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Response of common bean (*Phaseolus vulgaris* L.) to nutrient amendments across variable agro-climatic conditions in Ghana

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Common bean (*Phaseolus vulgaris* L.) is an important crop with the potential to curb malnutrition in Sub-Saharan Africa (SSA). However, poor soil fertility is considered to be the major constraint for bean production in SSA. This study determines canopy spread, chlorophyll content, stomatal conductance, and seed yield of common beans in a field experiment conducted at Fumesua (rain-forest) and Akumadan (forest–savannah transition) agroecological zones. The study was conducted in the 2018 and 2019 cropping seasons using a split-plot arranged in a randomized complete block design with three replicates. The treatments consisted of the main plot factor namely varieties (Lv. "Semanhyia" and "Ennepa"*)* and the sub-plot factor P (75 kg ha^{-1}), NPK (100 kg ha^{-1}), ACARP organic fertilizer (4 t ha^{-1}), ACARP plus NPK (2 t ha^{-1} + 50 kg ha^{-1}), ACARP plus P (2 t ha^{-1} + 38 kg ha^{-1}) and control (zero-amendments). Results showed that co-application of P, NPK, and ACARP fertilizer increased plant height and canopy spread by ≈9.54 and 11.25% compared with their sole application and the control, respectively. Similarly, the combined application of the organic and inorganic fertilizers increased chlorophyll content and stomatal conductance by 36.43 and 23.79% compared to their sole application and the control respectively. These observations translate into increased crop biomass and therefore seed yield (≈ 42.54 - 46.58%). A significant variety and nutrient interaction were observed in the number of pods per plant and seed yield, irrespective of the location. The results suggest that the growth and yield response of the crop may be optimized with the co-application of both P, and NPK with ACARP organic fertilizer.

Key words: Crop productivity, fertilization, crop physiology, common beans.

INTRODUCTION

Fertilizer use and low intensity have been cited as one of the main factors hindering agricultural productivity in sub-Saharan Africa (SSA) (Tetteh et al., 2018). Fertilizer usage in sub-Saharan Africa is the lowest in the world, estimated at 10% of the world's average (Wortmann et al., 2019). However, the projected crop production is anticipated to emanate from crop intensification. In addition to the limited fertilizer usage is the increased soil degradation as observed by Maatman et al. (2007). Soil degradation is considered a major global problem, but more significant in developing countries where the majority of the people depend on crop production for their livelihoods (Tully et al., 2015).

Poor soil management is the major cause of land degradation among biophysical and socioeconomic factors (Olsson et al., 2019). Continuous cropping with little or no nutrient replenishment has led to soil nutrient depletion on smallholder farms in sub-Saharan Africa (Kihara et al., 2015). Consequently, crop yields obtained from smallholder farms are far below the potential yield resulting in yield gaps. Research efforts to improve soil fertility have focused on N, P, and K fertilizers (Moharana et al., 2017). However, continuous application of such fertilizers alone has contributed to the depletion of other essential nutrients triggering lack of response to future fertilizer applications and a possible reduction in crop yield. It has been noted that integrated soil fertility management such as combined application of organic and inorganic fertilizer is a key soil fertility management intervention that could improve crop productivity. It has gained much attention as a key option for boosting crop productivity by combining fertilizer use with other approaches adapted to local environments (Vanlauwe et al., 2014). To optimize common bean productivity in the midst of the challenges, it is imperative that innovative plant nutrition strategies are identified and implemented to solve multiple nutrient deficiencies that limit bean production.

Common bean (*Phaseolus vulgaris* L.) is an important grain legume providing a source of protein, dietary fiber, starch, and minerals such as potassium, thiamine, vitamin B_6 and folic acid in diets affordable by the poor (Economist Intelligence Unit, 2012; Garden-Robinson and McNea, 2013). It is considered the second most important source of human food (after maize) and the third most important source of calories (after maize and cassava). The crop is produced on about 4.5 million hectares annually by smallholder farmers, particularly women. Sales of beans now exceed US$ 500 million annually, with an export value of about US$110 million (Food and Agricultural Organization of the United Nations| Statistics (FAOSTAT), 2010). Though commercial farms may make some contributions to beans production, it is the smallholder farmers who are and will be the primary source of food for the growing African urban population (Montpellier, 2013). Therefore, improving productivity is important in smallholder farming systems. However, common bean production is characterized by low yields caused by nitrogen and phosphorus deficiency and pest attacks (Economist Intelligence Unit, 2012). Bean yields in sub-Saharan Africa, including Ghana average only 0.6 t ha^{-1} compared to attainable yields of >1.5 t ha^{-1} (Chianu et al., 2011). Poor soil fertility is considered to be the major constraint for bean production across many countries in SSA, including Ghana (Ministry of Food Agriculture (MOFA), 2018). Over the last decades, farmlands have been cultivated intensively due to an increased population, resulting in a decline in soil fertility and severe soil erosion, hampering bean production. In the case of Ghana, beans production appears to be gaining interest, but productivity remains relatively low despite some yield increases through crop improvement (IFPRI, 2014). Common bean has high N and P requirements for expressing its genetic potential. Furthermore, the common bean is reported to have the lowest N_2- fixation rate among grain legumes (Martinez-Romero, 2003) and generally responds poorly to the inoculation of rhizobia (Rebeschini et al., 2014). As a result, common beans are being generally considered more responsive than other legumes to soil amendments.

However, increasing yield of crops including common beans often come under scrutiny because of the amount of fertilizer needed to produce such high yields and the possibility of increased environmental impacts of high-nutrient input cropping systems. Yet, meeting the growing demand for food requires effective implementation of the principles of sustainable intensification of global agriculture (Godfray et al., 2010). Efficient and sustainable use of fertilizers is essential for meeting this challenge; particularly, in the Ghanaian soils where effective actions are needed to improve the fast-degrading soil and protect the soil resource while meeting food production targets. In this study, our intention was to build on the existing knowledge from other studies on common bean nutrition, (Dereje et al., 2018; Tesfaye et al., 2015; Rebeschini et al., 2014). Therefore, we hypothesized that fertile soil results in increased productivity by common beans than those on low fertile soil. Our objectives were to: (1) investigate the effect of triple super phosphate (P), N-P_2O_5-K_2O (NPK) and ACARP organic fertilizer on the productivity of common beans in two agro-ecological zones, (2) determine if different triple super phosphate (P), N-P_2O_5-K_2O (NPK) and ACARP organic fertilizer rates enhance stomatal conductance, chlorophyll content, biomass and therefore seed yield of applied nutrients, and (3) provide an alternative fertilization strategy for common bean in the

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Table 1. Precipitation (mm) recorded during the experimental period.

Months	Fumesua		Akumadan	
	2018	2019	2018	2019
January	0	1.4	0	0
February	29.8	81.4	45.3	5.9
March	228.2	99.6	108.6	126.8
April	212.4	177.2	92	61.4
May	189.3	134.6	215.1	120.3
June	387.6	223.4	192.2	212
July	143	110.1	180.3	58.43
August	91.8	24.8	120.5	117.2
September	233.3	158.1	294.8	271.43
October	197.1	316.6	124.1	95.8
November	10.1	8.8	35.1	4.7
Dec	6.5	41.8	5.8	61.45
Total	1729.1	1377.8	1413.8	1135.41

context of different agro-ecological zones.

MATERIALS AND METHODS

Site description

The experiment was established in the 2018 and 2019 cropping seasons under rain-fed conditions in the southern part of Ghana. The study was conducted at CSIR-Crops Research Institute experimental field at Fumesua (6.7109° N, 1.5172° W) in the semi-deciduous forest zone and Akumadan (7.3960° N, 1.9539° W) in the forest-savannah transition zone. The soil types in the study areas are classified as Ferric Acrisol, Asuansi soil series, and Ferric Lixisol respectively (FAO/Unesco, 1997). The top soils consist of sandy loam and dark brown (Adjei-Gyapong and Asiamah, 2002). Before sowing, soil samples were taken from a depth of 0 to 30 cm to determine baseline soil properties. The sandy–loam soil at Fumesua and Akumadan has a pH value in 0–30 cm soil layer of ≈4.5; 4.8, soil organic carbon was 1.45%; 1.75%; total nitrogen (N) was 0.15; 0.47%, and phosphorus (P) was 15.27; 16.52%, respectively. The pH of the soil was determined using a soil pH meter (model: Sartorius PB–10, Germany) using soil to water ratio of 1: 2.5 as described by (McLean, 1982). The total nitrogen content (TN) of the soil was determined using the Kjeldahl digestion and distillation procedure as described by Bremner and Mulvaney (1982). The soil in the study area is generally low in fertility and has poor moisture retention capacity. The results of soil analysis before sowing showed deficient soil conditions at the experimental site (Landon, 1991). Both study areas experienced bimodal rainfall, that is, major rainy season from March to mid-August and the minor rainy season from September to November. Average long-term maximum and minimum temperatures span between 21 and 32℃ and temperature condition in the study years ranges between 22 and 31℃. Cultivation practice at the experimental site is continuous cropping under conventional tillage, involving soil inversion and smoothing operations coupled with residue removal. The crop prior to the experiment commencement was cassava (*Manihot esculenta* L). The monthly rainfall recorded during the course of the study is presented in Table 1. Rainfall data of the study sites were obtained from the Ghana Metrological Agency. Seasonal rainfall recorded in 2018 and 2019 during the research was 1729.1 and 1377.8 mm in Fumesua, and 1413.8 and 1135.41 mm respectively.

Experimental design and treatment application

The study was conducted using split-plot arranged in randomized complete block design with common bean varieties released by CSIR-Crops Research Institute as the main plot (Lv. “Semanhyia” and “Ennepa”). The crop was planted between the 25th to 27th of August and harvested during the first and second week of November every year. The treatments were sole or combined application of triple super phosphate (P), N-P_2O_5-K_2O (NPK) and ACARP (Accra Compost and Recycling Plant) organic fertilizer and two common bean varieties (Lv. “Semanhyia” and “Ennepa”). The subplot factors were P (75 kg ha^{-1}), N.P.K.15:15:15 (100 kg ha^{-1}), ACARP organic compost (4 t ha^{-1}), ACARP organic fertilizer plus N.P.K.15:15:15 (2 t ha^{-1} + 50 kg ha^{-1}), ACARP organic fertilizer plus P (2 t ha^{-1} + 38 kg ha^{-1}) and control (zero-amendments).The NPK (15-15-15) and P were applied at 60-60-60 kg/ha as N, P_2O_5 and K_2O and triple superphosphate respectively. The treatments are T1: P (75 kg ha^{-1}), T2: NPK (100 kg ha^{-1}), T3: ACARP organic fertilizer (4 t ha^{-1}), T4: ACARP plus NPK (2 t ha-1 + 50 kg ha^{-1}), T5: ACARP plus P (2 t ha^{-1} + 38 kg ha^{-1}) and T6: control (zero-amendments).

The ACARP is an organic fertilizer sourced from a local waste company known as the Accra Compost and Recycling Plant. The nutrient contents of the ACARP organic compost are N (1.5%), P (1.0%), and K (1.0%). All the nutrient amendments were applied once at fourteen (MOFA), 2018) days after planting. The individual plot’s measured 4 m by 5 m and the plots were separated by 0.5 m width protection rows. Common bean was planted at 20 cm intrarows and 50 cm interrows and harvest area per plot was 1.5 m by 3 m.

Crop physiological parameters

Crop measurements were made using BBCH scale as described by Enriquez-hidalgo et al. (2020). Plant height was measured from the soil surface to the tip of the main stem at the mid-pod filling stage and expressed in cm (phenological stage R4). Chlorophyll measurement was carried out by Soil-plant analysis development (SPAD) –portable chlorophyll meter (model SPAD-502-PLUS, Konica Minolta, USA) by measuring ten fully expanded solar radiation-exposed upper leaves per plot. Measurements were conducted at (Vn: n^{th} trifoliolate leaf unfolded at node) and flowering stages (R2: 50% open flowers). This equipment measures the ratio of the light absorbance in the red and near-infrared region and is expressed as SPAD values (Monje and Bugbee, 1992). Stomatal conductance (Gs) was measured under natural light on days with clear skies using a porometer (Model AP4 Delta-T Devices, Cambridge UK). The stomatal conductance was measured at (Vn: n^{th} trifoliolate leaf unfolded at a node) and flowering stages (R2: 50% open flowers). Four representative plants in the six inner rows were chosen per plot for the measurement and averaged.

Yield and yield-related traits

At harvest maturity (RH: 80% of pods at mature color), all the plants in the two central rows were cut at soil level and heaped at the center of the plot. Ten plants were randomly sampled and all the pods on each plant were counted and recorded to determine the number of pods per plant. The biomass of the ten selected plants was put in large brown envelopes and oven dried at 105°C for 45 min, and subsequently to constant weight at 85°C (Yeboah et al., 2016).

Later, all pods from the net plot area (1.5 m by 3 m) were harvested into perforated harvest bags, sun-dried, and threshed.

Table 2. Analysis of variance for plant height (cm), canopy spread (cm), chlorophyll content and stomatal conductance.

Source	df	Plant height	Canopy spread	Chlorophyll content		Stomatal conductance	
				Vegetative	Flowering	Vegetative	Flowering
Variety (V)	1	0.02	0.01	0.00	0.00	0.00	0.00
Nutrient (N)	5	0.00	0.00	0.00	0.00	0.00	0.00
Location (L)	1	0.00	0.00	0.00	0.00	0.00	0.01
Year (Y)	1	0.00	0.6	0.00	0.00	0.73	0.62
V * N	5	0.98	0.93	0.00	0.03	0.62	0.69
V * L	1	0.00	0.68	0.13	0.31	0.15	0.26
V * Y	1	0.31	0.36	0.23	0.14	0.60	0.42
N * L	5	0.67	0.37	0.58	0.76	0.45	0.38
N * Y	5	0.94	0.32	0.53	0.26	0.81	0.77
L * Y	1	0.28	0.59	0.15	0.79	0.11	0.63
Error	96						
Total	144						

Values in the table represent the probability level at P < 0.05.

The seed was then weighed and seed moisture content was determined using a moisture meter to extrapolate seed yield in kg ha^{-1}. Yields reported here are adjusted to 12% moisture content.

Statistical analysis

Statistical analyses were undertaken using the Univariate model of statistical package SPSS 22.0 (IBM Corporation, Chicago, IL, USA) at a probability level of 5% (P < 0.05). Differences between the means were determined using Tukey's HSD (Honestly Significant Difference) test. Bivariate correlation analysis (two-tailed) was also performed using Pearson's correlation coefficients.

RESULTS

Plant height and canopy spread

Variety, location, and their interaction significantly (P<0.05) affected plant height and canopy spread (Table 2). Nutrients and Year independently influenced plant height and canopy spread. Co-application of phosphorus, NPK, and ACARP organic fertilizer increased plant height by 7.68 and 10.78% compared with the sole application of P, NPK and ACARP organic fertilizer and the control respectively (Figure 1a). Combining ACARP organic compost with either P or NPK produced similar results. "Ennepa" had significantly (P<0.05) higher plant height at Fumesua whiles "Semanhyia" recorded the highest at Akumadan (Figure 1b). With respect to canopy spread, the combined application of the ACARP organic fertilizer and P and NPK increased canopy spread by 9.15% and 11.65% relative to their sole application and the control respectively (Figure 2a). In terms of the impact of location on plant height and canopy spread, both were higher (that is, increased by approximately 10.91%) at Fumesua compared with Akumadan (Figures 1b and 2b). The results also showed that, 'Semanhyia' variety had the greatest canopy spread than 'Ennepa' variety in both locations (Figure 2b).

Chlorophyll content and stomatal conductance

There was a significant variety × nutrient management interaction in affecting chlorophyll content (Table 2). The analysis of variance indicated a significant (P < 0.05) effect of treatment factors on chlorophyll content and stomatal conductance at the two critical growth stages (vegetative and flowering). Combined application of phosphorus, NPK and ACARP organic fertilizer led to significantly higher chlorophyll content; an increase of 36.43% and 10.46% was recorded compared to the control and the sole application of P, NPK and ACARP, respectively (Figure 3a). At Akumadan, chlorophyll content was increased by 11.36% compared with Fumesua (Figure 3b). Irrespective of variety, the effect of the treatment on chlorophyll content was similar. At both growth stages of measurement and with both varieties, co-application of the P, NPK, and ACARP produced the greatest chlorophyll content; an increase of 23.89 and 41.22% was recorded compared to their sole application (Figure 3a). Sole application of phosphorus and NPK enhanced stomatal conductance by 20.19 and 23.79% relative to the control, but the effect was lesser than their co-application (Figure 4a).

Stomatal conductance under ACARP organic fertilizer plus phosphorus fertilizer was the greatest (410.46 mol (H_2O) m^{-2} s^{-1}), followed by ACARP organic fertilizer applied together with NPK (401.57 mol (H_2O) m^{-2} s^{-1}). The greatest stomatal conductance was observed at

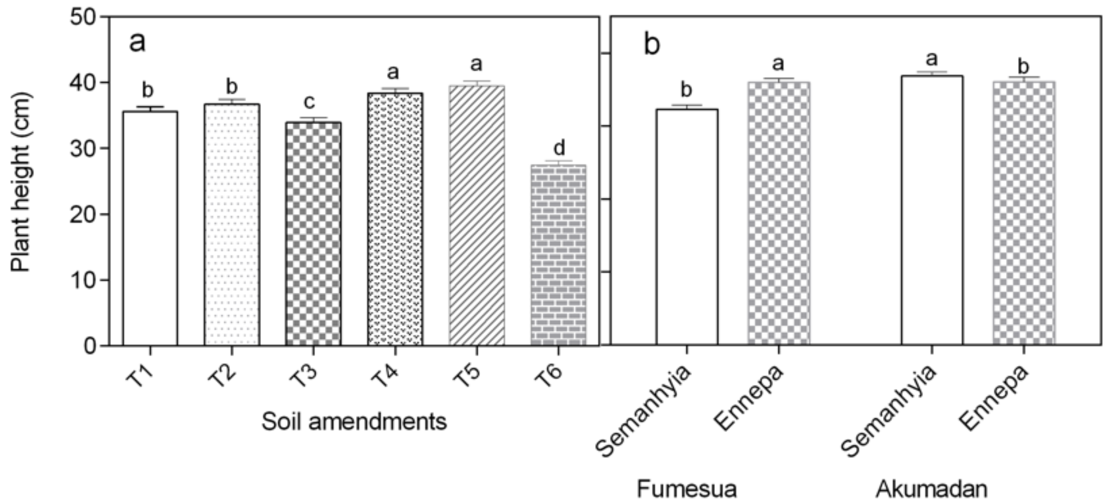

Figure 1. Effect of treatment on plant height. Bars with different letters in the figure are statistically different at P < 0.05. Error bars represent the standard error of means. Means comparison was done using Tukey HSD (honestly significant difference) (P < 0.05). T1-T6 in the figure represent: T_1: P (75 kg ha^{-1}), T_2: NPK (100 kg ha^{-1}), T_3: ACARP organic fertilizer (4 t ha^{-1}), T_4: ACARP plus NPK (2 t ha^{-1} + 50 kg ha^{-1}), T_5: ACARP plus P (2 t ha^{-1} + 38 kg ha^{-1}) and T_6: control (zero-amendments). Figure 'a' and 'b' represent the impact of soil amendment and the interaction effect of location and variety on plant height, respectively.

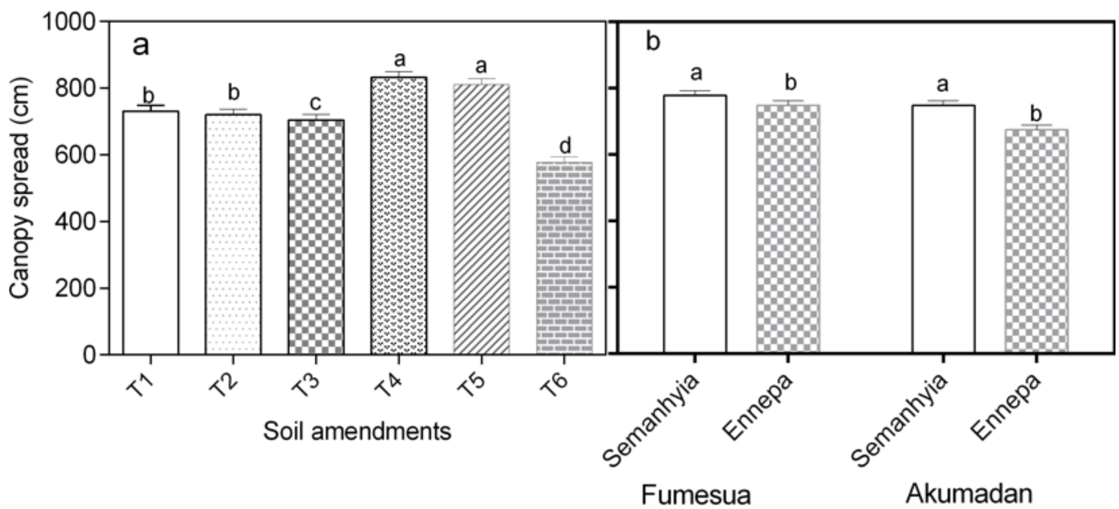

Figure 2. Effect of treatment on canopy spread. Bars with different letters in the figure are statistically different at P < 0.05. Error bars represent the standard error of means. Means comparison was done using Tukey HSD (honestly significant difference) (P < 0.05). T1-T6 in the figure represent: T_1: P (75 kg ha^{-1}), T_2: NPK (100 kg ha^{-1}), T_3: ACARP organic fertilizer (4 t ha^{-1}), T_4: ACARP plus NPK (2 t ha^{-1} + 50 kg ha^{-1}), T_5: ACARP plus P (2 t ha^{-1} + 38 kg ha^{-1}) and T_6: control (zero-amendments). Figure 'a' and 'b' represent impact of soil amendment and the interaction effect of location and variety on canopy spread, respectively.

Akumadan (411.03 mol (H_2O) m^{-2} s^{-1}) compare to Fumesua (311.58 mol (H_2O) m^{-2} s^{-1}), representing an increase of 31.91% (Figure 4b).

Yield and yield parameters

The analysis of variance indicated a significant (P < 0.05) effect of treatment factors on number of pods per plant and seed yield (Table 3). The results also showed significant interaction between variety and nutrients in affecting number of pods per plant and seed yield (Figure 5a, 6a). Also, there was a significant nutrient × year interaction as well as location x year in affecting biomass yield (Table 3). Irrespective of the nutrient applied, higher

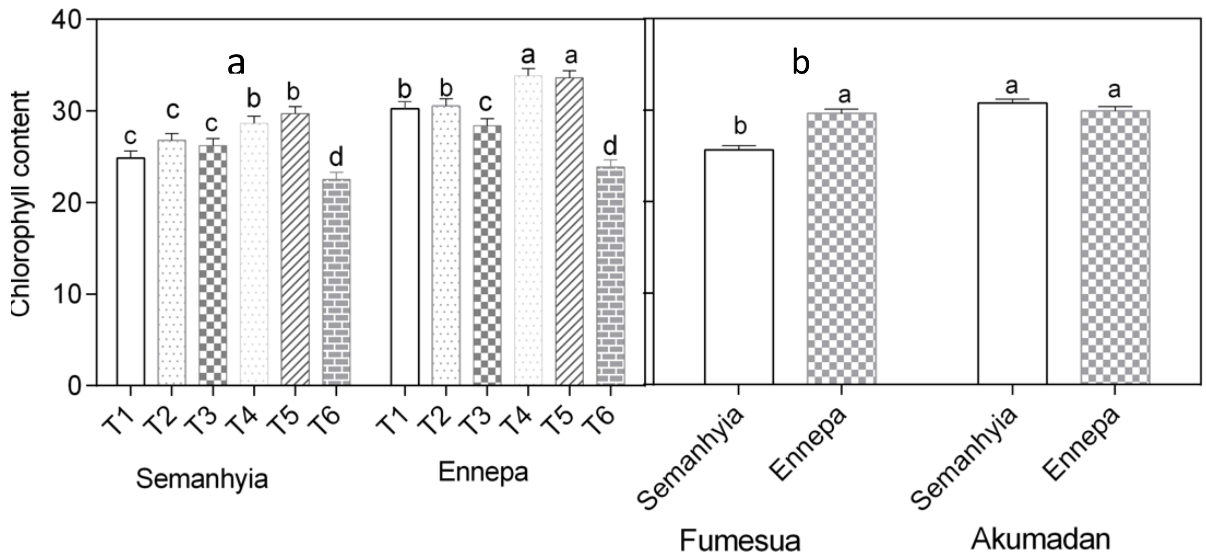

Figure 3. Effect of treatment on chlorophyll content. Bars with different letters in the figure are statistically different at P < 0.05. Error bars represent the standard error of means. Means comparison was done using Tukey HSD (honestly significant difference) (P < 0.05). T1-T6 in the figure represent: T_1: P (75 kg ha^{-1}), T_2: NPK (100 kg ha^{-1}), T_3: ACARP organic fertilizer (4 t ha^{-1}), T_4: ACARP plus NPK (2 t ha^{-1} + 50 kg ha^{-1}), T_5: ACARP plus P (2 t ha^{-1} + 38 kg ha^{-1}) and T_6: control (zero-amendments). Figure 'a' and 'b' represent impact of soil amendment and interaction effect of location and variety on chlorophyll content respectively

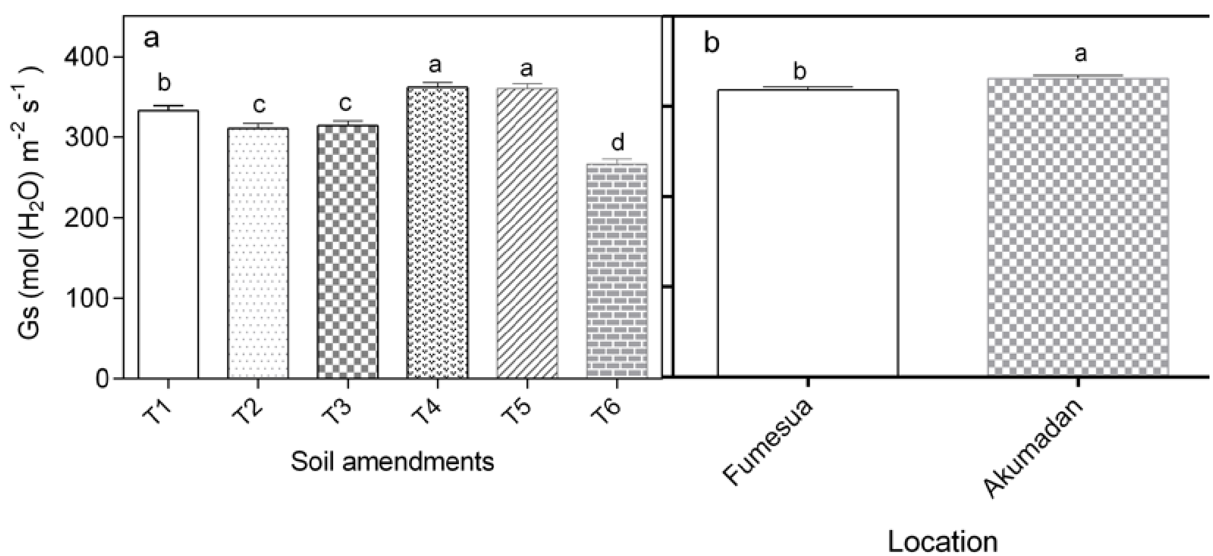

Figure 4. Effect of treatment on stomatal conductance (Gs). Bars with different letters in the figure are statistically different at P < 0.05. Error bars represent the standard error of means. Means comparison was done using Tukey HSD (honestly significant difference) (P < 0.05). T1-T6 represent: T_1: P (75 kg ha^{-1}), T_2: NPK (100 kg ha^{-1}), T_3: ACARP organic fertilizer (4 t ha^{-1}), T_4: ACARP plus NPK (2 t ha^{-1} + 50 kg ha^{-1}), T_5: ACARP plus P (2 t ha^{-1} + 38 kg ha^{-1}) and T_6: control (zero-amendments). Figure 'a' and 'b' represent impact of soil amendment and location on stomatal conductance, respectively.

biomass yield was recorded in 2018 compared to 2019 (data not shown). The control recorded significantly lower biomass yield compared to almost all the treatments, an average decrease of 42.61% was observed (data not shown). The effect of year on biomass performance was dependent on location. Akumadan had the highest

Table 3. Analysis of variance for biomass yield pods/plant and seed yield.

Source	df	Biomass yield	pods/plant	Seed yield
Variety (V)	1	0.26	0.00	0.00
Nutrient (N)	5	0.00	0.00	0.00
Location (L)	1	0.02	0.00	0.00
Year (Y)	1	0.00	0.02	0.00
V * N	5	0.66	0.01	0.00
V * L	1	0.59	0.23	0.61
V * Y	1	0.95	0.17	0.73
N * L	5	0.45	0.27	0.96
N * Y	5	0.03	0.20	0.43
L * Y	1	0.42	0.72	0.70
Error	96			
Total	144			

Values in the table represent the probability level at P < 0.05.

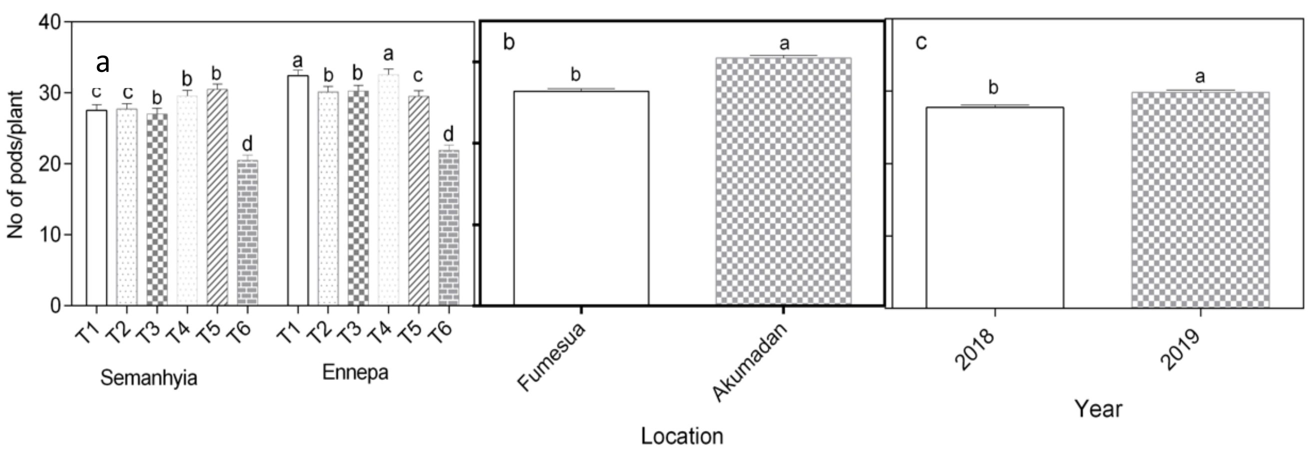

Figure 5. Effect of treatment on number of pods per plant. Bars with different letters in the figure are statistically different at P < 0.05. Error bars represent the standard error of means. Means comparison was done using Tukey HSD (honestly significant difference) (P < 0.05). T1-T6 in the figure represent: T_1: P (75 kg ha^{-1}), T_2: NPK (100 kg ha^{-1}), T_3: ACARP organic fertilizer (4 t ha^{-1}), T_4: ACARP plus NPK (2 t ha^{-1} + 50 kg ha^{-1}), T_5: ACARP plus P (2 t ha^{-1} + 38 kg ha^{-1}) and T_6: control (zero-amendments). Figure 'a', 'b' and 'c' represent interaction between variety and treatment on number of pods per plant, and location and year on no of pods per plant respectively.

biomass yield compared to Fumesua. Irrespective of variety, the combined application of phosphorus, NPK, and ACARP organic fertilizer increased seed yield by 46.47% compared with the control (Figure 6). Similarly, under all the varieties, the co-application of the nutrients resulted in a 22.40% increase in seed yield (Figure 6a). A similar results trend was observed in the number of pods per plant (Figure 5).

Correlation analysis

The Pearson′s correlation coefficient is presented in Table 4. Plant height showed a significant (positive) correlation with seed yield (r = 0.660, P<0.01) and biomass yield (r = 0.360, P<0.01). Significant correlations were also observed between stomatal conductance and chlorophyll content and seed yield (r = 0.410 and 0.619 respectively, P<0.01). Highly significant correlations were also observed between biomass yield and seed yield (r = 0.279, P<0.01). A significant linear relationship was found between chlorophyll content and stomatal conductance (r = 0.484, P<0.01) and also seed yield (r = 0.410, P<0.01). Significant correlations were also observed between number of pods per plant, chlorophyll content, and stomatal conductance.

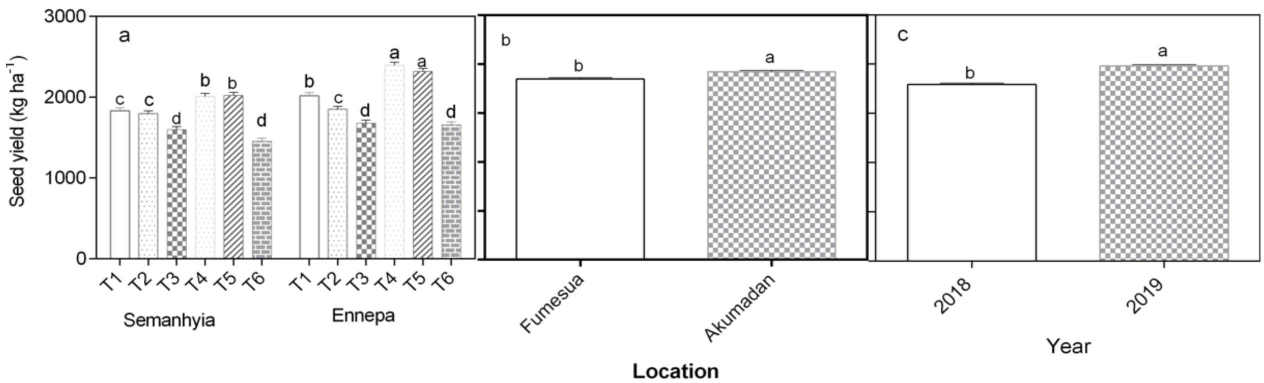

Figure 6. Effect of treatment on seed yield. Bars with different letters in the figure are statistically different at P < 0.05. Error bars represent the standard error of means. Means comparison was done using Tukey HSD (honestly significant difference) (P < 0.05). T1-T6 in the figure represent: T_1: P (75 kg ha^{-1}), T_2: NPK (100 kg ha^{-1}), T_3: ACARP organic fertilizer (4 t ha^{-1}), T_4: ACARP plus NPK (2 t ha^{-1} + 50 kg ha^{-1}), T_5: ACARP plus P (2 t ha^{-1} + 38 kg ha^{-1}) and T_6: control (zero-amendments). Figure 'a', 'b' and 'c' represent interaction between variety and treatment on seed yield, and location and year on seed yield respectively.

Table 4. Relationships between measured traits during the experimental period.

Variable	Plant height	Canopy spread	Chlorophyll content	Stomatal conductance	Biomass yield	Seed yield
Pods per plant	0.438**	0.215**	0.383**	0.467**	0.538**	0.452**
plant height		0.381**	0.322**	0.518**	0.360**	0.660**
canopy spread			0.301**	0.429**	0.295**	0.395**
Chlorophyll content				0.484**	0.383**	0.410**
Stomatal conductance					0.437**	0.619**
Biomass yield						0.279**

** Correlation is significant at the 0.01 level (2-tailed).

DISCUSSION

Soil fertility is key to achieving resilient and sustainable food production and enhancing livelihoods of smallholder farmers, particularly in Sub-saharan Africa. The work reported in this article showed that the combined application of ACARP organic fertilizer with either phosphorus or NPK at rates reported in this study has the potential to increase the productivity of common beans in the tropical soils of Ghana. This assertion is supported by the fact that plant height, canopy spread, stomatal conductance, chlorophyll content, biomass, and seed yield were maximized when the crop was fertilized with a combined application of ACARP organic fertilizer with either P or NPK. In the present study, co-application of ACARP organic fertilizer with either phosphorus or NPK improved chlorophyll content, and stomatal conductance. The improvement in these traits may be attributed to improved plant-available nutrients from the combined application of P, NPK, and organic organic fertilizer. In support (Carvalho et al., 2017) indicated that tropical soils are deficient in several nutrients so two or more fertilizers applied to crops help to increase crop productivity. The results of this study affirm the importance of the combined application of organic and inorganic fertilizer in improving crop production, including common bean. Exploring the appropriate nutrient management technology for common bean production in Ghana with largely degraded soils (1) is very significant. This is due to the fact that the crop originated from areas with moderate fertile soils, so cultivating the crop in marginal fields as is often the case with cowpea will not produce same results. Worldwide, the cultivation of common beans on degraded soils has resulted in low productivity of the crop (Beebe et al., 2012), so it has little tolerance to low soil fertility.

The increase in nutrient-availability when ACARP organic fertilizer was applied together with P or NPK translated into increased stomatal conductance and therefore yield and yield components compared with unfertilized controls and sole application of the ACARP organic fertilizer, P and NPK. This is evidenced by the fact that chlorophyll content, and stomatal conductance significantly and positively correlated with the number of pods per plant and seed yield. Also, biomass yield significantly and positively correlated with seed yield. The productive potential of common bean is ultimately determined by the number of pods per plant and the number of seeds per pod which are the main yield components. In this study, number of pods per plant, biomass and seed yield were significantly (P<0.05) influenced by the interaction effect of variety and nutrients, indicating the effect of nutrients on the varieties studied. The increase in the number of pods per plant, biomass, and seed yield might be due to the metabolic role that combined application of ACARP organic fertilizer with either P or NPK plays in promoting the reproductive growth of the crop. Rafat and Sharifi (2015) demonstrated that availability of plant nutrient stimulated the productivity of the plant. In our study, the effect of the treatment was greater when ACARP organic fertilizer was applied together with Phosphorus fertilizer than when it was applied together with NPK. This result is supported by Rafat and Sharifi (2015) and Tesfaye et al. (2015), who reported significant variations in the number of pods per plant and seed yield on different crops including common beans due to the application of P with organic fertilizer.

The increase in seed yield may also be attributed to the overall improvement in growth and physiological indicators (plant height, canopy spread, chlorophyll content, stomatal conductance, and biomass yield), which translated into an improvement in the number of pods per plant, number of seeds per pod and seed yield. This result is consistent with the findings of Dereje et al., (2018) and Gifole et al. (2011) who observed significant increases in biomass yield and therefore seed yield of common beans in response to nutrient application under field environment. These results strongly suggest multiple soil fertility limitations in the two variable soils for common bean production that cannot be addressed by sole application of P, NPK and ACARP organic fertilizer. While cowpea can generally grow on infertile soils or marginal soils, attempts to grow common bean on such soils often results in very low yields (Tesfaye et al., 2015). Ecologically, common beans do not have sufficient capacity to overcome the soil infertility hurdle in Ghanaian soils (Gobeze and Legese, 2015). In contrast, (Tolera et al., 2005) reported a non-significant effect of nutrients on the seed yield of climbing beans on acid soils in Ethiopia. The improvement in beans productivity when ACARP organic fertilizer was applied together with either NPK or P is a significant finding in the context of waste disposal and reduction in environmental pollution due to excess waste generation in Ghana and application of inorganic fertilizers . Recycling of organic waste for use as a soil amendment minimizes its subsequent handling and disposal problems and minimizes the use of inorganic fertilizer. In this study the significant difference among the common bean cultivars in yield and yield components may be ascribed to the genotypic variations for nutrient use efficiency of the varieties (Abaidoo et al., 2007). The genotypic variations for nutrient use efficiency may arise from variation in nutrient acquisition and translocation (Fageria et al., 2012). Stomatal conductance, biomass and seed yield were greater at Akumadan relative to Fumesua. These findings may be due to the amount of rainfall received since rainfall can affect growth and development, especially in rain-fed cropping systems (Shen et al., 2011; Ndamani and Watanabe, 2014).

Soil fertility restoration is necessary to increase crop production and achieve food and nutrition security, particularly in fragile agroecology such as Ghana. The results of this study provide stakeholders including farmers, extension officers, and policy makers with information on the outcome of combined application of organic fertilizer and inorganic fertilizer on common beans.

Conclusion

The combined application of ACARP organic fertilizer with either P or NPK fertilizer to common beans resulted in increased plant height, canopy spread, and chlorophyll content, especially when ACARP organic fertilizer was applied alongside P fertilizer. This resulted in significantly greater effect on the measured traits than the other treatments tested. Increase in chlorophyll content had a beneficial effect on stomatal conductance and biomass yield, which translated into higher seed yield when ACARP organic fertilizer was applied to soil in combination with P or NPK fertilizer. This result is important as many growers used single fertilizers for common bean production. The results reported in this study were consistent with significant positive correlations observed between stomatal conductance, chlorophyll content, biomass yield and seed yield. This confirmed that seed yield is sensitive to changes in stomatal conductance and chlorophyll content, and that variationsin those traits can result in significant impacts on seed yield. This set of results offers new insights into the beneficial use of ACARP organic fertilizer applied with either P or NPK as a soil conditioner for common bean production in Ghanaian soils. This study provides novel evidence of the effectiveness of integrated nutrient application in increasing common bean productivity in Ghana, which has a different ecosystem from South and East Africa, where the crop is domiciled in Africa. Consequently, this is likely the first report on the positive role of these nutrients on common bean production in variable agroecology in Ghana.

CONSENT FOR PUBLICATION

The authors give consent to the African Journal of Aricultural Research to publish and distribute this paper

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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