Influence of phosphorus fertiliser blend on grain yield, nutrient concentration, and profitability of soyabean in the Southern Guinea Savanna of Ghana

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Influence of phosphorus fertiliser blend on grain yield, nutrient concentration, and profitability of soyabean in the Southern Guinea Savanna of Ghana

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Abstract

We conducted on-farm trials in the southern Guinea Savanna of Ghana in 2016 and 2017 to evaluate soyabean response to three fertiliser blends to guide farmers towards profitable adoption of appropriate phosphorus (P) fertiliser blend for improved soyabean production. Old YARA Legume (OYL), New YARA Legume (NYL) and Triple Superphosphate (TSP) fertiliser blends were evaluated. In both years, the P fertiliser blends were evaluated in a Randomised Complete Block Design with 20, 30, and 40 kg P ha^{-1} application rates together with control. P fertiliser application increased soyabean yields by 1070 kg ha^{-1}. In 2016, fertiliser blend use efficiency (BUE) ranged from 2.9 kg grain per kg fertiliser blend applied with the NYL applied at 40 kg P ha^{-1} to 7.4 kg grain per kg fertiliser blend applied with the TSP applied at 40 kg P ha^{-1} with significant differences between treatments. In 2017, BUE ranged from 2.5 kg grain per kg fertiliser blend applied with OYL applied at 40 kg P ha^{-1} to 9.2 kg grain per kg fertiliser blend applied with the TSP applied at 40 kg P ha^{-1} with significant differences between treatments. However, P use efficiency did not significantly differ between the different treatments both in the 2016 and 2017 trials. In both 2016 and 2017 trials, the highest benefit cost ratio was attained at the lowest application rate for all the three fertiliser blends suggesting the need to review the current application rate of 30 kg P fertiliser ha^{-1} promoted in northern Ghana. Furthermore, the provision of credit and/or subsidy for farmers by the government is required to enable uptake and utilisation of fertilisers by farmers.

Keywords: Agronomic/nutrient use efficiency, benefit/cost ratio, fertiliser blend use efficiency, grain nutrient concentration, legume, soil properties, smallholder farmers

Introduction

Soyabean (*Glycine max* L.) is among the most economically essential grain legumes globally. The total world production of soyabeans for the year 2019 was estimated at 350 million metric tons, with 3.1 million metric tons originating from Africa and Western Africa accounting for 920,000 metric tons, respectively (FAOSTATS 2020). In West Africa, soyabean is a significant component of the predominantly cereal-based farming systems in the Guinea Savanna agro-ecological zone. Besides serving as a source of household income and nutritional security, especially among underprivileged households, it is a significant component in animal feed preparation (Sanginga and Bergvinson 2015). Due to its symbiosis with nitrogen-fixing bacteria, soyabean has the additional advantage of reducing the need for mineral nitrogen fertiliser to the subsequent cereal crop when grown in rotation (Sanginga 2003; Giller et al. 2011), which is a key component of integrated soil fertility management (Vanlauwe et al. 2015).

Despite its importance, the grain yield of soyabean is low. According to FAOSTATS (2020), soyabean yields in West Africa is estimated at 1.05 t ha^{-1}, which is far below the potential yield of 3.0 t ha^{-1} (AGRA 2016) and the global average of 2.8 t ha-^{1} (FAOSTATS 2020). Use of low yielding varieties, low soil phosphorus (P), high cost of inputs (seeds and fertilisers), limited access to quality rhizobia inoculants, inadequate and erratic rainfall have been blamed for the causes of the low yields of soyabean (Buah et al. 2017; Kolawole 2012; Ulzen et al. 2016).

In the Guinea Savanna agro-ecological zone of Ghana, where about 95 % of Ghana's soyabean is produced (MoFA 2019), the crop is often cultivated without fertiliser because it is considered a secondary crop to cereal crops and thus promoted as a crop that requires no fertilisation. Soils in the Guinea Savanna are, however, low in fertility. This situation is exacerbated by nutrient depletion through crop harvest without replenishment. Although soyabean can access atmospheric N through symbiotic nitrogen fixation, this process can be limited by ineffective native rhizobia and low availability of other nutrients, particularly phosphorus (O'Hara et al. 2002).

Studies (Ahiabor et al. 2014; Aziz et al. 2016; Ronner et al. 2016) have shown that soyabean yield could be increased by applying 20-30 kg P fertiliser ha^{-1}. The yield increase in soyabean as high as 452 kg ha^{-1} has been obtained by applying P fertiliser in Northern Nigeria (Ronner et al. 2016). The additive effect of both P fertiliser and rhizobium inoculant could result in a yield increase of 777 kg ha^{-1}. Besides P fertiliser, other nutrients, particularly calcium and boron, have been found to play critical roles in legume symbiosis (Weisany et al. 2013; Asante et al., 2017).

Over the past decade, fertiliser companies in Ghana have developed phosphorus-based fertiliser blends to boost soyabean production. While these fertilisers are being promoted by research, extension, and several Non-Governmental Organisations in the Guinea Savanna agro-ecological zone, their agronomic use efficiency and economic viability are yet to be adequately assessed in any study. Knowing the agronomic use efficiency and economic viability of various P fertilisers being promoted in Ghana will guide farmers towards profitable adoption of appropriate P fertiliser blend for improved soyabean production. Moreover, previous studies on soyabean response to P fertiliser used triple superphosphate as a fertiliser source (Ahiabor et al. 2014; Aziz et al. 2016; Adjei-Nsiah et al. 2018a&b), while other P sources (not TSP) are being promoted in northern Ghana. The objective of the present study was, therefore, to evaluate the response of soyabean to different P fertiliser blends being promoted in northern Ghana and to assess the economic viability of the use of the different blends to guide farmers towards their profitable adoption for soyabean production in the southern Guinea savanna agro-ecological zone of Ghana.

Materials and methods

Study sites

The study was conducted for two years in the 2016 and 2017 cropping seasons in Yendi municipal areas, located in the eastern corridor of the Northern Region of Ghana, between Latitude 9^0 35^0 North and Longitude 0^0 30^0 West. The area falls within the southern Guinea Savanna agro-ecological zone characterised by vast, low-lying areas of semi-arid grassland interspersed with savanna woodland, a dry and hot climate, with a uni-modal rainfall pattern (Wiredu et al. 2010). The soils in the area which developed over voltaian sandstones, shales, and mudstones are classified as Savanna Ochrosol and groundwater Laterites in the interim Ghana soil classification system (Adjei-Gyapong and Asiamah 2002) and as Plinthosols in the World Reference Base for soil resources (WRB 2015); which is equivalent to Plinthaquox in the USDA soil classification system (USDA 2019). The organic matter and nitrogen (N) contents of the soils are low (Hoskins, 2007), and the basic cations of the soils were heavily leached (Table 1). This situation is increasingly worsened by the extensive bush burning and bad agricultural practices such as burning crop residues after harvest and plowing along the slopes. The rainy season starts in May and ends in October, with a dry season from November to April. The average annual rainfall is about 1,125 mm, with wide variation in season. The average temperature ranges between 27 and 36 °C giving rise to a high-temperature range. During the 2016 and 2017 growing seasons, the rainfall amount was about 1391 mm and 1205 mm, respectively (Figure 1).

Experimental design, treatments, and crop management

In 2016, the trial was conducted in a Randomised Complete Block Design (RCBD) with four replicates. The three fertiliser blends evaluated were Old YARA Legume (OYL) (4 % N, 10.9 % P, 14.9 % K); New YARA Legume (NYL) (4 % N, 7.9 % P, 10.8 % K, 0.3 % B, 10 % soluble Ca, 1.7 % Mg, 2 % S) and Triple superphosphate (TSP) (20 % P). Each of the blends was evaluated at three different application rates (20, 30, and 40 kg P fertiliser ha^{-1}) together with a control treatment (No fertiliser), giving a total of 10 treatments. Sowing was done in July 2016. In 2017, the trial was conducted in RCBD in four communities, with each community representing a block. The experimental plots were either previously cropped to maize, cowpea, or groundnut. The same 10 fertiliser treatments evaluated in 2016 were used in 2017. Sowing was done in July 2017.

In both 2016 and 2017, the plot size was 5 × 5 m with planting distances of 50 × 10 cm, respectively, at two seeds per hill with a seed rate of 40 kg ha^{-1}. The fields were ploughed with a tractor and harrowed with a hoe, after which the fields were laid out. The phosphorus fertilisers were applied at planting in furrows 10 cm away from the planting line. Weed control was done twice at 4 and 7 weeks after sowing using hoes.

Data collection

In both the 2016 and 2017 cropping seasons, the soyabean plants were harvested when about 95 % of the pods had turned brown. Ten plants were randomly picked after harvest from the harvested plants to determine their podding capacities. All the pods were removed from these ten plants, counted, and the average number of pods per plant was estimated. The harvested plants were then threshed, winnowed, and the grains were sun-dried for three days, weighed, and then the weight recorded. Sub-samples of grains were taken from each treatment and oven-dried at 65 °C for 72 hours. In 2016, sub-samples of grains were milled into powder to pass through a 1 mm sieve and analysed for nitrogen, phosphorus, boron, and zinc. P was determined by the molybdenum blue colourimetric method (Nagul et al., 2015) and N by the micro-Kjeldahl method (Yuen and Pollard 1953; Guebel and Nudel 1991).

During the establishment of the field trials, soil samples were taken from a 0–20 cm depth of the soil from every field. Five soil core samples were taken randomly, and thoroughly mixed for further analyses. These samples were air-dried and sieved with a 2 mm mesh and sent to the analytical services laboratory of the International Institute of Tropical Agriculture (IITA) in Ibadan for routine analysis of the physico-chemical properties (Table 1). Soils were analysed for pH (H_2O, 1:1 soil to H_2O ratio) (Lierop and Mackenzie 1977), organic C (Walkley-Black) (FAO, 2019), total N (Kjeldahl) (Guebel and Nudel 1991), P (Mehlich) (Shang et al., 2013), exchangeable K, Ca and Mg, micronutrients; Zn, Cu, Fe and Mn (Ammonium acetate-EDTA extractable method) (Shahandeh and Hossner 1994). The agronomic P use efficiency (PUE) was calculated as shown in equation 1 [(Yuen and Pollard 1953); Table S1].

$$\textbf{Agronomic P use efficiency} = \frac{\textbf{Yield of fertilised plot} - \textbf{Yield of control plot}}{\textbf{Amount of P applied}} \ldots.\textbf{Eq1}$$

Agronomic fertiliser blend use efficiency (BUE) was also computed, as shown in equation 2

$$\textbf{Agronomic fertiliser blend use efficiency} = \frac{\textbf{Yield of fertilised plot} - \textbf{Yield of control plot}}{\textbf{Amount of fertiliser blend applied}} \ldots.\textbf{Eq2}$$

An economic analysis was performed on the profitability of using the different P fertiliser blends at the different application rates. The fertiliser cost was determined using the different fertiliser blends and labour costs for fertiliser application based on the current labour rates in the communities. The price for the grain legumes was the average market price for 2017. All the amounts are expressed in U.S. dollars (USD, $) at the average exchange rate Jan.–Nov. 2017 (4.4 GHC = $1.00) (Bank of Ghana 2017). The economic analysis was performed using a Microsoft Excel spreadsheet (ver. 2016). The benefit/cost ratio (BCR) was estimated as shown in equation 3 (Levine, 2003).

$$\boldsymbol{Benefit/Cost\ ratio} = \frac{\textbf{Revenue from kg P fertiliser blend applied}}{\textbf{Cost of kg P fertiliser blend applied}} \ldots.\textbf{Eq3}$$

Sensitivity analysis was conducted to determine the effects of price shocks on soyabean production in the project area. The sensitivity analysis was based on the premise that, within the last five years, soyabean price has fluctuated between 209 and 356 USD per metric tons while the cost of fertiliser use has increased by about 10 %.

Statistical analyses

The effects of P on yield, agronomic PUE, and P fertiliser BUEs were determined by performing analysis of variance (ANOVA) using Genstat statistical software (vers. 12; VSN International Limited, Hemel Hempstead, UK). The least significant difference (LSD) method was used for mean separation at a 5 % significant level.

Results

Soyabean response to different phosphorus fertiliser blends and application rates

In 2016 and 2017, fertiliser blend and application rate ($p < 0.05$) significantly influenced soyabean grain yield with the NYL at 40 kg P ha-1 rate, giving the highest grain yield of 2.59 t ha-1 in 2016 and 2.14 t ha^{-1} in 2017. In both 2016 and 2017, P application increased the number of pods per plant compared with the control, which resulted in higher grain yield (Figure 2). In both 2016 and 2017, the highest grain yield increase over the control (131 and 171 %, respectively for 2016 and 2017) was obtained with the NYL applied at 40 kg P ha^{-1} followed by the NYL applied at 30 kg P ha^{-1} (120 and 144 %) (Figure 2). PUE did not significantly differ between the different fertiliser treatments, although OYL appeared to have a higher PUE followed by NYL and TSP, particularly at the 20 kg P ha^{-1} rate (Table 3).

However, there were significant ($p < 0.05$) differences in BUE between the different fertiliser treatments in 2016 and 2017. In 2016, BUE ranged from 2.9 kg grain/kg fertiliser blend applied with the NYL at the 40 kg P ha^{-1} rate to 7.4 kg grain $^{-1}$ /kg fertiliser blend applied with the 20 kg P ha^{-1} rate of the TSP. Similar results were obtained for the 2017 season; BUE spanned from 2.5 kg $grain^{-1}$ kg fertiliser blend applied with the OYL at the 40 kg P ha^{-1} rate to 9.2 kg grain $^{-1}$ /kg fertiliser blend applied with the 20 kg P ha^{-1} rate of the TSP (Table 2).

Soyabean response to different phosphorus fertiliser blends application and benefit/cost ratios for different fertiliser blends in Yendi

The current input prices of 0.55, 0.50, and $ 0.43 kg-^{1} of TSP, OYL, and NYL, respectively, (and labour for fertiliser application of USD 0.18) and the soyabean price of USD 0.34 kg $^{-1}$ suggest that, to break even, the response of soyabean to the various P fertiliser blends should at least be

2.15, 2.0 and 1.79 kg grain per kg fertiliser blend applied for TSP, OYL, and NYL, respectively. For the NYL, this gives benefit-cost ratios (BCRs) of 1.9, 1.80, and 1.6, respectively for the 20, 30, and 40 kg ha^{-1} rates (Table 3). For the OYL, the BCRs are 2.3, 2.0, and 1.6, respectively, for 20, 30, and 40 kg ha^{-1} rates, while for the TSP, the BCRs are 3.8, 2.9, and 2.8 for the 20, 30, and 40 kg ha^{-1} application rates, respectively (Table 3).

Sensitivity analysis indicates that in a situation where the price of soyabean grains falls to USD 0.21 per kg, fertiliser use will be profitable for all fertiliser blends and rates except the 40 kg ha^{-1} application rate for the NYL and the OYL (Table 4). Also, when the cost of fertiliser use is escalated by 10 % and the grain price increases to USD 0.36 per kg grain, all the fertiliser blends at the different application rates will be profitable with the 20 kg ha^{-1} TSP rate giving the highest BCR of 3.74 (Table 3).

Effect of P fertiliser blend on nutrients concentration in soyabean grain

Application of P fertiliser blend significantly influenced P, boron (B), and zinc (Zn) concentrations in the soyabean grains. Grain P concentration ranged from 0.32 % in the control treatments to 0.44 % in the 20 and 30 kg P ha^{-1} application rate of the OYL (Table 4). Grain concentration of B was highest in the 30 kg P ha^{-1} application rate of the NYL plot and lowest in the 40 kg P ha^{-1} rate of the OYL. It appears that concentration of P influenced B concentration in grains as the treatments which had a lower concentration of P had a higher concentration of B. Zinc concentration in the grains was also influenced significantly by grain P concentration with the control plots which had the least concentration (0.32 %) of P and the highest (31.57 mg/kg) concentration of Zn (Table 4).

Discussion

The study suggests that P fertiliser blend application increased the yield of soyabean on farmers' fields where soil conditions were sub-optimal for soyabean production, as evidenced by the soil physico-chemical analyses (Table 1). pH is an important soil characteristic and a major determinant of soil fertility. Acidity and alkalinity are closely associated with the physico-chemical elements of the soil–plant system (Nanganoa et al., 2020; Mak-Mensah et al., 2021). Previous studies have found that increasing soil acidity accelerates the loss of essential elements such as K, Ca, and Mg; and decreases soil cation exchange capacity, affecting the geochemical cycle of soil nutrients (Nanganoa et al., 2020; Ságio et al., 2013). pH and organic matter are important indicators of the soil environment, as they can influence trace elements absorption in crops, compromising crop yield and quality (Nanganoa et al., 2020; Mak-Mensah et al., 2021). In the experimental soils, K fertilisers may be applied, as well as agronomic practices such as organic matter and biochar application could improve exchangeable cations (Ca and Mg) content and micronutrients.

Yields were generally higher in 2016 than in the 2017 cropping season, although soils used for the 2017 trial were better in terms of nutrients than soil used for the 2016 trial (Table 1 and S1; Figure 2). The yield difference between the two seasons could be ascribed to a better rainfall pattern in 2016 than in 2017 (Figure 1). Although P fertiliser varied with fertiliser blend application rate, it shows an average positive effect of 1070 kg ha^{-1} for soyabean. Eventhough, our results are consistent with previous results obtained in similar studies in similar environments (Ahiabor et al. 2015; Ronner et al. 2016; Adjei-Nsiah et al. 2018a, b & c), the response obtained in the present study is higher than the values reported in these previous studies. In this study, soyabean responded well to the three different P fertiliser blends. Grain legumes response to P fertiliser application has been reported by several researchers (Kamara et al. 2007; Mahamood et al. 2009; Kamanga et al. 2010; Karikari et al. 2015; Ronner et al. 2016; Kyei-Boahen et al. 2017; Adjei-Nsiah et al. 2018a&b). The response may be attributed to increased uptake of micronutrients, rapid plant growth, enhanced nitrogen fixation, enhanced flowering, and podding. This is because P is known to play essential roles in several processes in legumes, including energy transfer, nodulation, atmospheric nitrogen fixation, flower initiation, fruit development, and seed formation (Beegle and Durst 2002; Krasilnikoff et al. 2005; Ndakidem and Dakor 2007; Nyoki et al. 2013). In our current studies, P application culminated in a remarkable podding ability of the soyabean resulting in higher grain yields (Figure 2).

The NYL fertiliser gave a better response in terms of grain yield than the other fertiliser blends due to the added nutrients in the NYL fertiliser such as N, K, Ca, Mg, and B which may have partly played essential roles in N-fixation in the soyabean (Asante et al., 2017; Adjei-Nsiah and Ahiabor 2018b&c). These nutrients were nevertheless deficient in the soils used for the current study (Tables 1). However, despite the highest response in yield per hectare, the NYL fertiliser blend did not necessarily yield the highest net benefit. This is because the increase in yield could not compensate for the added nutrients' cost. Thus, although the TSP yielded the lowest PUE, it also yielded the highest net benefit on average, with the 20 kg P ha^{-1} application rate giving the highest BCR of 3.8. From the nutritional point of view, one may choose NYL over TSP because of the higher concentration of micronutrients such as B in the grains of soyabeans that received the NYL, blended with B and other nutrients. Besides increasing crop yield for human consumption, B may also address crop nutritional quality and attendant micronutrient dietary concerns associated with human health. For the three fertiliser blends, the highest BCR was attained at the lowest (20 kg P ha^{-1}) application rate. Although the 40 kg P ha^{-1} application rate of the NYL yielded the highest grain yield, it recorded the lowest BCR, possibly attributable to the lower revenue obtained from a kg of NYL fertiliser blend applied than that of TSP. This means that farmers would be better-off if they apply 20 kg P ha^{-1} of any of the P fertiliser blends. Thus, the current recommended application rate of 30 kg P ha^{-1} of TSP being promoted by research and extension in northern Ghana needs to be reviewed since it does not give the farmer the highest BCR.

The sensitivity analysis indicates that at the current interest rate of between 24 % and 29 % per annum charged by commercial banks and sometimes as high as 50 % in the informal financial sector, only TSP fertiliser applied at any rate, and the OYL applied at 20 kg P ha^{-1} are profitable if soyabean grain is sold even at USD 0.21 per kg grain. In a situation where the cost of fertiliser use increases by 10 % while soyabean price increases to USD 0.36 per kg grain, all the fertiliser blends except the OYL at 40 kg P ha^{-1} rate will be profitable. Thus, the financial appraisal of phosphorus fertiliser-use in soyabean production shows that fertiliser use in soyabean production can be profitable in northern Ghana in the advent of adverse price fluctuations. In northern Ghana, the use of TSP fertiliser and rhizobium inoculant was found to be more profitable than when no input was applied to soyabean over two years (Adjei-Nsiah et al. 2018a). Thus, farmers who use phosphorus fertilisers can increase the profitability of their soyabean production and, simultaneously, build their soil phosphorus capital to improve the productivity of subsequent crops grown in rotation. It is anticipated that these promising results will encourage soyabean farmers to move towards the use of TSP fertiliser since such a venture can improve their productivity and increase their profit margins.

Application of the P fertiliser blends generally improved P concentration in grains but occasioned a reduced concentration of Zn and B. Reduced Zn concentration with P application has been reported in other studies (Alloway 2008; Nyoki and Ndakidemi 2014). In cowpea, Nyoki and Ndakidemi (2014) reported that application of P at the level of 40 and 80 kg ha^{-1} reduced Zn uptake in pods. Sahrawat et al. (2008) attributed reduced concentration of Zn with P fertiliser application to several mechanisms including dilution effects on the concentration of Zn in plants. In wheat, Seth and Aery (2017) reported that B concentration decreased significantly at higher P levels than lower P levels. Studies by Brdar-Jokanovi (2020) and Kaya et al. (2009) also reported that high P content could reduce B content in leaves, while Blackwell et al. (2019) demonstrated that increasing P supply led to the decrease in B concentration in plant tissues, as found in our present study. The lower B concentration in treatments with higher P concentrations may be attributed to a dilution effect caused by higher yields (enabled by P fertiliser applications). However, the exceptionally higher concentration (17.08-17.51 mg/kg) of B in the NYL blend irrespective of the P rate could be ascribed to the presence of B in the blend.

Conclusion

The study has shown a high positive response of soyabean to phosphorus-based fertiliser blends with an average response of 1 t ha^{-1}. Although NYL fertiliser averagely had a higher PUE (39.3 kg grain per kg P applied) compared with the TSP fertiliser (33.0 kg grain per kg P applied), the TSP had a higher BCR (3.2) than the NYL (1.8) due to the higher revenue obtained from a kg of TSP fertiliser blend applied than that of NYL. This suggests that farmers will be better off if they apply TSP instead of either NYL or OYL, P fertiliser blended with other nutrients. The study, therefore, suggests that TSP could be applied to soyabeans to increase yield. However, in terms of nutritional security, it may be more appropriate to consider the use of NYL because of its blend with micro-nutrient such as B, which in addition to increasing crop yield for human consumption, may also address crop nutritional quality and attendant micronutrient or dietary deficiencies associated with human health. While these fertiliser blends appear to result in a higher BCR, they are not widely used by farmers due to low awareness, high cost, and unavailability in rural areas. This suggests the need for government to facilitate farmers' access to credit or subsidise these inputs to enhance widespread farmer utilisation.

The study also suggests that the current recommended application rate of 30 kg P ha^{-1} needs to be revised since the highest BCR was obtained at the application rate of 20 kg P ha^{-1} for all the three P fertiliser blends. The residual effect of the various blends on subsequent cereal crops grown after the soyabean needs to be evaluated.

Conflict of interest

The authors declare that there is no conflict of interest.

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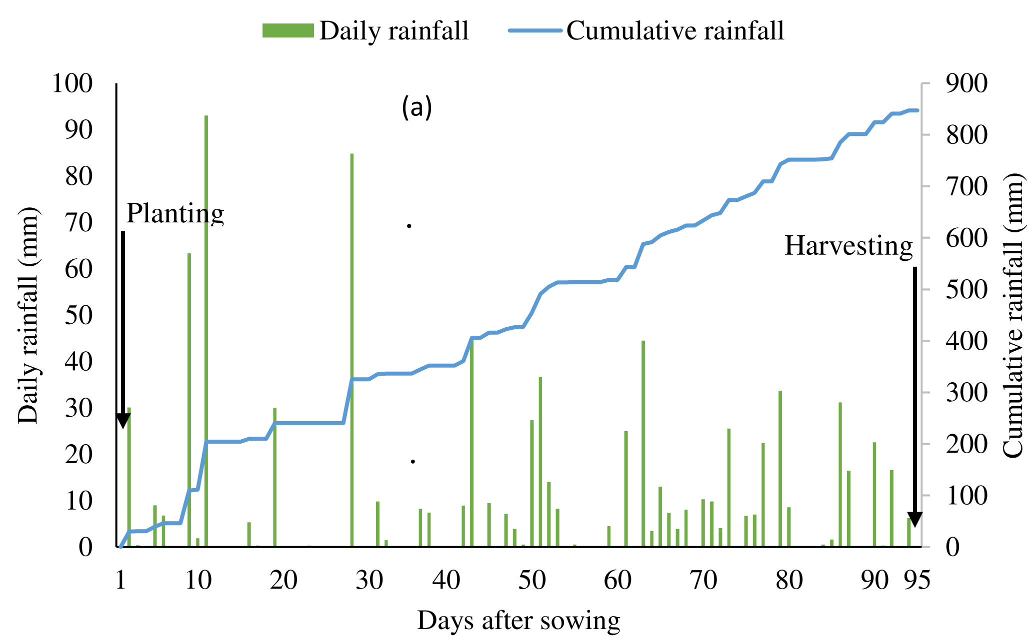

(b)

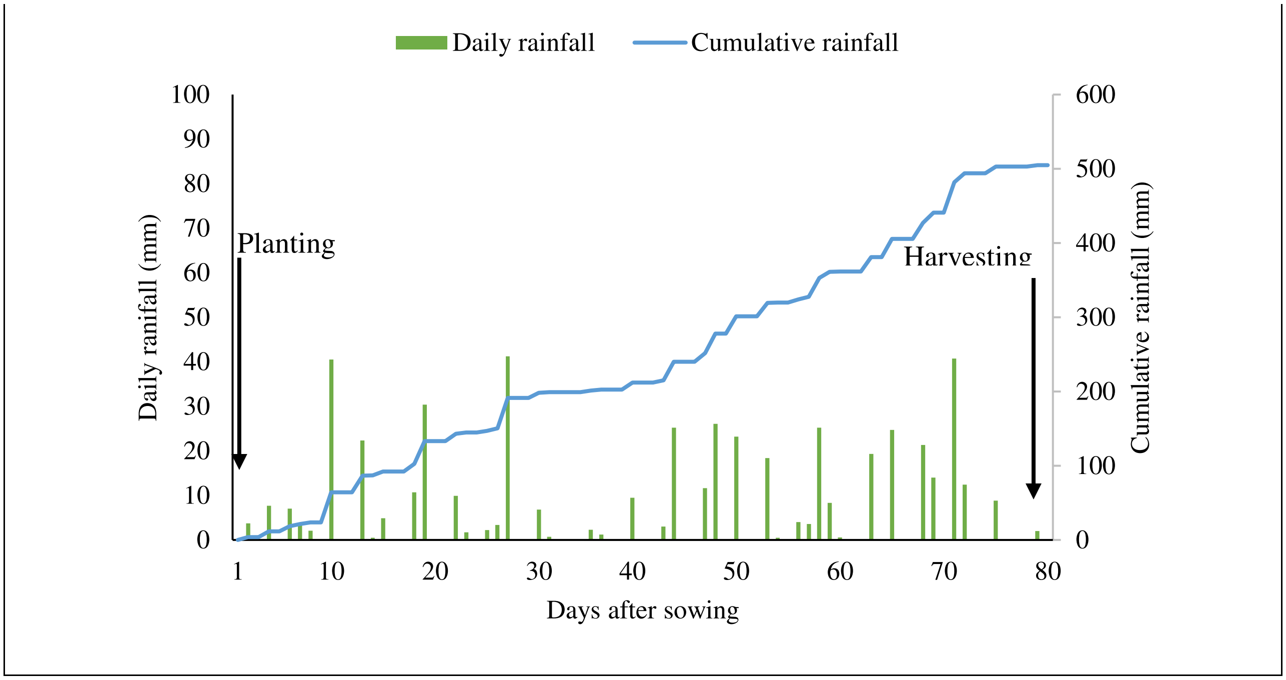

Figure 1: Daily and cumulative rainfall during the (a) 2016 and (b) 2017 growing seasons in Yendi, Ghana

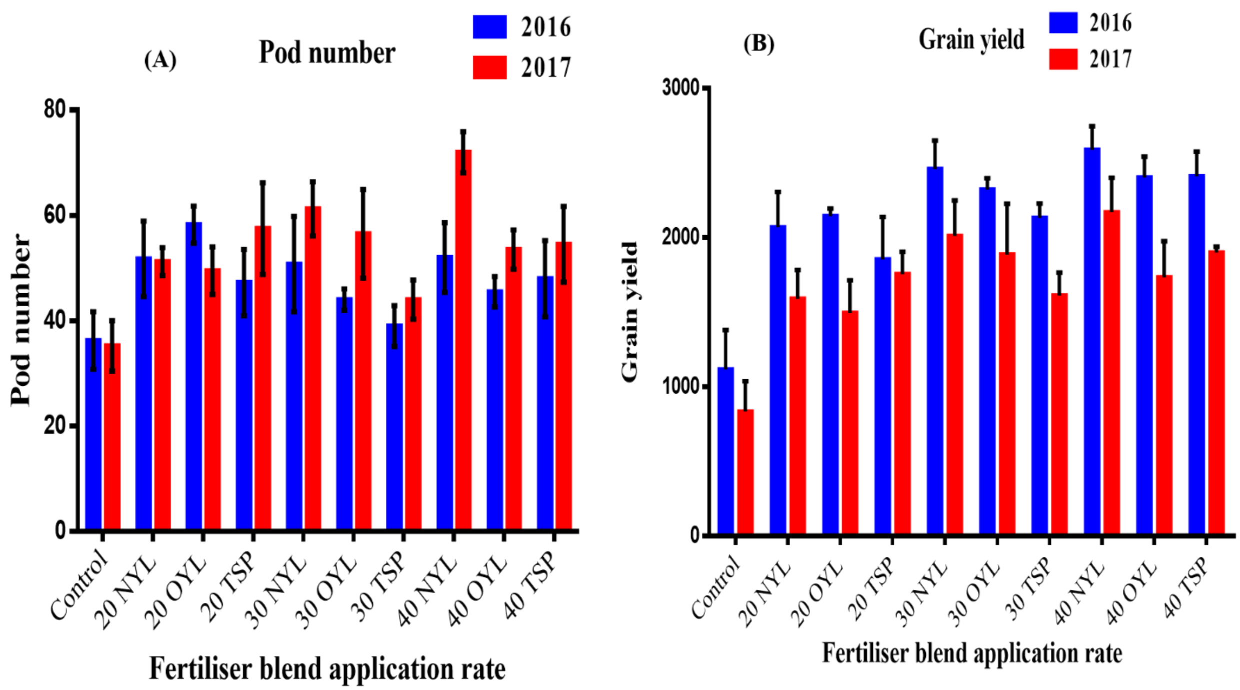

Figure 2: Effect of fertiliser blend application rate on number of pods per plant and grain yield (t ha-1) of soyabean in 2016 and 2017 cropping seasons. (**A**) Effect of fertiliser blend application rate on number of pods per plant in 2016 and 2017 cropping seasons. (**B**) Effect of fertiliser blend application rate on grain yield (t ha-1) of soyabean in 2016 and 2017 cropping seasons. The error bars indicate the standard errors of the means. NYL – New Yara Legume, OYL – Old YARA Legume, TSP – Triple Super Phosphate.

Table 1: Soil physico-chemical properties of the experimental fields in 2016 and 2017

Year	pH	Organic carbon ($g\ kg^{-1}$)	Total nitrogen ($g\ kg^{-1}$)	Available phosphorus ($mg\ kg^{-1}$)	Exchangeable cations ($cmol_{(+)}\ kg^{-1}$)				Micro-nutrients ($mg\ kg^{-1}$)			Soil texture (%)		
					K	Ca	Mg	Zn	Cu	Mn	Fe	Sand	Clay	Silt
2016	6.5	3.2	0.25	9.10	0.06	0.65	0.25	7.28	1.78	36.02	71.74	52	16	32
2017	6.1	6.4	0.54	6.37	0.14	1.89	0.84	10.23	2.54	98.27	79.28	52.5	15	32.5

Soil pH was measured as 1 : 2.5 H_2O; organic carbon refers to soil organic carbon; K refers to soil exchangeable potassium, Ca refers to soil exchangeable calcium, Mg refers to soil exchangeable magnesium, Zn refers to soil exchangeable zinc, Cu refers to soil exchangeable copper, Mn refers to soil exchangeable manganese, Fe refers to soil exchangeable iron.

Table 2: Response of soyabean to P fertiliser blends and benefit-cost ratios of application of different P fertiliser blends to soyabean in Yendi

Fertiliser blend and application rate	Phosphorus use efficiency (kg grain, kg P ha^{-1} applied)			Fertiliser blend use efficiency (kg grain, kg P ha^{-1} fertiliser blend applied)			Revenue from a kg of P fertiliser blend applied (USD$)†			Cost of kg fertiliser blend applied (USD$)‡	Benefit/cost ratio		
	2016	2017	Mean	2016	2017	Mean	2016	2017	Mean		2016	2017	Mean
20 kg P ha^{-1} NYL	48	36	42.0	3.8 ^{cd}	2.9 ^{c}	3.4	1.3 ^{cd}	1.0 ^{bc}	1.2	0.61	2.1 ^{bcd}	1.6 ^{b}	1.9
30 kg P ha^{-1} NYL	45	37	41.0	3.5 ^{cd}	2.9 ^{c}	3.2	1.2 ^{cd}	1.0 ^{bc}	1.1	0.61	2.0 ^{bcd}	1.6 ^{b}	1.8
40 kg P ha^{-1} NYL	37	33	35.0	2.9 ^{d}	2.6 ^{c}	8	1.0 ^{d}	0.9 ^{c}	1.0	0.61	1.6 ^{d}	1.5 ^{b}	1.6
20 kg P ha^{-1} OYL	51	33	42.0	5.6 ^{abc}	3.6 ^{bc}	4.6	1.9 ^{acd}	1.2 ^{bc}	1.6	0.68	2.8 ^{abcd}	1.8 ^{b}	2.3
30 kg P ha^{-1} OYL	40	33	36.5	4.4 ^{bcd}	3.6 ^{bc}	4.0	1.5 ^{bcd}	1.2 ^{bc}	1.4	0.68	2.2 ^{bcd}	1.8 ^{b}	2.0
40 kg P ha^{-1} OYL	32	23	27.5	3.5 ^{cd}	2.5 ^{c}	3.0	1.2 ^{cd}	0.9 ^{c}	1.1	0.68	1.8 d	1.3 ^{b}	1.6
20 kg P ha^{-1} TSP	37	45	41.0	7.4 ^{a}	9.2 ^{a}	8.3	2.5 ^{a}	3.1 ^{a}	2.8	0.73	3.5 a	4.0 ^{a}	3.8
30 kg P ha^{-1} TSP	34	23	28.5	6.9 ^{ab}	5.6 ^{b}	6.3	2.3 ^{ab}	1.9 ^{b}	2.1	0.73	3.2 ^{ab}	2.6 ^{b}	2.9
40 kg P ha^{-1} TSP	32	27	29.5	6.5 ^{ab}	5.5 ^{b}	6.0	2.2 ^{ab}	1.9 ^{b}	2.1	0.73	3.0 ^{abc}	2.6 ^{b}	2.8
$LSD_{0.05}$	NS	NS		2.48	2.87		0.84	0.98			1.2	1.38	

† Prices of soyabean grains were estimated at $ 0.34 per kg. ‡ Includes the cost of labor for fertiliser application of $ 0.61, $ 0.68, $ 0.73 per kg for NYL, OLY, and TSP, respectively. NS = Non-significant; NYL = New YARA Legume; OYL = Old YARA Legume; TSP = Triple Super Phosphate

Table 3: Sensitivity analysis (based on kg of fertiliser blend applied) for the three fertiliser blends in Yendi

Situation	Fertiliser blend and application rate	Cost of kg fertiliser blend applied (USD)	Gross returns on kg fertiliser blend applied	Net returns on kg fertiliser blend applied	Benefit/cost ratio
Grain selling at USD 0.21/kg	20 kg P ha^{-1} NYL	0.61	0.71	0.10	1.16
	30 kg P ha^{-1} NYL	0.61	0.67	0.08	1.10
	40 kg P ha^{-1} NYL	0.61	0.59	-0.02	0.97
	20 kg P ha^{-1} OYL	0.68	0.97	0.29	1.43
	30 kg P ha^{-1} OYL	0.68	0.84	0.16	1.24
	40 kg P ha^{-1} OYL	0.68	0.63	-0.05	0.93
	20 kg P ha^{-1} TSP	0.73	1.74	1.01	2.38
	30 kg P ha^{-1} TSP	0.73	1.32	0.59	1.81
	40 kg P ha^{-1} TSP	0.73	1.26	0.53	1.73
Grain selling at USD 0.36 /kg with 10 % cost over run	20 kg P ha^{-1} NYL	0.67	1.22	0.55	1.82
	30 kg P ha^{-1} NYL	0.67	1.15	0.48	1.72
	40 kg P ha^{-1} NYL	0.67	1.01	0.34	1.51
	20 kg P ha^{-1} OYL	0.75	1.66	0.91	2.21
	30 kg P ha^{-1} OYL	0.75	1.44	0.69	1.92
	40 kg P ha^{-1} OYL	0.75	1.08	0.33	1.44
	20 kg P ha^{-1} TSP	0.80	2.99	2.19	3.74
	30 kg P ha^{-1} TSP	0.80	2.27	1.47	2.84
	40 kg P ha^{-1} TSP	0.80	2.16	1.36	2.70

Table 4: Effect of fertiliser blend on soyabean grains nutrient concentration

Fertiliser blend application rate	P (%)	B (mg/kg)	Zn (mg/kg)
Control	0.32 ^{a}	16.36 ^{abc}	31.57 ^{a}
20 kg P ha-^{1} NYL	0.38 ^{b}	17.36 ^{ab}	25.24 ^{b}
30 kg P ha^{-1} NYL	0.39 ^{b}	17.51 ^{ab}	24.41 ^{b}
40 kg P ha^{-1} NYL	0.40 ^{b}	17.08 ^{ab}	23.69 ^{b}
20 kg P ha^{-1} OYL	0.44 ^{bc}	13.40 ^{cd}	25.03 ^{b}
30 kg P ha^{-1} OYL	0.44 ^{bc}	12.51 ^{cde}	24.23 ^{b}
40 kg P ha^{-1} OYL	0.42 ^{b}	11.35 ^{e}	23.35 ^{b}
20 kg P ha^{-1} TSP	0.38 ^{b}	14.83^{bcd}	25.66 ^{b}
30 kg P ha^{-1} TSP	0.40 ^{b}	14.91 ^{bcd}	25.12 ^{b}
40 kg P ha^{-1} TSP	0.40 ^{b}	15.06 ^{bc}	24.01 ^{b}
LSD $_{0.05}$	0.046	1.635	2.390

NS = Not significant; TSP = Triple super phosphate; OYL= Old YARA Legume; NYL = New YARA Legume

Figures

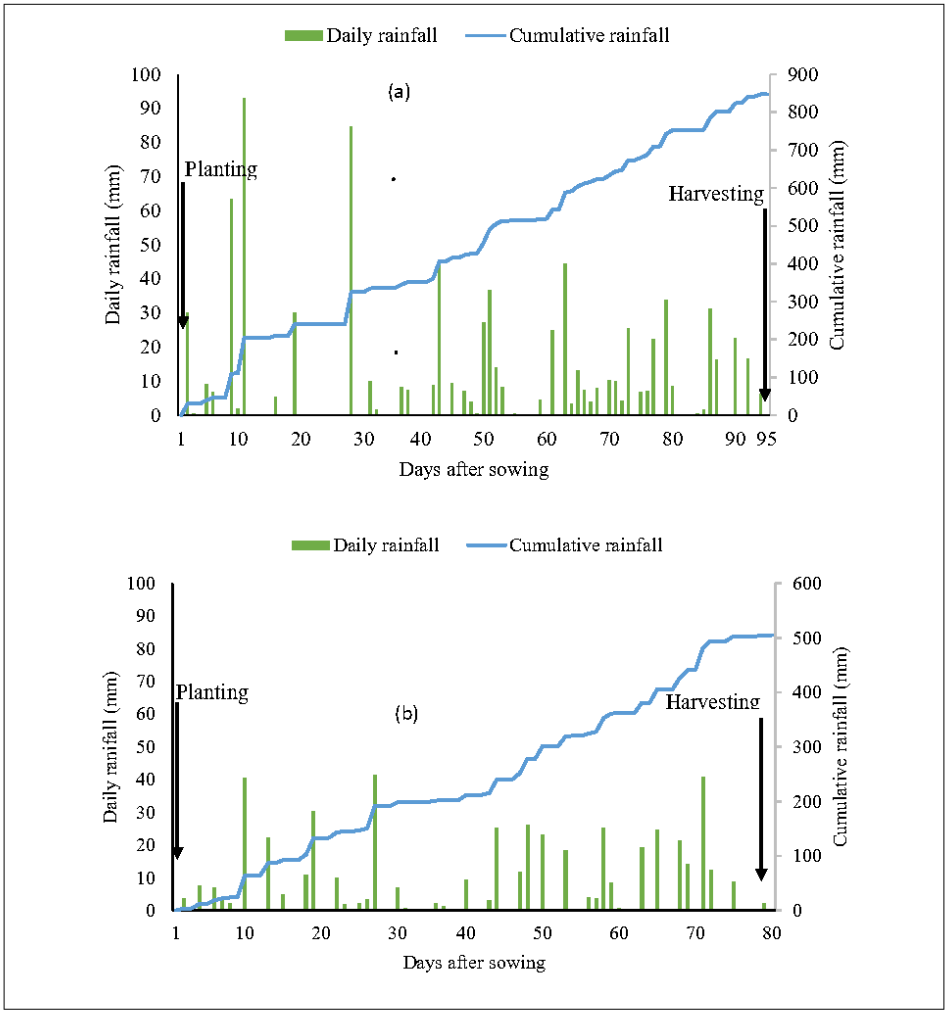

Figure 1: Daily and cumulative rainfall during the (a) 2016 and (b) 2017 growing seasons in Yendi, Ghana

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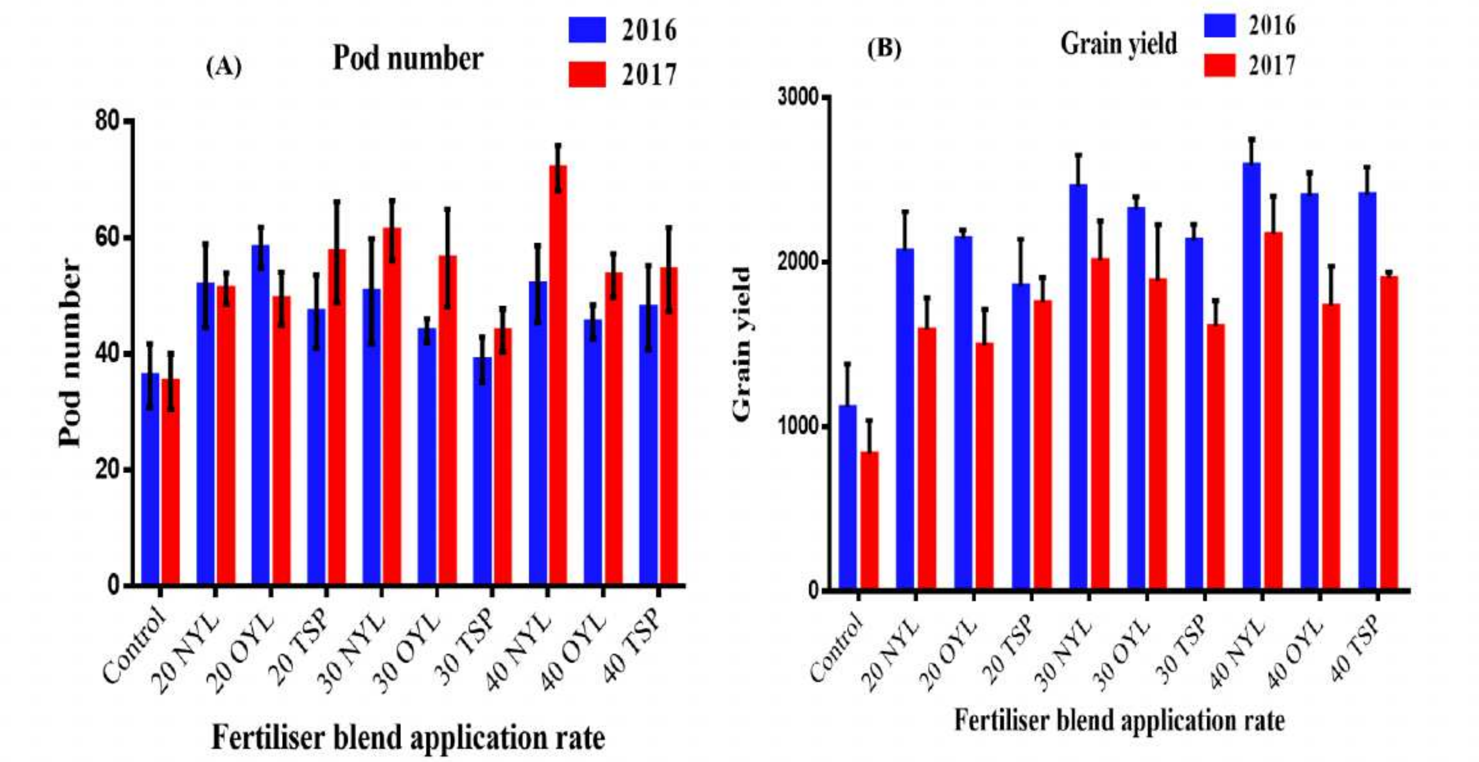

Figure 2

Effect of fertiliser blend application rate on number of pods per plant and grain yield (t ha-1) of soyabean in 2016 and 2017 cropping seasons. (A) Effect of fertiliser blend application rate on number of pods per plant in 2016 and 2017 cropping seasons. (B) Effect of fertiliser blend application rate on grain yield (t ha-1) of soyabean in 2016 and 2017 cropping seasons. The error bars indicate the standard errors of the means. NYL – New Yara Legume, OYL – Old YARA Legume, TSP – Triple Super Phosphate

Supplementary Files

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- TableS1.Supplementarymaterial.pdf