}} \times 100.$$

Data analysis

All data were subjected to analysis of variance (ANOVA) using GENSTAT 2009 package. The Least Significant Difference (LSD) at probability of 5 percent was used to compare treatment means.

Results

Climatic information

The climate at Nyankpala is warm with a unimodal annual rainfall of 800-1200 mm which falls mostly between May/June to October. This is followed by 6 months of long dry season characterized by the dry North-East trade winds also known as the Harmattan with high risk of uncontrollable wild fires leading to loss of vegetation cover of the soil. Temperatures range from minimum of 26 °C to a maximum of 39 °C with a mean of 32 °C (Table 1). During the harmattan period temperatures are between 16 and 18 °C during the night and 34 °C during the day.

TABLE 1

Climatic data of Nyankpala during the 2012 and 2013 cropping season

Month	*Temperature (° C)*		*Rainfall (mm)*		*Relative humidity (%)*		*Number of rainy days*	
	2012	*2013*	*2012*	*2013*	*2012*	*2013*	*2012*	*2013*
June	27.7	27.8	149.0	161.9	81.0	79.0	8.0	8.0
July	26.1	26.7	199.0	203.8	86.0	84.0	13.0	10.0
August	25.7	25.9	77.0	217.4	85.0	84.0	6.0	13.0
September	26.6	26.4	209.0	164.1	84.0	79.0	13.0	14.0
October	27.6	27.6	151.0	119.7	80.0	79.0	13.0	13.0
November	29.1	29.0	0.0	23.3	73.0	68.0	0.0	2.0
December	27.3	27.5	4.8	0.0	53.0	60.0	1.0	0.0
Total	-	-	790.0	890.2	-	-	54.0	70.0

Source: 2012 and 2013 weather figures from CSIR-SARI

Initial soil chemical properties

The soil chemical analysis of the study areas as presented in Table 2 indicates that both soils were acidic with *p*H values ranged from 5.21 to 5.97 in 2012 and 2013. The common characteristics of savanna soils are evident as percent total nitrogen ranged from 0.02 to 0.04 percent and organic carbon from 0.07 to 0.51 percent in 2012 and 2013, respectively.

Available phosphorus was also very low ranging from 3.24 to 3.44 mg kg^{-1} in both seasons, hence the need for P fertilization, especially for crops like soybean. Exchangeable bases were also very low (< 2 Cmols/kg soil) at both sites during the periods.

TABLE 2

Initial soil chemical properties at Experimental sites in 2012 and 2013 cropping seasons

Soil chemical property	*2012*	*2013*
Soil *p*H(1:2.5; H_2O)	5.97	5.21
Total N (%)	0.04	0.02
Organic carbon (%)	0.51	0.07
Organic matter (%)	0.88	0.47
Available P (mg/kg)	3.44	3.24
Exchangeable bases (Cmol/kg)		
K	0.04	0.19
Na	0.05	0.12
Ca	1.54	2.40
Mg	0.50	0.80

Source: Soil analysis, 2012 and 2013

Final soil chemical properties

The final (after harvest) soil analysis indicated that soil *p*H was between 5.10 and 6.33 in 2012 and 2013 cropping seasons (Table 3). In 2012, the effect of Jenguma on *p*H differed significantly ($P < 0.05$) from Quarshie and Anidaso. However, at the same location in 2013, all varieties did not show significant ($P > 0.05$) difference in *p*H. The results also indicated that the three varieties were not significantly ($P > 0.05$) different in their contribution to soil organic carbon in both cropping seasons. Similarly, the three varieties were not significantly ($P > 0.005$) different in percent total N in the two cropping seasons.

The inoculant and the nitrogen level treatments were not significantly ($P > 0.05$) different in *p*H in both seasons. Also, the N fertilizer treatments and inoculant did not differ significantly ($P > 0.05$) in percent organic carbon in both years. The control (0 kg N ha^{-1}), however, was significantly lower ($P < 0.05$) than the inoculant and all the other N treatments effects in percent organic carbon in 2013. In terms of percent total N, the treatments were not significantly different in 2012. The control showed significantly ($P < 0.05$) lower total N than the inoculant and the fertilizer levels in both years.

TABLE 3

Effect of variety, inoculant and N fertilizer on pH, organic carbon, and total N at the experimental site in 2012 and 2013

Treatments	*2012 cropping season*			*2013 cropping season*		
Variety	*pH*	*Organic carbon (%)*	*Total N (%)*	*pH*	*Organic carbon (%)*	*Total N (%)*
Janguma	6.10	0.75	0.06	5.20	0.32	0.03
Quarshie	6.11	0.76	0.07	5.24	0.32	0.03
Anidaso	6.33	0.63	0.07	5.33	0.32	0.03
LSD (5%)	0.07	NS	NS	NS	NS	NS
N level (Kg N ha^{-1})						
0	6.21	0.58	0.03	5.21	0.23	0.02
Inoc	6.19	0.67	0.07	5.26	0.33	0.03
15	6.15	0.72	0.07	5.27	0.33	0.03
30	6.12	0.80	0.07	5.31	0.34	0.03
45	6.12	0.79	007	5.22	0.37	0.03
LSD (5 %)	NS	0.22	0.4	NS	0.40	0.10
CV (%)	7.70	0.60	9.70	3.20	0.30	9.90

NS= Not significant at 5 % probability.

Growth parameters

The results of plant height at 20, 40 and 60 DAP are presented in Table 4. At 20 DAP, the Anidaso variety recorded significantly ($P < 0.05$) higher plant height than Jenguma. At 40 DAP, the three varieties had similar heights ($P > 0.05$) different. At 60 DAP, plant height of Jenguma variety was significantly higher than those of the two other varieties. On all sampling dates, the 45 kg N ha^{-1} treatment effect had the greatest effect on plant height, although its effect was similar to that of the 30 kg N ha^{-1} treatment.

The inoculant treatment effect was significantly higher than the control treatment at all sampling dates while treatment effect of the 30 kg N ha^{-1} was significantly higher than that of the 15 kg N ha^{-1}.

Varieties × N treatments interactions were not significant in plant height on all the sampling

TABLE 4

Effect of variety, N fertilizer and inoculation on plant height at 20, 40 and 60 DAP

Treatment	*Plant height in 2012 cropping season (cm)*			*Plant height in 2013 cropping season (cm)*		
Variety	*20 DAP*	*40 DAP*	*60 DAP*	*20 DAP*	*40 DAP*	*60 DAP*
Jenguma	12.6	33.3	51.6	12.40	32.40	51.70
Quarshie	12.9	33.5	47.5	12.70	33.00	46.50
Anidaso	13.1	33.8	47.5	12.90	33.40	49.80
LSD (5%)	0.34	NS	3.54	0.36	NS	2.85
N levels (kg N ha^{-1})						
0	11.6	25.8	43.8	11.30	24.80	37.70
Inoculant	12.2	30.4	47.6	12.10	30.00	45.90
15	13.2	35.2	48.3	12.80	34.50	46.60
30	13.6	37.6	51.6	13.50	36.90	50.40
45	13.8	38.5	52.5	13.70	38.50	54.20
LSD (5%)	0.4	1.6	4.6	0.47	1.66	3.68
CV (%)	4.7	5.2	11.6	4.80	6.70	14.40

NS= Not significant at 5 % probability.

Number of primary branches was significantly different ($P < 0.05$) among the varieties (Table 5), with Quarshie producing the greatest number of branches which was significantly higher than the other two varieties. The results showed that Nitrogen application did not affect branch production. Leaf area was significantly affected by soybean variety, as Anidaso had the highest leaf area, followed by Jenguma and Quarshie in that order. Leaf area results from the N treatments showed that the 45 kg N ha^{-1} treatment had affected the leaf area the most. The N-applied and the inoculant treatments effects were greater than the control treatment effect during the sampling periods. Differences in leaf area between 15 and 30 kg N ha^{-1} treatments were not significant during the period of sampling. It was also observed that variety × N fertilizer interaction did not result in significant ($P > 0.05$) difference in number of branches and leaf area in both seasons.

TABLE 5

Influence of variety, N fertilizer and inoculant on number of primary branches and leaf area at 60 DAP

Treatment	*Growth parameters in 2012*		*Growth parameters in 2013*	
Variety	*Number of branches*	*Leaf area (cm^2)*	*Number of branches*	*Leaf area (cm^2)*
Jenguma	2.4	68.7	2.50	50.00
Quarshie	3.5	56.6	2.50	61.90
Anidaso	1.8	80.3	2.20	74.20
LSD (5%)	0.6	5.9	0.20	7.10
N level (kg N ha^{-1})				
0	2.4	53.7	2.20	49.40
Inoculant	2.9	67.1	2.90	69.00
15	2.6	70.8	2.20	68.00
30	2.5	71.5	2.20	76.70
45	2.5	79.5	2.10	78.70
LSD (5%)	NS	7.5	0.40	9.10
CV (%)	14.7	14.1	14.10	14.50

NS= Not significant at 5 percent probability

The varietal difference in nodule dry weight and nodule numbers were not significant ($P > 0.05$), while shoot dry weight was, however, significantly different among the varieties with Quarshie recording the greatest dry weight (Table 6). The application of different levels of nitrogen fertilizer and inoculant to the soybean produced greater nodule dry weight than the control treatment. The results showed there was no significant ($P > 0.05$) difference in nodule dry weight among the inoculant and the fertilizer levels, but all treatment effects were significantly higher than the control. For shoot dry weight, there was varietal difference among the three in 2012 with Quarshie recording the greatest shoot dry weight in both years. The greatest effect of the treatments was recorded for 30 and 45 kg N ha^{-1} treatments which were significantly higher ($P < 0.05$) than the control and the inoculant treatments. Additionally, the control treatment effect was the least among the treatments.

TABLE 6

Effect of variety, N fertilizer and inoculant on nodule number, nodule and shoot dry weights at 60 DAP in 2012 and 2013 cropping seasons

Treatment	*2012 cropping seasons*			*2013 cropping seasons*		
Variety	*Nodule number plant^{-1}*	*Nodule dry weight plant^{-1} (g)*	*Shoot dry weight (kg ha^{-1})*	*Nodule number plant^{-1}*	*Nodule dry weight plant^{-1} (g)*	*Shoot dry weight (kg ha^{-1})*
Jenguma	16.40	0.816	4288	14.00	0.512	4897.00
Quarshie	17.40	0.817	5686	14.00	0.504	5018.00
Anidaso	16.70	0.818	4917	15.00	0.548	4698.00
LSD (5%)	NS	NS	406.4	NS	NS	NS
N level (kg N ha^{-1})						
0	15.90	0.624	3487	16.00	0.579	3777.00
Inoculant	20.50	0.859	4733	23.00	0.725	4813.00
15	14.40	0.849	4880	13.00	0.533	4770.00
30	11.80	0.853	5427	11.00	0.430	5137.00
45	11.50	0.895	5492	9.00	0.339	5415.00
LSD (5%)	3.40	0.058	524.7	3.40	0.155	760.80
CV (%)	12.10	2.8	12.8	6.00	10.50	18.80

NS= Not significant at 5 percent probability.

Grain yield, Nitrogen derived from the atmosphere and Nitrogen fixation

The result showed that grain yield among the varieties was significantly different (Table 7). Jengum produced significantly greater grain yield than the Anidaso, but Quarshie and Anidaso varieties produced similar grain yields. The 45 kg N ha^{-1} treatment effect was the greatest, and this was significantly higher than all other treatment effects. The inoculant treatment effects was also significantly higher than the control treatment effect, but significantly lower than the 15 kg N ha^{-1} treatment effect, which gave the least response among the N-applied treatments.

The amount of N-derived from the atmosphere (%Ndfa) during both years showed that varietal effect was not significant. The %Ndfa as a result of the control treatment was significantly lower than the inoculant effect in both years. The 45 kg N ha^{-1} treatment had the highest %Ndfa which was significantly higher than those of the control and inoculant treatments in both years. The other N fertilizer treatment effects were similar. Soybean variety did not affect nitrogen fixed. Among the N fertilizer treatments, N fixation was greatest in the 45 kg N ha^{-1} treatment but was significantly higher than the control treatment effect only. All the N-

TABLE 7

Effect of variety, N fertilizer and inoculant on grain yield, nitrogen derived from the atmosphere (Ndfa) and N fixed at the study sites

Treatment	*2012 Cropping season*			*2013 Cropping season*		
Variety	*Grain yield (kg ha^{-1})*	*Ndfa (%)*	*Total N fixed (kg N ha^{-1})*	*Grain yield (kg ha^{-1})*	*Ndfa (%)*	*Total N fixed (kg N ha^{-1})*
Jenguma	2048	59.70	83.80	2065	59.10	74.40
Quarshie	1950	59.10	82.30	1994	58.20	74.90
Anidaso	1925	57.60	79.00	1968	61.00	75.80
LSD (5%)	96.5	NS	NS	79.2	NS	NS
N level (kg/ha)						
0	1590	46.20	48.20	1551	50.60	57.00
Inoculant	1855	59.90	81.30	1867	58.50	73.20
15	2012	61.60	87.20	2148	62.50	81.30
30	2100	62.40	84.40	2185	62.80	82.60
45	2146	66.00	88.20	2292	65.20	82.90
LSD (5%)	125.0	4.60	13.70	102.2	9.20	11.70
CV (%)	7.8	9.00	19.10	6.2	12.20	12.60

NS= Not significant at 5% probability.

Discussion

Soil chemical properties

It was observed from the initial soil analysis that the soils were highly deficient in total N and organic carbon, which are key to crop growth and yield. Phosphorus was also found to be inadequate and, hence, the basal application of 30 kg P ha^{-1} at planting. The final soil test (after harvest) as expected showed that the soils were acidic in both years. There was, however, a slight increase in the *p*H level that could not be attributed to the varietal effects. The increase in *p*H level could be attributed to the dissolution of ashes from burnt crop residue and yam stakes from the previous seasons. It has been reported that wood ash contain about 20 percent calcium and could raise the *p*H level of soils (Griffin, 2006). It was established that the varietal effects on organic carbon at the experimental sites after harvest increased over the initial organic carbon level. In 2012 at Nyankpala, Quarshie contributed to increasing organic carbon from the initial level of 0.51 to 0.76 percent (32 %), which was similar to that of Jenguma, while Anidaso increased it by 19 percent.

Effects of variety, N fertilizer application and inoculation on plant growth

Generally, plants of Anidaso were tallest only at 20 DAP while those of Jenguma was tallest at 60 DAP in both years. Varietal differences in plant height had been observed in several crops and in soybean, in particular, as several workers have attributed this to genotypic difference among the varieties (Ahmed *et al.*, 2010; Ponnuswamy *et al.*, 2001). The progressive increase in height in all varieties across sampling periods in both years has been recorded by several workers in crops. Plant bodies are normally small during the early part of their growth and are not able to use all the growth resources, but with increase in plant body, more resources are used, and, therefore, growth becomes rapid (Gardner *et al.,* 1985), hence, the rapid increase (about 300%) between 20 and 40 DAP. The slow growth between 40 and 60 DAP was because the plants were approaching the reproductive stages of growth.

There was increase in plant height following application of N fertilizer and inoculants over the control with the 45 kg N/ha treatment recording the highest. Plant heights of all N-applied treatments were greater than the inoculant treatment effect, which is in keeping with earlier findings that soybean height increases with increasing level of N fertilizer (Umeh *et al.,* 2011; Osodeke, 2001). The results also agree with Achakzai *et al*., (2012) who reported a significant difference among N fertilizer treatment levels compared with no N fertilizer treatment. The better performance of the inoculation treatment at 40 and 60 DAP over the control treatment is consistent with the findings of Malik *et al.,* (2006), who found out that the effects of inoculation treatment on plant height was significantly higher than the control. This study revealed that the 15 kg N ha^{-1} and the inoculant produced similar plant height of 68.5 cm and 68.4 cm, respectively, at 60 DAP suggesting the two treatments have similar effects in study area.

The probable cause of difference in number of branches as well as leaf area could be due to genotypic differences as suggested by Umeh *et al*. (2011), where the number of branches differed significantly in all varieties. The non-significant effect of the N fertilizer on the number of branches is in contrast with the findings of Bekere *et al*., (2013) and Umeh *et al.* (2011), where N fertilization of soybean significantly affected number of branches of soybean. Leaf area differences among varieties have also been related to genetic make-up (Ponnuswamy *et al*., 2001; Ahmed *et al.,* 2010). Among the N-applied treatments, the 45 kg N/ha treatment effect produced the greatest leaf area on all sampling periods and the inoculant treatment was significantly higher than that of the control treatment. This may be due to the N availability following N fertilizer applications and inoculation as its importance for leaf production is well known in plant and crop physiology (Gardener *et al.*, 1985; Umeh *et al.*, 2011; Ahmed *et al.*, 2013).

Effect of variety, N fertilizer and inoculation on nodule number, nodule and shoot dry weights

Nodule number and nodule dry weight did not vary among the soybean varieties as earlier reported by Abdul-Latif (2013). It has been reported that some varieties that produced numerically greater number of nodules had lower nodule dry weight because their nodules were small in size whilst those that produce less number of nodules recorded bigger nodule weight (Giller, 2001). Additionally, nodule dry weight of the N- applied and inoculation treatment effect were greater than the control treatment effect, confirming the report by Asei *et al*., (2015), that inoculant treatments record significantly higher nodule dry weight than the control treatment.

Effect of variety, N fertilizer and inoculation on grain yield and N fixation

The varieties showed a higher yield in this study as against yields of 0.8-1.2 tons ha^{-1} reported for the same varieties in the Guinea savanna zone of Ghana (MiDA, 2010; Mbanya, 2011; Abdul-Latif, 2013). This is obviously due to the use of the improved varieties and other management practices such as inoculation, the right spacing, and starter N fertilizer application. The effect of variety on grain yield was significantly different in both years and could be attributed to genotypic difference of the varieties (Achakzai *et al.,* 2012). It was observed that the 45 kg N ha^{-1} treatment produced the greatest grain yield than both the inoculant and the control treatments. The results agree with Thies *et al*., (1991), who reported significantly higher grain yield due to N fertilizer application than inoculation. It also agrees with the reports of Umeh *et al.,* (2011), who observed that application of N fertilizer significantly increased grain yield of soybean. The increase in the N fertilizer levels correspon-dingly increased the N fixation during the study period with the N treatments fixing more N than the control treatment and, hence, corresponding high grain yield. All the N fertilizer levels and the inoculant significantly fixed more N than the control since N was available for the healthy growth of the plants.

Conclusion and recommendations

The results showed that all the varieties nodulated freely with the introduced rhizobia. Nodulation and nodule dry weights were similar in all the varieties. Additionally, inoculation resulted in greater growth and grain yield and amount of N fixed over the uninoculated control. Soybean grain yield was greatest following application of 45 kg N ha^{-1} over the other N rates. This indicates that 45 kg N ha^{-1} rate would be the best rate for soybean farmers in Tolon and its environs, where soil properties are similar. It is, therefore, recommended that for more profitable soybean production, inoculation or starter N fertilizer application at 30 – 45 kg N ha^{-1} should be practiced in the district.

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