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Influence of phosphorus fertilizer blends on insect pest incidence, yield and profitability of soybean production in the Guinea Savannah agro-ecological zone of Ghana

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Field studies were conducted to test the effects of different fertilization regimes on insect pest abundance and grain yields of soybean, as well as on their profitability in the Guinea Savannah zones of Ghana. A total of five fertilization regimes were tested, and these were: 250 kg ha^{-1} TSP (46% P_2O_5 or 20%P) applied at sowing; 250 kg ha^{-1} YARA Legume II (4%N, 7.9%P, 10.8% K, 31%CaO (insoluble), 6%CaO (soluble), 3% MgO, 3%S, 0.075% B) applied at sowing; 250 kg ha^{-1} YARA Legume II applied at four weeks after sowing (WAS); 65kg ha^{-1} Nitrabor (15.45% N, 26%CaO, 0.3 B) applied at sowing plus 185 kg ha^{-1} YARA Legume I (0 % N, 7.9% P, 10.8% K, 31% CaO (insoluble), 4%S, 2% MgO) applied at 4WAS; 185 kg ha^{-1} YARA Legume I applied at sowing plus 65 kg ha^{-1} Nitrabor applied at 4WAS. The experiments were laid in randomized complete block designs with three replicates. Fertilization enhanced soybeans' ability to overcome pest infestations, with plants treated with Nit-65+YLI-185 and YL II-250 + 0 Fert recording lower pest populations and significantly lower pest damages compared to the unfertilized plot. Fertilizer application increased soybean yield by 2269 kg ha^{-1} in the on-station experiment and by 1334 kg ha^{-1} in the on-farm experiment. In the on-station experiment, fertilizer use efficiency ranged from 5.5 kg grain per kg fertilizer applied at the 250 kg ha^{-1} YARA Legume II at 4 WAS to 12 kg grain per kg fertilizer applied with the 65kg ha-1 Nitrabor at sowing plus 185 kg ha-1 YARA Legume I at 4WAS. A similar observation was made in the on-farm experiment but with lower values. Phosphorus use efficiency followed a similar pattern as in the fertilizer use efficiency in both the on-station and on-farm experiments. The highest value cost ratio was attained with 65kg ha-1 Nitrabor at sowing plus 185 kg ha-1 YARA Legume I at 4WAS treatment in both the on-station and on-farm experiments, indicating the potential of increasing the productivity of soybean and the income of farmers in northern Ghana through the regime of fertilization.

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1. INTRODUCTİON

Soybean (Glycine max (L.) Merr.) is an economically important grain legume globally. In 2021, approximately 350 million tons of soybean were produced; 3.1 million tons originated from Africa. West Africa accounted for about a third of Africa's total production (FAO, 2022). In West Africa, soybeans are an important component of the predominantly cereal- based farming systems in the savannah agro-ecological zone. The crop provides both income and nutritional security, especially for underprivileged households in this region. When grown in rotation, soybean reduces the mineral nitrogen fertilizer required for cereal crops due to its symbiosis with nitrogen-fixing bacteria, rhizobia (Giller et al., 2011). Despite its importance, soybean yields in the savannas of West Africa are extremely low, hardly exceeding one ton per hectare compared with the potential yield of 3.0 tons per hectare (AGRA, 2016). The low yield has been blamed on the use by farmers of low-yielding varieties, low soil fertility and limited use of inputs, particularly phosphorus fertilizers and rhizobium inoculants.

Soils in the Guinea savannah zone of Ghana are, however, low in fertility, which needs to be replenished through fertilization. Also, insect pests are assuming economic importance in soybean production (Abdullai, 2017). Soybean yield losses, estimated to be as high as 25.8% to 42.8%, have been attributed to infestation and damage by foliage- feeding and pod-sucking insects (Abudulai et al. 2012). Abudulai et al. (2012) reported significant damage caused by armyworms, Spodoptera spp and stink bugs Nezara viridula. Pod-sucking bugs are highly polyphagous and typically suck sap from pods, seeds, and other parts of the soybean plant. These bugs also cause necrosis which inhibits the agronomic performance of soybean, leading to an adverse economic impact on yield. According to Singh (2015), pod-sucking bugs, defoliators, phloem and stem feeders reduce the ability of soybean crops to fully utilize nutrients from the soils.

Although several studies have demonstrated the yield benefits of using phosphorus fertilizer and its blends on soybean in the Guinea savannas of West Africa (Ronner et al., 2016, Adjei-Nsiah et al, 2018, Adjei-Nsiah et al., 2021), few studies have evaluated the effects of phosphorus fertilizer blends on pest incidence in soybeans in the Savannah agro-ecology of West Africa. While Ochiro (2013) has demonstrated the effects of P and K fertilizers on soybean's resistance to insect pests, no clear relationship has been established between soyabean nutrition and its resistance to insect pests. YARA Ghana has over the past decade developed several phosphorus fertilizer blends as alternatives to the traditional TSP fertilizer being promoted by research and development in Ghana to improve soybean nutrition in northern Ghana. However, these formulations have not been evaluated in any one experiment to determine their agronomic efficacy, as well as their effects on pest incidence in soybean in the savannah agro-ecology of West Africa. The economic feasibility of these formulations has also not been evaluated. The present study was, therefore, carried out to test the influence of YARA fertilizer blends on insect pest infestations and the agronomic efficiency of soybean. It also assessed the economic viability of these Phosphorus fertilizer blends to guide farmers in the savannah agro-ecology in profitable soybean production.

2.0. MATERİALS AND METHODS

2.1. Study sites

On-station and on-farm trials were conducted in the Guinea savanna zone of Ghana to assess the influence of different fertilizer regimes on insect pest infestations and grain yields of soybean. The on-station experiment was carried out at the Experimental Farm of the University of Development Studies, Nyankpala, while the on-farm trial was conducted at Yendi Municipal (9o26'32.92"N, 0o022.95"W; 200 m asl) in the Northern Region of Ghana. These areas fall within the southern Guinea Savannah agro-ecological zone which is characterized by vast, low-lying areas of semi-arid grassland interspersed with savannah woodland. The soils in the area were developed over voltaian basin sandstones, shale, and mudstones. They have been classified as savannah ochrosols and groundwater laterites in the interim soil classification system for Ghana (Adjei-Gyapong and Asiamah 2002) and as plinthosols in the World Reference Base for soil resources (IUSS Working Group WRB 2015). The organic carbon (OC) and nitrogen (N) content of the soils are low (Hoskins 1997) and the basic cations are heavily leached.

Experimental design, treatments, and crop management.

At each location the experiment was conducted in a randomized complete block design with three replicates. Six treatments consisting of untreated control and five fertilization regimes were evaluated. The five fertilizer regimes were:

(i) YaraLegume I (0 % N, 7.9% P, 10.8% K, 31% CaO (insoluble), 4%S, 2% MgO) applied at 185kg/ha (14.62 kg P/ha) at sowing and top-dressed with Nitrabor (15.45% N, 26%CaO, 0.3 B) at 65kg/ha at 4WAS,

(ii) Nitrabor applied at 65kg/ha at sowing and top-dressed with YaraLegume I applied at 185kg/ha (14.62 kg P/ha) at 4WAS,

(iii) YaraLegume II (4%N, 7.9%P, 10.8% K, 31%CaO (insoluble), 6%CaO (soluble), 3% MgO, 3%S, 0.075% B) applied at 250kg/ha (19.75 P/ha) only at sowing,

(iv) YaraLegume II applied at 250kg/ha (19.75kg P/ha) only at 4 weeks after sowing (WAS),

(v) Triple super phosphate (TSP-46% P_2O_5 or 20%P) at 250 kg/ha (50kg P/ha) at sowing.

Table 1. Experimental treatments and time of application

Treatment	Time of application	
	At planting	4 WAS
YLI-185+NIT-65	185 kg ha^{-1} YLI	65 kg ha^{-1} NIT

NIT-65 + YLI-185	65 kg ha^{-1} NIT	185 kg ha^{-1} YL1
YLII-250 + 0 FERT	250 kg ha^{-1} YLII	No fertilization
0 FERT + YLII-250	No fertilization	250 kg ha^{-1} NYLII
TSP-250 + 0 FERT	250 kg ha^{-1} TSP	No fertilization
CONTROL	No fertilization	No fertilization

YLI=YARA Legume 1; YL II=YARA Legume II; NIT=Nitrabor; TSP=Triple super phosphate

Each field was disc plowed with a tractor and levelled with hand hoe in early July. Treatment plots each measured 5 m by 5 m with 1 m alley between plots and 2 m alley between blocks. The soyabean variety Jenguma was used for the study. It was planted at 40 cm between rows and 10 cm within rows at 2 seeds per stand. The pre-emergence herbicide, Glyphader 480 (360g/l glyphosate a.i.; SL) was applied at a rate of 2.5l/ha at planting to control surviving weeds. At each experimental site, application of the fertilizer treatments was done strictly in accordance with the protocol indicated in Table 1 above, using the deep placement method. Post-emerged weeds were controlled by hand weeding at 3, and 6 WAS. Bunds were constructed around each plot prior to application of the treatments to prevent fertilizer drift into adjacent plots. There was no insecticide application in the fields.

2.2. Data collection

Plant height

Plant height was taken at 4, 6 and 8 weeks after sowing (WAS). This was taken for 10 randomly selected plants in each treatment within a 3 m x 3 m middle section.Measurement was made from the base of the plants (above ground) to the highest growing point with the aid of a measuring tape attached to a straight edge stick. At 60 days after sowing (DAS) each treatment was closely observed with care and percentage flowering was assigned by visually judging the prevalence of flowers in the treatment plot.

Insect infestations

Determination of foliage feeders and their abundance was done 2 weeks after plant emergence. Three inner rows were selected from each plot for sampling, which involved rapid visual examination of selected rows in each plot for defoliator insects. Target species were grasshoppers, flea beetles and leafworms. All plants in the selected rows were counted and visually examined to record the number of defoliator insects (i.e. abundance). For actively flying insects, particularly during the seedling stage, the sweep net was used in collecting samples. Each sweep net sample consists of 3 separate sweeps done continuously by briskly thrusting the net downward in an arc of about 3 feet and perpendicular to the plant rows.

Damage scores

Scouting for damage by leaf-feeding insects also involved visually estimating the percentage of the total leaf surface consumed by the insects. The method for taking a single sample was to look up and down the row of plants and leaves in each plot and estimate the percentage defoliation on the plants observed using a 1-30 scoring scale, previously used by Badii (2005) where:

1-5 % = very low defoliation
6-10 % = low defoliation
11-15 % = high defoliation
16-20 % = very high defoliation,
21-25 % = severe defoliation, and
26-30 % = complete defoliation beyond recovery.

The estimated value for each sample was recorded and the procedure repeated for all samples from each plot. The average for the individual defoliation estimates over all the samples taken was computed.

Pod-Sucking Bugs infestations

Scouting for pod-sucking insects involved checking for stink bug infestation and damage using the same technique and procedures described above. However, most stink bugs occurred later than leaf worms, and scouting began when the soybean plants started to bloom (i.e., at 50 % flowering) and continued until pod development and maturity. Also, it was necessary to sample several sites in each plot (5-6 per plot) due to the tremendous variability in stink bug distribution within the field.

The rigid shake cloth (0.9 m x 0.9 m) white-coloured cloth, sometimes called a beat sheet or ground cloth technique, was used to sample and estimate the abundance of leafworms and leaf beetles in the field. The cloth was gently placed on the ground between the soybean rows at about a 45º angle, the plants were gently bent over the open side of the device, and the foliage was stricken down with the forearm or stick to dislodge caterpillars and/or beetles onto the sheet. Care was taken to prevent the plants from sweeping across the sheet and displacing the insects. Leafworms and/or beetles that fell onto the cloth were identified and counted.

Pod damage assessments

At the pod formation stage, green pods were sampled from each plot, transported to a laboratory, and examined for external feeding symptoms, after which they were dissected at the suture to evaluate for evidence of internal feeding on the interior pod wall and seed coat. Observed symptoms of stink bug feeding on green pods included shriveling, indentions, discoloration, and puncture marks.

Yields

An area of 25 m^2 per treatment was harvested, threshed, and winnowed. The grains were then air dried for two days and weighed at 12% moisture content. A moisture meter was used to ensure 12% moisture. Seeds were then weighed to obtain the yield for each treatment.

Soil analysis

During the establishment of the field experiments, top soil (0-20 cm depth) samples were collected from the on-station and on-farm fields. These samples were air-dried, sieved with a 2 mm mesh and analyzed for physico-chemical properties.

The agronomic P use efficiency (PUE) was calculated as shown in equation 1 (Yuen and Pollard 1953).

$$\text{Agronomic P use efficiency} = \frac{\text{Yield of fertilized plot} - \text{Yield of control plot}}{\text{Amount of P applied}} \quad (1)$$

The agronomic fertilizer use efficiency (AFUE) was computed using equation 2 (Vanlauwe et al 20111):

$$\text{Agronomic fertilizer use efficiency} = \frac{\text{Yield of fertilized plot} - \text{Yield of control plot}}{\text{Amount of fertilizer applied}} \quad (2)$$

Value cost ratio analysis

An economic analysis was performed on the profitability of using the different fertilization regimes. Profitability of applying P fertilizer blend to soyabean during the 2021 planting was evaluated through the value cost ratio (VCR) equation (Roy et al., 2006).

$$VCR = \frac{\text{Value of extra grain produced due to treatment } (\$\ ha^{-1})}{\text{Cost of treatment } (\$\ ha^{-1})} \quad (3)$$

As previously described by Roy et al. (2006), a VCR value ≥ 2 is considered profitable, VCR ≤ 1 is not profitable.

The price for soybean was the average market price for November 2021-May 2022. All the amounts are expressed in U.S. dollars (US$) at the average exchange rate for the period November 2021–May 2022 (6.5 GHC = US$1.00) (Bank of Ghana, 2022). The economic analysis was performed using a Microsoft Excel spreadsheet (version 2016). The VCR was estimated as shown in equation 3 (Roy et al., 2006). A sensitivity analysis was also carried out to determine the effects of price shocks on soybean production in the project area. The sensitivity analysis was based on the premise that, within the last three years, the soybean price has fluctuated between US$ 315 and US$ 878 per ton, while the cost of fertilizer use has increased by about 125%.

2.3. Data analysis

All count values were log transformed to normalize the data before analysis. Data were subjected to the Analysis of Variance (ANOVA) model using Genstat statistical package (12^{th} edition) and treatment means were compared using Fisher test for Least Significance Difference (LSD) at 5% probability level.

3.0. RESULTS

3.1. Soil Chemical properties

Soils samples which were analyzed for their chemical properties were moderately and strongly acidic, i.e., low pH values (Table 2). The total N for both the on-station and on- farm plots were also low. The on-farm fields had relatively high Organic matter but lowerphosphorus, potassium, calcium, and magnesium than the on-station field.

Table 2. Initial soil chemical properties of the experimental field

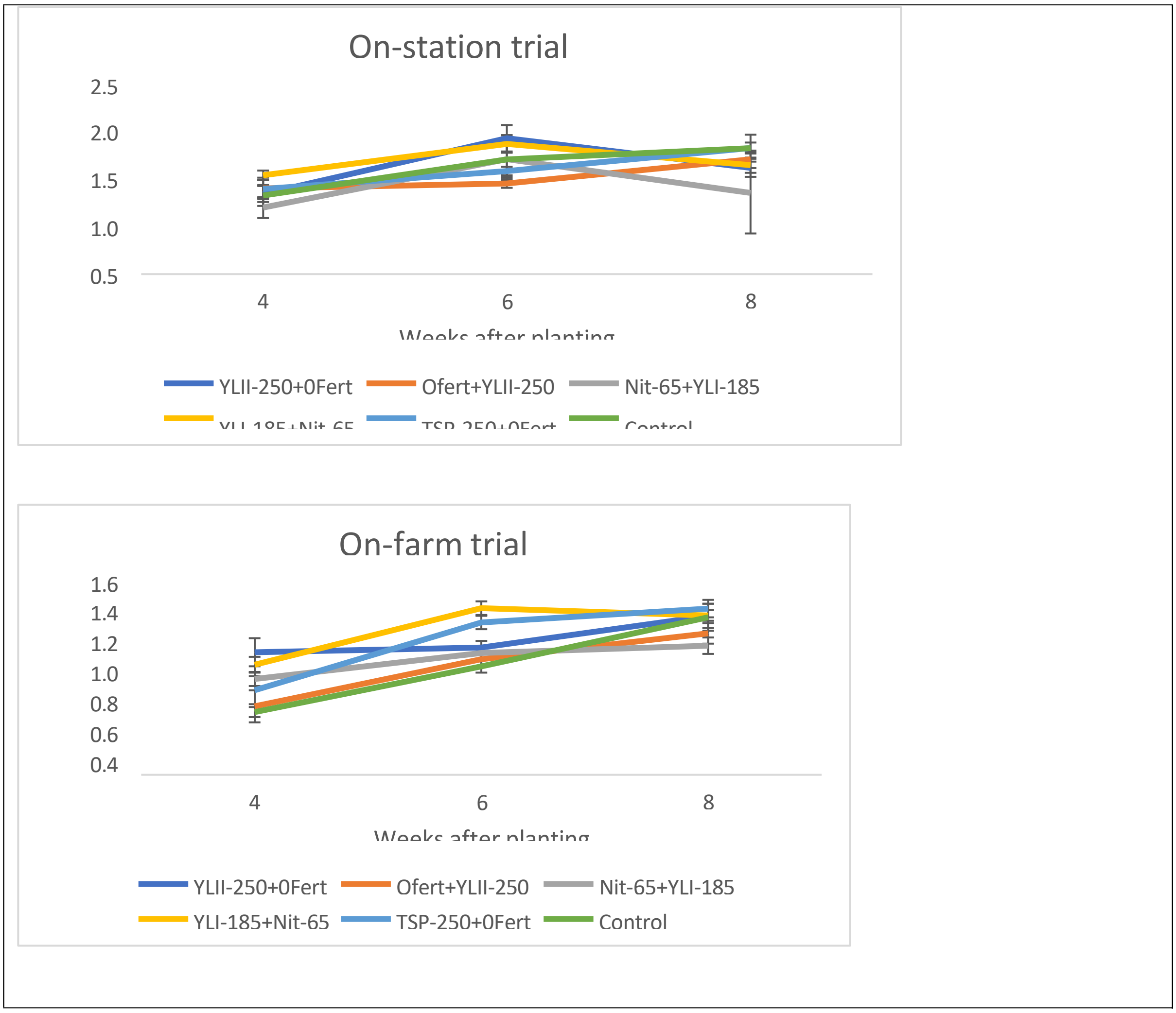
	pH	OC (%)	Total N (%)	Available P (mg kg^{-1})	Exchangeable cations (Cmol+/kg)		
					K	Ca	Mg
On-station	5.38	0.546	0.049	12.53	0.203	2.0	2.2
On-farm	5.28	0.78	0.068	8.085	0.146	1.6	0.8

3.2. Nodulation

At 4 WAP, nodule count at on-station was significantly affected (P<0.299) by the fertilization regimes (Figure 3). The number of nodules at 4WAS ranged from 0.87 with the Nit-65+YLI-185 to 1.29 with YLI-185+Nit-65. The number of nodules in the control plot was not significantly different from that of Nit-65+YLI-185, TSP-250+0Fert and 0fert+YLII-250.

Similarly, soybean nodulation at on-farm was significantly affected (P<0.001) by the fertilizer treatments at 4 WAS (Figure 4). Number of nodules was found to range between 0.518 in the control plot and 1.02 in the YLII-250+0Fert. The number of nodules from the control plot was similar to that of 0fert+YLII-250 and TSP-250+0Fert. Fertilization did not significantly influence nodulation at 6WAS (Figure 3). However, plants treated with YLII-250+0Fert recorded the highest nodulation, while those treated with 0fert+YLII-250 recorded the lowest.

At on-farm, however, a significant effect (P<0.001) on nodulation at 6 WAP was observed (Figure 4). The nodule count ranged from 0.89 in the control plot to 1.37 in the YLI-185+Nit-65 treated plot.



3.3. Flower production

At on-station, fertilization significantly (P<0.033) affected percent flowering of the soybean plants at 60 DAS (Figure 4.3). Percent flowering at 60 DAS ranged from 41.67% with the Nit-65+YLI-185 treated plots to 73.33% with the 0fert+YLII-250 treated plots.

Percent flowering from the untreated plot was higher than that from Nit-65+YLI-185 and YLI-185+Nit-65. Similarly, at on-farm, soybean flowering was significantly affected (P<0.001) by the fertilization regimes (Figure 4.3). Plants in the control plot recorded the highest flower load while plants in the YLI-185+Nit-65 treated plots produced the least flowers.

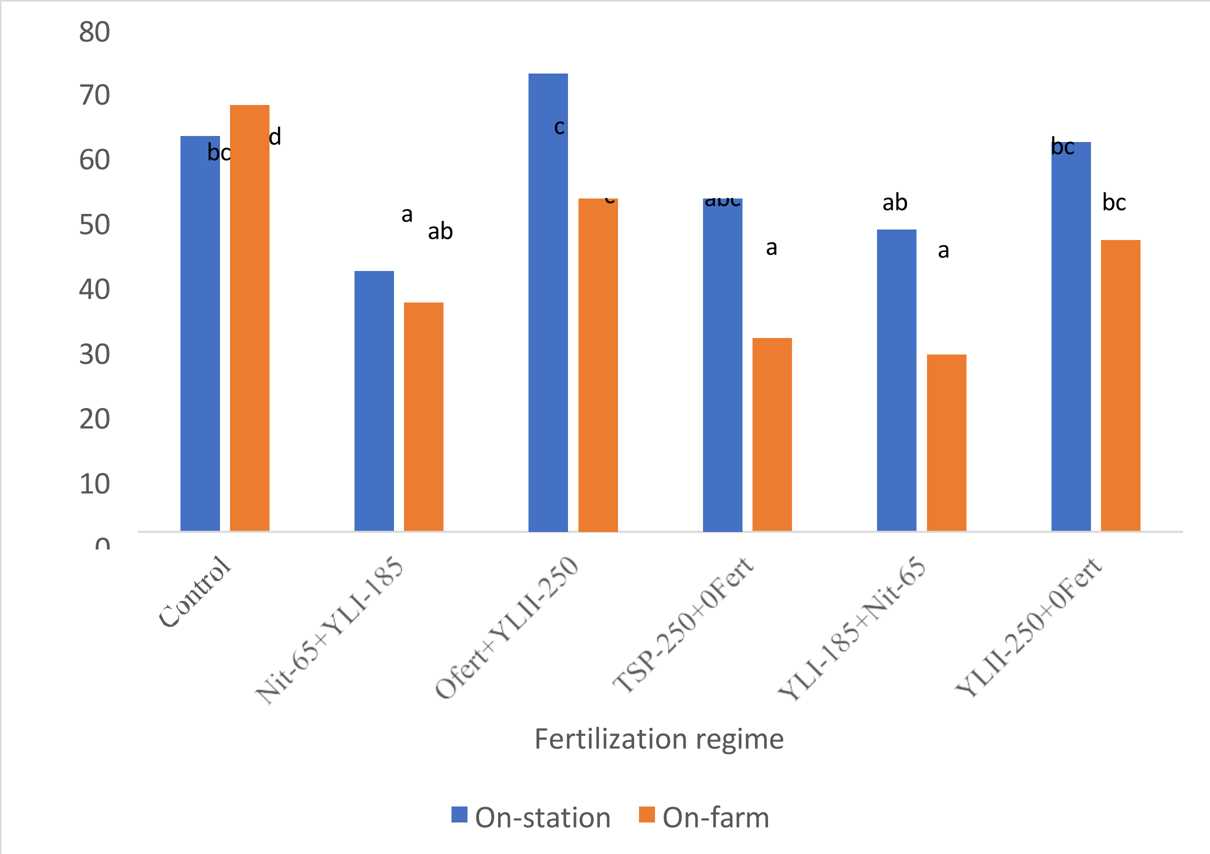


Figure 2. Effect of fertilization on flowering at 60 days after sowing

3.4. Pest abundance and damage

3.4.1. Foliage feeders

The major foliage feeding insects identified during the vegetative growth stage of the soybean were variegated grasshoppers, (*Zonercerus variegatus* Lin.), leaf worms (*Cerotoma trifurcate* Chev.) and leaf beetles (*Anticarsia gemmatalis* Hüb.) (Plate 4.1). In both on-station and on-farm experiments, the fertilization regimes had no significant effect (P<0.635) on the mean population density of grasshoppers (*Zonocerus variegatus* L.) (Table 3)

However, leaf beetle (*C. trifurcate*) population was significantly influenced by fertilization regimes in the on-station and on-farm experiments. In the on-stationexperiment, mean number of C. trifurcate per row of soybean was found to range from 0.55 in 0fert+YLII-250 to 1.21 in YLII-250+0Fert. Beetle population in the untreated control plot was found to be similar to those of the other treatments except YLII- 250+0Fert.

In the on-farm experiment, beetles population ranged from 1.8 with the YLII-250+0Fert treated plots to 2.7 in the plots treated with Nit-65+YLI-185.

The fertilization regimes also showed significant effect (P< 0.001) on the population of leaf worms (A. gemmatalis) in both the on-station and on-farm experiments. In both experiments, the YLI-185+Nit-65 treated plots had the least population of leaf worms. In contrast, the TSP-250+0Fert and the 0fert+YLII-250 treated plots recorded the highest populations in the on-station and on-farm experiments, respectively.

The damage incidence of all the leaf-feeding insects was significantly (P< 0.004) affected by the fertilization regimes in both the on-station and on-farm experiments (Table 3). Percentage defoliation ranged from 8.33 in the Nit-65+YLI-185 treated plots to 11.87% in the 0fert+YLII-250 treated plots in the on-station experiment, while in the on-fam experiment % defoliation ranged from 7.7% in the Nit-65+YLI-185 treated plots to 13% in the plots treated with the YLI-185+Nit-65.

Table 3: Population density and damage incidence of foliage-feeding insects on soybean under YARA fertilization regimes,

2021cropping season.

	On-station				On-farm			
Fertilizer regime	*Z. variegatus*	*C. trifurcate*	*A. gemmatalis*	% defoliation	*Z. variegatus*	*C. trifurcate*	*A. gemmatalis*	% defoliation
Control	1.5a	0.6ab	63.7bc	11.4c	1.9a	2.4b	43.2cd	12.57bc
Nit-65+YLI- 185	1.4a	1.1ab	24.9a	8.33a	2.2a	2.7b	33.3abc	7.70a
Ofert+YLII-250	1.4a	0.6a	53.6b	11.87c	1.8a	2.4b	46.1d	10.73abc
TSP-250+0Fert	1.5a	0.9ab	68.4c	11.10bc	1.9a	1.9a	37.1bcd	11.83abc
YLI-185+Nit-65	1.7a	0.8ab	24.6a	9.53ab	2.2a	2.5b	25.1a	13.0bc
YLII-250+0Fert	1.7a	1.2b	27.3a	9.2a	2.1a	1.8a	28.4ab	8.33c

3.4.2. Pod sucking bugs

The major pod-sucking bugs identified during the reproductive growth stage of the soybean were the giant corried bug, *Anaplocnemis curvipes* (Thunberg), the minor correid bug, *Riptortus dentipes* (Fabricius) and the green stink bug, *Nezara viridula* (Linnaeus)

In both the on-station and on-farm trials, the population density of *R. dentipes* per row of soybean was not significantly affected (P<0.320) by the fertilization regimes (Table 4).

The population density of *M. jaculus* was significantly affected (P<0.017) by the fertilization regimes at the on-station (Table 4). The mean number of *M. jaculus* ranged from 0.16 in control to 0.69 in YLI-185+Nit-65. However, in the on-farm trial, there was no significant effect (P<0.820) of fertilization on the population density of *M. jaculus.*

In both the on-station and on-farm trials, the population of *N. viridula* was not significantly affected (P<0.210) by the fertilization regimes.

Pod damage attributed to pod-sucking insects was not significantly affected (P<0.135) by the fertilization regimes in both the on-station and on-farm trials. However, per cent of damaged pods was highest (48.84) in soybean plants treated with TSP-250+0Fert, and lowest (29.77) in plots treated with 0fert+YLII-250 in the on-station trial, while in the on- farm trial, the highest (63.85) and lowest (34.12) *N. viridula* populations were observed in soybean plants treated with YLII-250+0Fert and control, respectively.

Table 4. Infestation and damage levels of pod-sucking bugs on soybean under the different fertilization regimes

	On-station				On-farm			
Fertilizer regime	*R. dentipe s*	*M. jaculu s*	*N. viridul a*	%damag ed po ds	*R. denti*	*M. jaculus*	*N. viridula*	% damaged pods
Control	0.7a	0.2a	0.2a	32.4ab	0.6a	0.4a	0.2a	63.8b

Nit-65+YLI-185	1.0a	0.4ab	0.6b	37.4ab	0.7a	0.4a	0.1a	39.6ab
Ofert+YLII-250	1.0a	0.7b	0.4ab	29.8a	0.7a	0.4a	0.2a	42.7ab
TSP-250+0Fert	1.0a	0.7b	0.3ab	48.8b	0.8a	0.3a	0.2a	57.7ab
YLI-185+Nit-65	1.0a	0.7b	0.2ab	48.7b	0.6a	0.4a	0.2a	61.2b

3.5. Soybean response to fertilization regimes

In both on-station and on-farm trials, fertilization regime significantly ($p<0.05$) influenced soybean grain yield. Soybean grain yield was significantly ($P<0.001$) improved by the fertilization regimes at on-station (Figure 3). Grain yield ranged from 761 kg/ha in the Control to 3751 kg/ha in Nit-65+YLI-185. Average yield increases of 183 %, 217 %, 327 %, 369 % and 392 % over the control were observed for 0fert+YLII-250, TSP-250+0Fert, YLII-250+0Fert, YLI-185+Nit-65 and Nit- 65+YLI-185, respectively.

Similarly, in the on-farm trial, grain yield was significantly improved ($P<0.001$) by the fertilizer treatments (Figure 3). Soybean grain yield ranged from 592 kg/ha in control to 2484 kg/ha in the plots treated with Nit-65+YLI-185. Average yield increases of 106 %, 178 %, 243 %, 278 % and 319 % over the control were observed for TSP-250+0Fert, 0fert+YLII-250, YLI-185+Nit-65, YLII-250+0Fert, and Nit- 65+YLI-185, respectively.

There were also significant ($p<0.05$) differences in PUE between the different fertilization regimes in both the on-station and on-farm experiments (Table 5). In the on-station experiment, the PUE ranged from 58.8 kg grain per kg P applied from the TSP-250 + 0 fert to 204 kg grain per kg P applied from the Nit-65 + YLI-185. Similar results were obtained with the on-farm trial, with the PUE ranging from 12kg grain per kg P in TSP fertilizer applied to 129 kg grain per kg P in Nit-65+YLI- 185 fertilizer applied.

There were also significant ($p<0.05$) differences in the fertilizer use efficiency (FUE) between the different fertilizer treatments in both the on-station and on-farm experiments. In the on-station experiment, FUE ranged from 5.6 kg grain per kg 0 fert + YLII-250 fertilizer blend applied to 12.0 kg grain per kg Nit-65 + YLI-185 fertilizer blend applied. Similar results were obtained for the on-farm experiment with the FUE ranging from 2.5 kg grain per kg TSP-250 + 0 fert applied to 7.6 kg grains per kg Nit-65 + YLI-185 fertilizer blend applied.

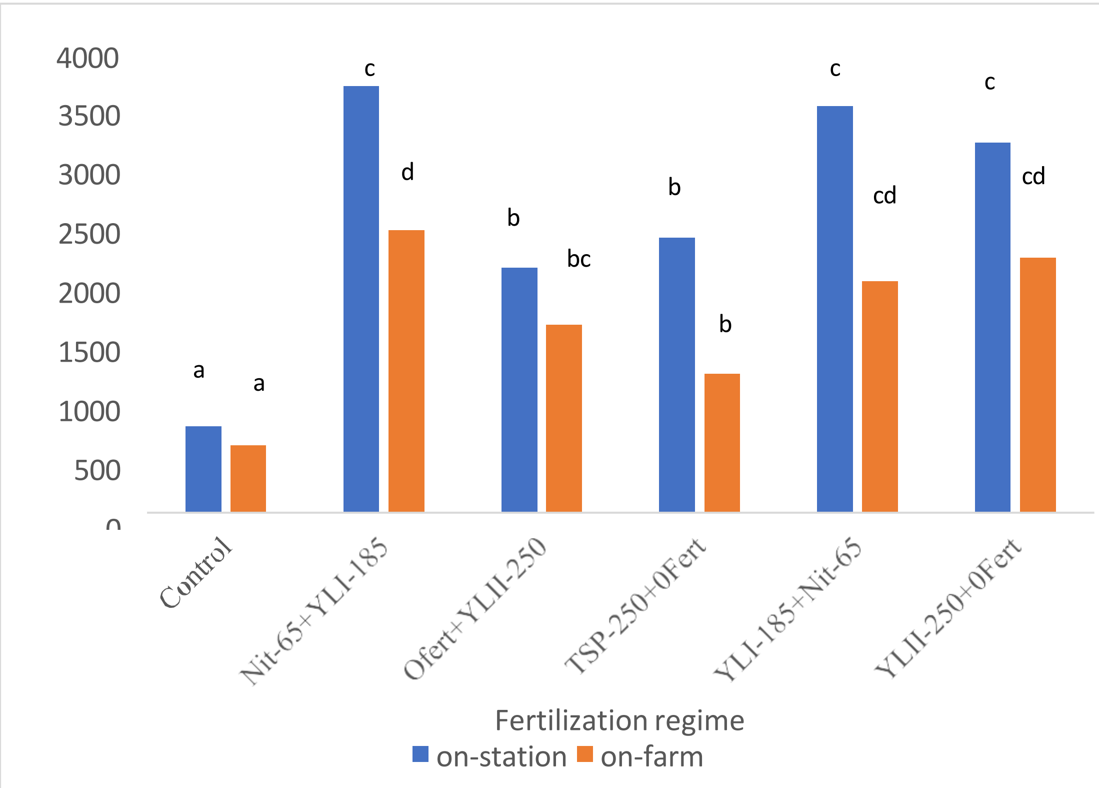


Figure 3. Soybean grain yield under YARA fertilization regimes, 2021 cropping season.

3.6. Value-cost ratios for different fertilization regimes

The value cost ratio analysis showed that all the treatments under both the on-station and on-farm experiments were economically viable and profitable. In both experiments, the Nit-65+YLI-185 was the most profitable fertilization regime while the TSP-250+0fert and 0fert+YLII-250 treatments were the least profitable in the on-farm and on-station experiments, respectively. Sensitivity analysis showed that if the price of soybean grains fell to US$ 315 per ton, fertilizer use would be profitable for all the fertilization regimes in the on-station experiment. For the on- farm experiment, all the fertilization regimes except the TSP-250+0Fert would be profitable. If the cost of fertilizer use increased by 125% and the grain price was increased to US$878 per ton, all the fertilization regimes in both the on-station and the on-farm experiments would be profitable, the Nit-65 + YLI-185 gave the best result, namely a VCR of 4.40 and 3.16 for the on-station and on-farm experiments respectively (Table 6).

Fertilization regime	PUE (kg grain/kg P applied)			FUE (kg grain/kg fertilizer applied)			Gross revenue/ha (US$)			Cost/ha (US $)			Value/Cost Ratio		
	On-statio	On-farm	Mean	On-statio	On-far	Mea	On-statio	On-	Mean	On-statio	On-farm	Mean	On-station	On-	Mean
TSP-250+0Fert	58.8a	12.6a	41.2	6.6a	2.5a	4.6	1672	846 a	1259.	377	430	403.5	4.42 a	1.96 a	3.19
0 Fert+YLII-250	70.5a	53.6b	62.1	5.6a	4.2a	4.9	1491	1142	1316.	369	450	409.5	4.03 a	2.52	3.28
YLII-250+0Fert	126.2	83.5b	104.8	10.0	6.6	8.3	2252	1151	1701.	403	477	440.0	5.59 b	3.24	4.42
YLI-185+Nit-65	192.3	98.6c	145.4	11.3	5.8	8.6	2473	1407	1940.	560	473	516.5	4.412	2.96	3.69
Nit-65+YLI-185	204.5	129.4	167.0	12.0	7.6c	9.8	2595	1719 c	2157.	566	494	530.0	4.58 b	3.47 c	4.03

TSP = Triple Super Phosphate Nit=Nitrabor
YLII = Yara Legume II PUE=Phosphorus use efficiency
YLI=Yara Legume I FUE=Fertilizer use efficiency

Table 6. Sensitivity analysis (based on kg of fertilizer applied per ha) in on station and on farm trials

Situation	Treatment	Cost of fertilizer applied/ha (US$)	Gross Returns/ha (US$)	Value/co4s0t4 ratio
On-station				
Grains selling at USD 315/ton	TSP-250+0Fert	377	761	2.02
	0 Fert+YLII-250	369	679	1.84
	YLII-250+0Fert	403	1025	2.54
	YLI-185+Nit-85	560	1125	2.01

On-farm	Nit-65+YLI-185	566	1181	2.09
	TSP-250+0Fert	430	385	0.90
	0Fert+YLII-250	450	520	1.16
	YLII-250+0Fert	477	706	1.48
	YLI-185+Nit-85	473	641	1.36
	Nit-65+YLI-185	494	782	1.58
On-station				
Grains selling at USD 878/ton with 125% cost over run	TSP-250+0Fert	674	2121	3.14
	0Fert+YLII-250	662	1892	2.86
	YLII-250+0Fert	712	2858	4.01
	YLI-185+Nit-85	741	3137	4.23
	Nit-65+YLI-185	749	3293	4.40
	TSP-250+0Fert	619	1074	1.74
	0Fert+YLII-250	639	1449	2.27
	YLII-250+0Fert	666	1968	2.95
	YLI-185+Nit-85	670	1785	2.66
	Nit-65+YLI-185	691	2181	3.16

TSP=Triple super phosphate YLI=Yara Legume I
Fert=Fertilizer Nit=Nitrabor YLII=Yara Legume II

4. DISCUSSION

4.1. Growth and development

As expected, the results of this study showed that soybean growth and development was affected by the fertilizer treatments. The supply of nitrogen in the form of nitrates and ammonium at the early stages of growth in Nit-65+YLI-185 and YLII-250+0Fert could have led to active protein synthesis, which translated into an increase in the overall height of the plants. In addition, the inclusion of calcium as a macronutrient could have enhanced plant height in Nit-65+YLI-185 and YLII-250+0Fert, as it is needed at the early growing points of new tissues to advance root and tip development. These findings corroborate Popovi *et al.* (2018), who observed that the use of nitrogen-based fertilizers such as calcium ammonium nitrates could have a significant effect on soybean plant height, nodulation, flowering and yield within certain levels and limits of application. Moreover, starter nitrogen might have enhanced plant height in treatments where early N was supplied. According to Basal and Szabó (2020), soybean plants have high N requirements for vegetative growth to produce optimum biomass. Hence, when supplied with adequate mineral N at the early stage, this can boost growth at their vegetative stage. Boron supply could also have accounted for increased growth, especially plant height, as it enhances the active development of root tips, leaves and buds by strengthening the structural and functional integrity of plant membranes. Ahmad and Kanwal (2014) found that boron is essential in maintaining the structural integrity of plant membranes and is needed in large quantities in the leaves, growing points and fruits. The reduced nodulation in on-farm soybean could be due to low soil nutrients relative to that of on-station. Soil analysis of both locations showed that the on-station field had relatively high phosphorus, potassium, calcium, and magnesium than the on-farm. However, the on-farm soil had high organic matter and nitrogen relative to the on-station. Higher nodulation at 4 and 6 weeks after planting in the on-station trial could have been due to the energy (ATP) provided by phosphorus in the fertilizers used. More specifically, the highest counts which were observed in YLII-250+0Fert and YLI-185+Nit-65 could have been due to the N, soluble Ca and B in these blends which enhanced root tip development for a more efficient assimilation of the other nutrients. On the other hand, in the on-station experiment, the insignificant effect of fertilization regimes on nodule count could have been caused by the relatively high P, K and Mg in the soil compared to the on-farm trial. A study by Laghari *et al*. (2016) revealed that nitrogen, when applied to plants, encourages the uptake and utilization of other nutrients including potassium phosphorus and controls the overall growth of plants.

Also, treatments with the lowest flowering at 60 days after sowing (Nit-65+NYLI-185 and NYL1-185+Nit-65) both had higher N, which could have delayed flowering due to accumulation of more plant biomass before flowering for high yield. Plants in treatments that flowered early (TSP-250+0Fert, YLII-250+0Fert, 0Fert+NYL II and control) could have been biologically stimulated to complete their growth cycle by undergoing early senescence of flowers and leaves due to limited or no N in the blend. Fioreze et al. (2018) revealed that Ca is needed in delaying the senescence of leaves and flowers to allow plants to assimilate optimum nutrient for enhanced growth and development.

4.2. Insect pest incidence

At both locations, abundance and incidence of the various pest species were generally not significantly affected by the fertilization regimes. However, for the on-station soybean, leafworms were the most abundant among the foliage feeders' guild with their proliferation most evident in all treatments except the control. In most cases, their abundance was prominent in treatments that showed vigorous vegetative growth, and this could be the result of the relatively higher growth of plants in fertilized treatments than in the control. This provided well developed leaves, thereby attracting defoliators such as leafworms. Singh (2015) affirms that defoliators and pod feeders are attracted to soybean plants with the best leaf development at the initial growth stage and with the most pods formation towards the end of the growth period.

Infestation in Nit-65+YLI-185 and YLII-250+0Fert was mostly similar and even though pest abundance was conspicuous in these treatments, there was still relatively reduced damage and very high yields over the control and TSP-250+0Fert. Nutrients such as K, soluble Ca and B could have induced and increased plant tolerance to infestation by the insect pests and as a result, high yields were achieved even with the high infestation levels. Bala et al. (2018) indicated that potassium provides high resistance against insect pests, enhances secondary compound metabolism, reduces carbohydrate accumulation and plant damage from insect pests. Their study also indicated the role of phosphorus in decreasing host suitability to various insect pest. However, TSP-250+0Fert, with a higher concentration of P than in the regimes used did not demonstrate the decreasing effect of phosphorous on plant host suitability, as its yield was low in comparison to YLI-185+Nit- 65, Nit-65+YLI-185 and YLII-250+0Fert. The presence of N, K, soluble Ca, and B in the other regimes could have accounted for this superior yield over TSP-250+0Fert and control treatments. As supported by Laghari et al. (2016), soluble Ca and B provide strength to the cell wall and stability to the cell membrane against external biotic stresses such as insect pests. Their study also indicated that B maintains the structural integrity of plant membranes, and this could have also added to the rigorous yield amidst the insect pest incidence.

4.3. Soybean's response to fertilization

At both locations, there was significant effect of fertilization regimes on grain yield, with the highest grain yield obtained with the Nit-65+YLI-185 treatment which significantly yielded higher than the other treatments. Although, our results are consistent with earlier studies (Ahiabor et al., 2015; Adjei-Nsiah et al., 2018; Adjei-Nsiah et al., 2021), in the same agro-ecological zone, the response to fertilization obtained in this study was higher than values reported in these earlier studies. Largely, the role of N, P, K, soluble Ca, and B could have resulted in the impact on yield, since all treatments were exposed to the same factors, except the varied fertilization regimes. More specifically, the provision of N at the initial growth stages could have played a major role in the growth and development of the plants. A study by Haruna et al. (2017) indicated that until nodulation, soybean plants depend on soil nitrogen for growth. This suggests that soybean grain yield was boosted because of the added starter nitrogen provided.

Sufficient nitrogen is essential for crop quality, increasing size of produce and plant proteins. The inclusion of phosphorus could have also enhanced the yields by aiding in the production and transport of fat, sugars, and protein in the soybean plant throughout its life cycle. In both locations, yields from YLI-185+Nit-65, Nit-65+YLI-185 and YLII- 250+0Fert were higher than that of TSP-250+0Fert and this could be due to the N, K, soluble Ca, and B which were not in TSP-250+0Fert. This postulated that soybean grain yield was not determined by the most abundant nutrient, but by the limiting nutrients. As evidenced by Ofori (2016), application of triple superphosphate at 25 kg N per hectare enhances soybean N and P uptake than rock phosphate fertilizer. However, results from this study clearly revealed the composite nutritional advantages of N, P, K, soluble Ca and B on soybean yield, as the highest yields (3751 kg/ha and 2484 kg/ha) were attained in Nit-65+YLI-185, at on-station and on-farm, respectively, even though Haruna et al. (2017) indicated the yield potential of the variety used (Jenguma) is 2.5-2.8 t/ha. According to Dragan et al. (2018), average soybean yield globally is about 2.76 t ha-1 with the highest yields being 3.16 t ha-1which is attributable to fertilization interventions.

This affirms the impact of the fertilization regimes on yield in this study. Results from soil analysis provided evidence that yields at on-station were higher than that of on-farm due to the relatively higher P, K and Mg that were prevalent in the on-station soils (probably due to previous crop production activities). The role of potassium in providing resistance against insect pest infestation could have also augmented yields. Adhikari et al. (2020) reported that potassium stimulates growth of strong stems, provides some disease and pest tolerance by increasing the thickness of the outer cell walls and improving the frost and drought tolerance of plants.

The roles of Ca and B in increasing crop yield cannot be overlooked as these nutrients could have accounted for the increased yields at both locations of the study. According to Barker (2019), Ca and B strengthen cell walls of plants, stops nutrients from leaching in plant cells, fills up pods and enhances root and tip development. At both locations, there was significant effect of fertilization regimes on 100 seed weight. Also, both locations witnessed the highest 100 seed weight in YLII-250+0Fert, even though that of on-station was relatively higher. This could have been due to the nutritional advantages provided by the inclusion of N, P, K, soluble Ca, and B. A study by Ahmad and Kanwal (2014) indicated that boron can maximize Ca uptake and this could have given YLI- 185+Nit-65 and YLII-250+0Fert, especially Nit-65+YLI-185 an added advantage over the other treatments for enhanced yield.

4.4. Value cost ratio

The VCR indicated that the application of any of the fertilizer regimes was largely profitable using the threshold of two indicated by Roy et al. (2006). Thus, farmers in Northern Ghana on average could realize returns of 3.19, 3.28, 4.03, 3.69 and 4.42 folds of every amount invested in the application of TSP-250+0fert, 0fert+YLII-250, Nit- 65+YLI-185, YLI-185+Nit-85; and YLII-250+0Fert. Even at the current interest rate of between 30-40% per annum charged by the commercial banks and as high as 60% charged by the informal sectors, all the fertilizer regimes are profitable suggesting that fertilizer application to soyabean is profitable in northern Ghana. In northern Ghana, the use of TSP or P blended fertilizers were more profitable than using no input (Adjei-Nsiah et al., 2018; Adjei-Nsiah et al., 2021). It is anticipated that these promising results will encourage soybean farmers to invest in the use of P blended fertilizers as it could improve their productivity and increase their profit margins.

CONCLUSION

Soybean responded to fertilizer application in the Guinea Savannah zone of Ghana with yield increases ranging between about 100 to 390% indicating the potential for farmers to increase their soybean production using phosphorus fertilizer blends. Despite higher pests' infestation in the three most promising fertilization regimes i.e., YLI-185+Nit-65, Nit-65+YLI-185 and YLII-250+0Fert, grain yields were not adversely affected due to reduced damage to both foliage and pods suggesting build-up of plant tolerance to insect pests' infestation due to added nutrients such as N, K, Ca and B to these blends. The initial N application of 65 kg Nitrabor per hectare followed by YLI application increased yield of soybean over the control by 4 to 5-folds: this corresponds to about 89% and 134% of the yield potential of Jenguma variety used in these experiments for the on-farm and on-station experiments respectively. The value cost ratio and revenue generated from the use of this fertilization regime indicate the potential of increasing income of soybean farmers in northern Ghana.

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