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Research Article
Growth Performance of Three Dry Bean Cultivars Affected by Different Rates of Phosphorus Fertilizer and Locations

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Abstract
Background and Objective: Development and growth of dry bean are always restricted by insufficient application of phosphorus fertilizer. This study aimed to examine the effect of cultivar, phosphorus fertilizer rate and location on the growth performance of dry bean. **Materials and Methods:** The experiment was a 5×3×3 factorial experiment fitted into a randomized complete block design. The Five levels (0, 1, 2, 3 and 4) of phosphorus fertilizer were applied during planting and these differed according to each location. The three dry bean cultivars used were PAN 123, PAN 148 and PAN 9292. Three locations of the study were Taung, Ventersdorp and Mafikeng. The measured growth parameters were plant height, number of leaves per plant, chlorophyll content, number of nodules per plant and root length. **Results:** Dry bean cultivar PAN 123 had a significantly higher number of leaves per plant, chlorophyll content and longer roots length as compared to other cultivars. Dry bean cultivar PAN 9292 had significantly higher plant height and nodules number per plant as compared to other cultivars. Dry bean planted at Taung had significantly higher plant height, number of leaves and nodules per plant and longer root length as compared to other locations. **Conclusion:** In terms of the growth performance of dry bean, PAN 123 is the recommended cultivar in this study. Location with a higher percentage of sand such as Taung is the best area for the production of dry bean.

Key words: Cultivar, dry bean, growth, location, nodules, phosphorus, plant height

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Dry bean is very sensitive to both drought stress and excessive rainfall and water requirements are quite high during the flowering and pod-filling stages. In most days during the growing period of common bean, the average daily air temperature is greater than 24°C[1]. Dry bean grows optimally in temperatures of about 24°C and the crop does not tolerate frost at any stage in its growth[2]. Temperatures below 15°C negatively influence germination and hypocotyl elongation of beans[3], while high temperatures can cause the abscission of flowers[4]. Low soil fertility, coupled with low pH rates and a shortage or excess of mineral salts could limit dry bean production[5].

Phosphorus is one of the beneficial determinants of plant growth[6]. Legume production is limited by the poor availability of phosphorus, as it is one of the most essential nutrients significantly affecting plant metabolism and growth[7]. Baddley and Watson[8] reported poor growth in broad bean plants in treatments where no phosphorus was applied before flowering. Phosphorus application has been found to have a significant enhancing effect on a number of parameters in pea production such as the number of branches, as well as the dry weight of the shoots and roots[9]. Adequate phosphorus results in rapid growth, earlier development and increased dry bean root development, which implies that plants can develop further and exploit soil for nutrients and moisture. As such, phosphorus deficiency might slow down the overall plant growth process[10].

Bean growth parameters such as plant height, leaf and branches number increase as the rates of phosphorus increase[11]. The accelerated photosynthetic area and dry matter accumulation is promoted through the phosphorus fertilizer which improves the partition of nutrients to the growing parts of the plant. When phosphorus fertilizer is low within the soil, the outstanding outcomes are a reduction in leaf growth, leaf surface area, as well as the quantity of dry bean leaves[12]. The effect of phosphorus in stimulating root and plant growth and initiating nodule formation, as well as influencing the general overall performance of the rhizobium bacteria has been reported[13]. Differences in the efficiency of phosphorus use in the case of the dry bean are related to the ability of the plants to grow in soils with low phosphorus content and this can be attributed to their distinctive root system morphology, their high root hair density rates and their copious root exudates[14]. The application of phosphorus significantly increases bean pods per plant and plant height at maturity stage[15].

The development of new cultivars with greater efficiency in terms of the applications of phosphorus, coupled with the best management practices, will help to develop sustainable agricultural systems to support resource-poor farmers[16]. Late maturing legumes are more tolerant to drought conditions than the early maturing legumes, which presents with limited growth potential under drought conditions[17]. However, once reproductive growth begins, the late maturing soybean variety halts vegetative growth larger than the early maturing type that continues to grow even after flowering has commenced.

The type of cultivar that performs well in terms of growth under different soil types of varying locations is not clear to most farmers. The rate of phosphorus fertilizer that results with increase growth of dry bean is still a challenge in most farmers. Farmers also generally find that the fertility of most of the African soils is poor, with phosphorus being largely deficient in most of them[18].

The objective of this study was to determine the effects of applying specific rates of phosphorus fertilizer to the soil, the type of cultivar and the location on the plant height, the number of leaves per plant, the chlorophyll content, the root length and the number of nodules per dry bean plant.

MATERIALS AND METHODS

Site description of the study area: The experiment was conducted during the 2017-2018 planting season at three environmentally-different locations in the North-West province, namely, the North-West University farm (Molelwane) near Mafikeng, an experimental station under the auspices of the Department of Agriculture at Taung and a privately owned Ventersdorp farm. The North-West University Research Farm is situated at 25°48'S, 45°38'E; 1012 masl. It falls within a semi-arid tropical savannah region and receives a summer rainfall, with an annual mean of 571 mm[19]. The mean maximum temperature is 37°C, while the mean minimum temperature ranges from 7-11°C. According to the South African soil classification system, the soils on the North-West University farm belong to the Hutton series, with sandy loam and a yellow sand alternating[19].

The second location, the Department of Agriculture Experimental Station at Taung, is situated at 27 30'S, 24°30'E and at an altitude of 1111 m above sea level. It has a mean rainfall of 1061 mm that begins in October. According to the South African Soil Classification, the soils at Taung belong to the Hutton series[19]. Taung has deep, fine, sand dominated red soils, which are freely drained and eutrophic, with the parent material having originated from aeolian deposits[20].

Table 1: A summary of the respective mean temperature and precipitation values for different locations during planting season

Location	Climate data	December	January	February	March	April	May	June
Taung	Maximum (°C)	34.8	36.0	33.1	31.0	26.2	24.8	23.6
	Minimum (°C)	16.8	17.8	17.9	15.4	12.7	4.4	0.6
	Rainfall (mm)	31.2	41.8	49.6	126.8	107.8	1.6	0.0
Mafikeng	Maximum (°C)	32.4	33.8	29.7	29.6	27.0	25.2	23.5
	Minimum (°C)	16.9	18.0	17.4	15.4	12.5	7.0	3.9
	Rainfall (mm)	48.6	71.8	108.8	90.0	27.6	26.0	0.0
Ventersdorp	Maximum (°C)	31.0	33.2	29.7	29.6	26.9	23.8	22.4
	Minimum (°C)	15.5	15.7	15.4	14.1	10.7	4.3	0.7
	Rainfall (mm)	80.6	63.4	95.4	79.4	47.4	15.2	0.0

Source: South African Weather Service (SAWS) 2017/2018

The third location, a Ventersdorp farmer's field, is situated at 22°59'50S, 29°30'7E and at an altitude of 1283 m above sea level. Ventersdorp experiences average temperatures of between 24 and 30°C in summer and a mean annual rainfall of 80 mm from December-March. The Ventersdorp farm field falls into a semi-arid savannah region, while the soil at the farm is classified as the Hutton form. The weather data for the three locations that prevailed during the course of this study are presented in Table 1.

Experimental design: The experimental design involved a 5×3×3 factorial experiment fitted into a Randomized Complete Block Design (RCBD), with four replications. The experiment in each location had 15 treatment combinations. Three different cultivars of dry bean (PAN 148, PAN 123 and PAN 9292) were planted during the seed planting stage at Mafikeng, Ventersdorp and Taung. Five quantities of phosphorus fertilizer were applied as follows: 0, 30, 45, 60 and 75 kg P ha^{-1} at Taung, 0, 45, 60, 75 and 90 kg P ha^{-1} at Ventersdorp and 0, 110, 114, 118 and 120 kg P ha^{-1} at Mafikeng. Each experiment per location involved 60 plots.

Land preparation: The conventional method of tillage was applied to loosen the soil for the proper development of the crop. The land was harrowed and ploughed to a considerable depth to get rid of the grass and weeds. The primary tillage system that was used; namely, a mouldboard plough, helped to loosen and aerate the top layer of the soil. The secondary method of tillage that was applied involved the use of a harrow to pulverize the soil further.

Pre-planting soil sampling: The soil samples were collected from the three respective sites, before planting during the 2017-18 planting season. They were taken at depths ranging from 0-15 cm across each field and a soil auger was used for this purpose.

Each sample was sieved using a 2 mm sieve and was placed in a separate package according to its location. The respective soil samples from the three locations were sent to the Agricultural Research Council at Rustenburg for chemical and physical analysis. The chemical properties of the soil were analyzed for soil pH using a pH meter, organic carbon using the Walkley-Black method as described by Sahrawat[21], N-NO_3^- and N-NH_4^+ using the Kjeldahl method as described by du Preez and Bate[22], phosphorus using the Bray1-P method as described by Gutierrez Boem *et al.*[23] and exchangeable potassium using the Kjeldahl method[22]. The physical properties of the soil were also analyzed for soil texture (sand, silt and clay (%)) at the Agricultural Research Council.

Plot size, row number and spacing: The sub-plot size in each replicate was 14 m^2 (4×3.5 m). A distance of 1 m was left between each plot and of 2 m between the replications. The total field size per location was 1480 m^2 (20×74 m) per location. The inter-row spacing for the experiment was 50 cm, while the intra-row spacing was 30 cm. The number of rows per plot was eight.

Planting and the source of the planting materials: Three different cultivars (PAN 148, PAN 9292 and PAN 123) of dry bean were purchased at the Noord Wes Koprassie at Lichtenburg. PAN 123 is a small white dry bean used for canning has a determinate growth habit. PAN 9292 and PAN 148 are red speckled kidney beans and have an indeterminate growth habit. The inorganic fertilizer used for the study was single superphosphate (SSP) and it was purchased at Noord Wes Koprassie in Lichtenburg.

Cultural practices: The dry bean seeds were sown by hand at an intra-row spacing of 30 cm and an inter-row spacing of 50 cm during planting. The dry bean plants were thinned at the seedling stage to maintain one plant per stand. The weeds at each location were removed manually at two week intervals at an early stage, before flowering and up to maturity. Supplementary irrigation by means of a sprinkler irrigation system was used at the three locations.

Table 2: Chemical and physical properties of the soil collected during planting season

	Locations		
Properties	Taung	Ventersdorp	Mafikeng
Chemical (mg kg^{-1})			
pH (KCl)	5.33	6.76	6.22
$N\text{-}NO_3^-$	14.00	7.50	11.15
$N\text{-}NH_4^+$	2.05	0.70	5.20
P (Bray-1)	9.00	63.00	22.00
Soil physical (%)			
Sand	87.00	70.00	85.00
Silt	3.00	11.00	2.00
Clay	10.00	19.00	13.00

Table 3: Respective phosphorus rates applied at Taung, Mafikeng and Ventersdorp during the 2017/18 planting season

Location	Available P (mg kg^{-1}) before planting	P rate applied (kg ha^{-1})	P rate (kg ha^{-1})
Mafikeng	63	0	0
		1	110
		2	114
		3	118
		4	120
Ventersdorp	22	0	0
		1	45
		2	60
		3	75
		4	90
Taung	9	0	0
		1	30
		2	45
		3	60
		4	75

P: Phosphorus fertilizer

Fertilizer application: Single superphosphate was applied at different rates depending on the availability of phosphorus in the soil at the three locations. At Ventersdorp, the quantity of phosphorus in the soil was 22 mg kg^{-1} and different quantities of single superphosphate were applied at the rates of 0, 45, 60, 75 and 90 kg of phosphorous ha^{-1}. The amount of phosphorus that was found in the soil at Taung amounted to 9 mg kg^{-1} and different quantities of single superphosphate were applied at rates of 0, 30, 45, 60 and 75 kg of phosphorus ha^{-1}.

The amount of phosphorus available in the soil at Mafikeng amounted to 63 mg kg^{-1} and single superphosphate fertilizer was applied at rates of 0, 110, 114, 118 and 120 kg of phosphorus ha^{-1}. The fertilizer was band-placed with the seed at planting at the three locations. The results of the soil chemical and physical properties before planting at three locations during 2017-18 planting season are indicated in Table 2. The rates of phosphorus fertilizer rates applied at three locations during the course of the study are indicated in Table 3.

Data collection: The vegetative and reproductive growth data were collected from the harvested area (6.25 m^2) for each plot. Four plants were randomly selected from the middle rows in the harvested area and tagged for data collection.

The vegetative data parameters were collected from the harvested area, which comprised blocks measuring 2.5×2.5 m. Four dry bean plants from within the harvested area were selected and their height was measured before and during flowering by means of a measuring tape. The height measurements were averaged at 48 and 78 Days After Planting (DAP) (before flowering and during flowering). The number of leaves per plant from the four selected plants within the plot were counted at 48 and 78 DAP and averaged. One matured dry bean leaf was selected from the tagged four-dry bean plants and using a chlorophyll meter (CCM-200), the chlorophyll content was measured from the top part of the leaf before and during flowering. Before flowering, the selected four-dry bean plants were carefully uprooted and the shoot was separated from the roots. The roots were then rinsed with water and the nodules were removed from the roots and counted. The number of nodules from the selected four plants was then averaged. The root lengths of the four plants were measured with a measuring tape and these values were averaged.

Statistical analysis: The data were subjected to an analysis of variance (ANOVA using the GenStat 11th edition (2008) test. Treatment differences were separated using the Least Significant Difference (LSD) at the rate of a 5% probability. The high factor rates for the interactions were considered under the measured parameters.

RESULTS AND DISCUSSION

Effects of phosphorus fertilizer rate, cultivar and location on the dry bean plant height at 48 and 78 DAP: Cultivar had significant effect ($p<0.001$) on the dry bean plant height at 48 and 78 Days After Planting (DAP) as indicated in Table 4. Cultivar PAN 9292 produced significantly taller plants (58.83 cm) than PAN 148 and PAN 123 at 48 DAP, respectively. PAN148 also produced significantly taller plants (93.92 cm) than PAN 123 at 78 DAP, respectively. The taller plants in both cultivars of red speckled beans (PAN 148 and PAN 9292) at the three locations could be attributed to their growth habit. This observation is corroborated by the results of Emam *et al.*[24], who reported that the difference in the plant height of the common bean could be attributed to the growth habit of the cultivars.

Table 4: Effects of treatment factors on dry bean plant height (cm) at 48 and 78 DAP

Factors	Before flowering (48 DAP)	After flowering (78 DAP)
P rate (kg ha^{-1})		
0	49.58	80.47
1	50.56	81.34
2	54.40	83.53
3	53.07	83.95
4	50.64	93.42
$LSD_{0.05}$	4.21	4.57
Cultivar		
Pan 123	46.00	69.67
Pan 148	50.12	93.92
Pan 9292	58.83	90.04
$LSD_{0.05}$	3.26	3.54
Location		
Mafikeng	47.18	96.20
Taung	71.61	86.34
Ventersdorp	36.16	71.08
$LSD_{0.05}$	3.26	3.54

P rate: Phosphorus fertilizer rate, DAP: Days after planting

Location had significant effect ($p<0.001$) on dry bean plant height at 48 and 78 DAP. The dry bean planted at Taung was significantly taller (71.61 cm) than the dry bean planted at Mafikeng and Ventersdorp respectively at 48 DAP. The dry bean planted at Mafikeng was also significantly taller (96.20 cm) than the dry bean planted at Taung and Ventersdorp respectively at 78 DAP. The taller plant height for all three of the cultivars planted at Taung could be attributed to the optimum temperature prevailing during the growth period, as opposed to the dry bean cultivars planted at Ventersdorp, where lower temperatures prevailed during the growth period. This observation is corroborated by the findings of Yoldas and Esiyok[25], who reported that growth and development of crop strongly depend on temperature.

The phosphorus fertilizer rate did not have any significant effect on dry bean plant height at 48 DAP. However, it had a significant effect ($p<0.001$) on dry bean plant height at 78 DAP. Dry bean fertilized with rate 4 phosphorus produced a significantly taller plant (93.42 cm) than dry bean fertilized with other quantities of phosphorus fertilizer. The taller plant height associated with the high rate of phosphorus fertilizer could be attributed to the phosphorus content of the soil prior to the soil analysis. This result is corroborated by the findings of Shahid *et al.*[26], who found that the soybean plant height increases significantly with an increase in the applications of phosphorus. The interaction of cultivar×location had a significant effect ($p = 0.002$) on dry bean plant height at 78 DAP.

Effects of phosphorus fertilizer rate, cultivar and location on the number of dry bean leaves per plant at 48 and 78 DAP: Cultivar had a significant effect ($p<0.01$) on the number of leaves per dry bean plant at 48 and 78 DAP as indicated in Table 5. Cultivar PAN 123 had a significantly higher number of leaves per plant (32.04) than PAN 148 and PAN 9292 respectively at 48 DAP. Cultivar PAN 123 also had a significantly higher number of leaves per plant (54.29) than PAN 148 and PAN 9292 respectively at 78 DAP. PAN 148 had a significantly higher number of leaves per plant (51.95) than PAN 9292 (49.05) at 78 DAP. The higher number of leaves per plant in the case of PAN 123 could be attributed to the growth habit of the cultivars because PAN 123 has a determinate growth habit (bushy type) as opposed to PAN 148 and PAN 9292, respectively, both of which have an indeterminate growth habit. This observation is corroborated by the findings of Sita *et al.*[27], who reported that the variation in the number of leaves per plant and plant height could be due to differences in the genetic makeup.

Locations had a significant effect ($p<0.001$) on the number of leaves per dry bean plant at 48 and at 78 DAP. The dry bean planted at Taung had a significantly larger number of leaves (44.11) than the dry bean planted at Mafikeng and Ventersdorp respectively at 48 DAP. The dry bean planted at Mafikeng also had a significantly larger number of leaves (19.93) than the dry bean planted at Ventersdorp at 48 DAP. The dry bean planted at Taung had a significantly larger number of leaves (76.70) than the dry bean planted at Mafikeng and Ventersdorp respectively at 78 DAP. The larger number of leaves per plant at Taung could be due to the physical properties of the soil. Taung has a good soil structure with a lower percentage of clay (Table 1); thus the larger number of leaves per plant could be attributed to the absorptive capacity of the root system in taking up the available nutrients in the soil. This result is corroborated by the findings of Sebetha *et al.*[28], who stated that the larger number of leaves in Red caloona was due to its greater nutrient absorbing capability, resulting from its root system, compared to PAN 311 cultivar. Phosphorus fertilizer rate had no significant effect on the number of leaves per dry bean plant at 48 and 78 DAP.

The interaction of cultivar×location had a significant effect ($p<0.001$) on the number of leaves per dry bean plant at 48 DAP. The interaction of cultivar×location also had a significant effect ($p = 0.020$) on the number of leaves per dry bean plant at 78 DAP. The interaction of the phosphorus fertilizer rate×location had a significant effect ($p = 0.022$) on the number of leaves per dry bean plant at 78 DAP.

Table 5: Effects of treatment factors on dry bean number of leaves and the leaf chlorophyll content at 48 and 78 DAP

	Number of leaves per dry bean plant		Chlorophyll content of the dry bean leaf (CCI)	
Factors	48 DAP	78 DAP	48 DAP	78 DAP
P rate (kg ha^{-1})				
0	27.28	49.67	30.00	28.53
1	26.27	50.33	27.98	26.39
2	30.10	50.89	27.30	24.49
3	28.95	52.83	28.23	25.53
4	27.28	55.09	29.14	26.51
$LSD_{0.05}$	4.43	4.70	2.76	2.51
Cultivar				
Pan 123	32.04	54.29	33.34	26.36
Pan 148	25.78	51.95	25.57	25.78
Pan 9292	26.12	49.05	26.68	26.73
$LSD_{0.05}$	3.43	3.64	2.14	1.94
Location				
Mafikeng	19.93	29.95	36.42	26.25
Taung	44.11	76.70	26.40	27.36
Ventersdorp	19.90	48.63	22.77	25.25
$LSD_{0.05}$	3.43	3.64	2.14	1.94

P rate: Phosphorus fertilizer rate, DAP: Days after planting

Effects of phosphorus fertilizer rate, cultivar and location on the chlorophyll content of the dry bean leaf at 48 and 78 DAP: As indicated in Table 5, cultivar had a significant effect (p<0.001) on the chlorophyll content of the dry bean leaf at 48 and 78 DAP. Cultivar PAN 123 had a significantly higher chlorophyll content of 33.34 (CCI) than PAN 148 and PAN 9292, respectively. The higher chlorophyll content in the leaves of cultivar PAN 123 could be attributed to its growth habit because it is a late maturing cultivar. It took more time to develop than PAN 148 and PAN 9292, which matured at an earlier stage. According to Borowiak *et al.*[29], the reasonable ratings of the chlorophyll content in the dry bean might be due to the stage that they had reached in their development.

The rate of application of the phosphorus fertilizer had a significant effect (p = 0.030) on the chlorophyll content of the dry bean leaf at 78 DAP. Dry bean without phosphorus fertilizer rate presented with a significantly higher leaf chlorophyll content of 28.53 (CCI) than dry bean treated with different rates of phosphorus. This observation contradicted the findings by Mfilinge *et al.*[30], who reported that, the application of phosphorus in bush bean indicated high total leaf chlorophyll content.

Location had a significant effect (p<0.001) on chlorophyll content of dry bean leaf at 48 DAP. The dry bean planted at Mafikeng had a significantly higher leaf chlorophyll content of 36.42 (CCI) than the dry bean planted at Taung and Ventersdorp respectively. The dry bean planted at Taung also had a significantly higher leaf chlorophyll content of 26.40 (CCI) than the dry bean planted at Ventersdorp. The highest leaf chlorophyll content in the dry bean was recorded at Mafikeng and could be attributed to the temperature and the amount of rainfall experienced at the location during the growing season. This observation is corroborated by the observation of Nagata *et al.*[31], who reported that 30°C is the optimum temperature at which general plant chlorophyll synthesis takes place.

The interaction of cultivar×location had a significant effect (p = 0.006) on the chlorophyll content of the dry bean leaf at 48 DAP.

Effects of phosphorus fertilizer rate, cultivar and location on the dry bean number of nodules per plant before flowering: Cultivar had a significant effect (p = 0.012) on the number of nodules per dry bean plant before flowering as indicated in Table 6. Cultivar PAN 9292 had significantly higher number of nodules per plant (2.90) than PAN 148 and PAN 123, respectively. The higher number of nodules per dry bean plant in PAN 9292 could be attributed to the growth habit of the cultivar and its nodulation ability. This observation is corroborated by the findings of Ndlovu[12], who stated that the dry bean number of nodules per plant and nodule dry weight is higher in red speckled bean than in the white haricot respectively.

Location had a significant effect (p<0.001) on the number of nodules per dry bean plant. The dry bean planted at Taung produced a significantly higher number of nodules per plant (3.90) than the dry bean planted at Mafikeng and Ventersdorp respectively. The higher number of nodules at Taung could be attributed to soil type of the location, which favoured the production of nodules. This observation agrees with the findings of Sebetha and Modi[32], who reported higher number of nodules per plant of cowpea planted at Taung due to sandy soil on that site.

Table 6: Effects of treatment factors on dry bean root length and number of nodules per plant before flowering

Factors	Number of nodules/plant	Root length (cm)
P rate (kg ha^{-1})		
0	2.38	9.85
1	2.81	9.44
2	2.34	10.87
3	2.37	11.95
4	2.34	10.27
$LSD_{0.05}$	1.15	2.22
Cultivar		
Pan 123	2.78	12.56
Pan 148	1.66	9.67
Pan 9292	2.90	9.19
$LSD_{0.05}$	0.89	1.72
Location		
Mafikeng	0.00	9.02
Taung	3.90	12.58
Ventersdorp	3.45	9.83
$LSD_{0.05}$	0.89	1.72

P rate: Phosphorus fertilizer rate, DAP: Days after planting

Phosphorus fertilizer rate had no significant effect on the number of nodules per dry bean plant. The interaction of cultivar×phosphorus fertilizer rate had significant effect (p = 0.034) on the number of nodules per dry bean plant before flowering.

The interaction of location×phosphorus fertilizer rate also had a significant effect (p = 0.011) on the number of nodules per dry bean plant before flowering. The interaction of cultivar×location had significant effect (p<0.001) on the number of nodules per dry bean plant before flowering.

Effects of phosphorus fertilizer rate, cultivar and location on the root length per dry bean plant before flowering: Cultivar had a significant effect (p<0.001) on the root length per dry bean plant before flowering as indicated in Table 6. Cultivar PAN 123 had a significantly longer root length (12.56 cm) than PAN 148 and PAN 9292, respectively. The longer root length in PAN 123 as opposed to that in PAN 148 and PAN 9292, respectively could be attributed to the variation in the growth habit of the dry bean cultivars. This result is corroborated by the findings of Fageria *et al.*[16], who reported a difference in root length among dry bean cultivars presenting with contrasting growth habits.

Location had a significant effect (p<0.001) on the dry bean root length per plant before flowering. Dry bean planted at Taung had a significantly longer root length (12.58 cm) than dry bean planted at Mafikeng and Ventersdorp respectively. The longer root length at Taung could be attributed to the soil structure at the site and the soil fertility status. This observation is in agreement with the results of Fageria *et al.*[16], who stated that soil structure is critical in root development as poor soil structure could impose a shortage of oxygen and cause a physical barrier to the development and growth of the roots.

The phosphorus fertilizer rate did not have any significant effect on the root length of the dry bean plant. The interaction of cultivar×location had a significant effect (p<0.001) on the root length (cm) per dry bean plant.

CONCLUSION

The growth and development of dry bean depend on the type of cultivar planted. In this study, dry bean cultivar PAN 123 produced a significantly higher number of leaves per plant, higher leaf chlorophyll content and also longer root length as compared to other cultivars. Cultivar PAN 9292 responded well in terms of taller plant height and higher number of leaf chlorophyll. Phosphorus fertilizer rate in this study contributed much to dry bean plant height during 78 days after planting, where phosphorus rate 4 (higher rate) produced taller plants. The growth and development of dry bean also depend on location and type of soil. In this study, location Taung with higher percentage of sand of 80% responded positively in terms of dry bean growth parameters, such as plant height, a number of leaves per plant, roots nodule number and root length. Therefore, the recommendation is that, PAN 123 is the best performing cultivars in terms of growth and location with a higher percentage of sand as good area for the production of dry bean.

SIGNIFICANCE STATEMENT

This study discovered that, the location with less percentage of clay can be beneficial for dry bean production. The increase in phosphorus fertilizer application contributed to the growth and development of dry bean. It was also discovered that, cultivar PAN 123 responded positively in terms of growth performance across different locations. This study will help the researchers to uncover the critical areas of interactions between location and cultivar on dry bean production, which many researchers were not able to explore.

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