Effects of plant density on growth parameters and yield of sugar bean (*Phaseolus vulgaris* L.) in Swaziland

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ABSTRACT

Field bean (*Phaseolus vulgaris* L.) consumed in Swaziland is mostly imported. Small-scale farmers can grow this crop in the country and obtain good yields if the correct planting density is identified. A field study was conducted during the growing season of 2004/2005 to determine the influence of different planting densities on growth parameters and yield of field bean. The experiment consisted of a randomised complete block design, with four replications. There were five planting densities (400,000; 200,000; 133,333; 100,000 and 66,667 plants/ha studied for 11 weeks. Results showed that Absolute Growth Rate (AGR) was significantly ($P < 0.01$) higher in the lower populations. The lowest population had AGR of 7.0 g/week whereas the highest plant population had AGR of 2.4 g/wk between 7 and 10 weeks after planting (WAP). At 7 WAP, the highest plant population had a significantly ($P < 0.01$) higher leaf area index, LAI, of 4.6 while the lowest plant population had LAI of 0.7. At 400,000 density of plants/ha, though the seed yield (695.8 kg/ha) was low, however, it was 56% higher than the yield (445.5 kg/ha) of the recommended plant population. Planting density of 400,000 plants/ha is suggested.

Keywords: Field bean, plant population, plant density, growth parameters, yield

INTRODUCTION

Field bean (*Phaseolus vulgaris* L.) is an important grain legume crop that is widely eaten, not only in Swaziland but also in other parts of the world (Buruchara, undated; Kelly, 2000; CIAT, 2001). After groundnut (*Arachis hypogaea* L.), field bean is the next major grain legume that is widely consumed in Swaziland (Nxumalo, personal communication, 2004). Field bean is not grown on a large scale in Swaziland, although the climatic conditions of the country favour commercial production of the crop. The amount of field bean consumed in Swaziland is not known. Per capita consumption of field bean is highest in Africa, reaching 66 kg/year in western Kenya and 55 kg/year in Rwanda (Buruchara, undated). Kelly (2000) reported that Mexico has the highest bean consumption in Latin America, with over 15 kg per capita annually. One of the most popular types of field bean in Swaziland is the speckled seed-type commonly known as sugar bean (Anon., 1991). Edje (1995) reported that field beans are important food crops in Malawi, where both seeds and fresh leaves are used as food. This crop has a great potential as one of the major food crops in Swaziland.

Though field bean has the capacity to fix nitrogen, its nitrogen-fixing ability is comparatively low hence the need to apply nitrogen fertilisers (Anon., 1991). Lindemann and Glover (2003) reported that groundnut, cowpea, soya beans (*Glycine max*) are good nitrogen fixers, being able to fix up to 280 kg of nitrogen/hectare; field bean fixes less nitrogen than these legumes. Sugar bean is also rich in vitamins A and C (Norman, 1992).

Field bean population densities used in the southern African semi-arid regions vary widely. In Swaziland, the recommended population is 200,000 plants/ha (Anon., 1991). In Zimbabwe and South Africa, Walker *et al.* (2004) used a range from a low density of 40,000 plants/ha to a high density of 160,000 plants/ha. They noted that intercropping maize and bean was advantageous. Studying insect pest incidence in field bean, Karel (1991) reported that the incidence of bean flies decreased with increasing plant populations from 66,666 to 533,332 plants/ha when field bean was intercropped with maize. Tsubo *et al.* (2003) using population densities of 4.2, 8.3, and 12.5 plants/m^2 for sole field bean, and 2.1, 4.2 and 6.3 plants/m^2 for bean-maize intercrop, concluded that plant density affected crop productivity and resource use in intercropping. They explained that final crop yield was influenced by crop growth; that is, good crop growth resulted in high crop yield. Since farmers might wish to maximise yields of sugar beans, it is important to carry out population studies that could improve the productivity of this crop. If a more suitable planting density is used by farmers to grow field bean on a large scale in Swaziland, this might help to reduce the importation of field beans. For appropriate management decisions, it would be beneficial to understand how plant population would influence different growth parameters of field bean in Swaziland. Therefore, this investigation was carried out to determine the effects of plant population on selected growth parameters and seed yield of field bean.

MATERIALS AND METHODS

A field experiment was conducted in the 2004/2005 cropping season in the Crop Production Department Farm in Luyengo Campus (26°34'S, 31°12'E; annual rainfall, 800 mm; mean annual temperature, 18°C; 750 m above sea level) of the University of Swaziland. The soil was an Oxisol of the Malkerns series (Murdoch, 1968). A randomised complete block design was used. There were five spacing treatments replicated four times. The treatments and their respective plant populations were: 50.0 cm x 5.0 cm (400,000 plants/ha); 50.0 cm x 10.0 cm – recommended spacing (200,000 plants/ha); 50.0 cm x 15.0 cm (133,333 plants/ha); 50.0 cm x 20.0 cm; (100,000 plants/ha); and 50.0 cm x 30.0 cm (66,667 plants/ha). Each plot was 4.5 m long and 4.0 m wide.

Land preparation was done by ploughing, followed by disc harrowing. One day before planting, a basal application of a compound fertiliser, N:P:K [2:3:2 (22) + Zn] was made by banding, at the rate of 400 kg/ha following soil analysis (Anon., 1991). The variety of field bean grown was *PAN 159*. Planting was done by hand, in mid-December 2004, using two seeds/station; these were later thinned to one plant/station at 10 days after sowing. Sprinkler irrigation was applied immediately after planting. Plots were irrigated to field capacity for the first three days after sowing, because after that time, regular rains were experienced. Further crop management (Anon., 1991) consisted of manual weeding at 4 and 7 weeks after planting (WAP), and monitoring for diseases and insect pests.

On each sampling date, three plants/plot were removed to determine the following growth parameters in each field bean population.

Leaf area/plant

The leaf area was measured using the cork borer method (Ndawula-Senyimoba, 1972; Edje and Osiru, 1988) using 30 leaf-discs and a cork borer that was 1.5 cm in diameter. The oven-dry mass of the 30 leaf discs and oven-dry mass of all the leaves were used to calculate the leaf area using the relationship:

$$\text{Leaf area} = \frac{\text{Area of 30 leaf discs (cm}^2\text{) x Dry leaf mass (g) of three plants used}}{\text{Dry mass of 30 leaf discs (g).}}$$

Leaf Area Index (LAI)

LAI was calculated (Ndawula-Senyimoba, 1972; Edje and Osiru, 1988) as the ratio of the leaf area to the land area occupied by sampled plants.

Relative growth rate (RGR)

This was determined using the method of Hunt (1978),

$$RGR = \frac{\ln W_2 - \ln W_1}{T_2 - T_1},$$

where W_1 was the crop dry mass at the previous sampling ; W_2 was the dry mass of the sample that followed; T_1 and T_2, were the corresponding weeks of sampling W_1 and W_2, respectively. The 'ln' in the formula represented natural logarithm.

Crop growth rate (CGR)

CGR was determined using the total dry mass of sampled plants at the respective times of sampling, and applying the formula of Hunt (1978):

$$CGR = \frac{W_2 - W_1}{T_2 - T_1} \times \frac{1}{P},$$

where W_1 and W_2 were the respective dry masses of the samples at T_1 and T_2, respectively, 'P' in represents the ground area covered by the plants sampled.

Net assimilation rate (NAR)

Using total dry mass of sampled plants at the respective times of sampling, NAR (Hunt, 1978) was mathematically expressed as:

$$NAR = \frac{W_2 - W_1}{LA_2 - LA_1} \times \frac{\ln LA_2 - \ln LA_1}{T_2 - T_1},$$

where W_1 and W_2 are the dry mass of the samples at the corresponding times T_1 and T_2, respectively; the LA_1 and LA_2 represent the corresponding leaf areas at T_1 and T_2. The 'ln' represents natural logarithm.

Absolute growth rate (AGR)

AGR was calculated as

$$\frac{W_2 - W_1}{T_2 - T_1},$$

Hunt (1978);

where W_1 and W_2 were the dry mass of the samples, corresponding to the respective times of sampling, T_1 (4 WAP) and T_2 (7 WAP or 10 WAP)

$$AGR = \frac{W_2 - W_1}{T_2 - T_1} = \frac{W_2 - W_1}{7\ WAP - 4\ WAP.}$$

Seed yield was determined as yield/plot at 10% moisture content and converted to yield/ha.
All data were statistically analysed using MSTAT-C statistical package, version 1.3 (Nissen, 1983). The least significant difference (LSD) test was used for mean separation at $P < 0.05$, unless otherwise stated.

RESULTS AND DISCUSSION

The soil analysis results indicated the following chemical properties of the soil: pH, 5.5; N, 0.2 mg/kg; P, 12.7 mg/kg; K, 0.8 mg/kg; exchangeable acidity, 0.6 cmol/kg and organic matter, 2.3%. Soil nutrient levels were considered adequate for the growth of field beans. Anon. (1991) had recommended that Swaziland soils might require liming if the soil pH fell below 5.5. Yield losses could be experienced in grain legumes if there is a nutrient deficiency (Nelson and Barber (1964); no nutrient deficiencies were observed in this investigation.

Leaf area/plant was larger in the higher plant densities than in the lower densities (Table 1) but there were no significant differences between the plant populations. Leaf area and LAI are among the growth parameters that could be influenced by a variation in plant population. That field beans in the highest population had higher leaf area/plant and higher LAI was in agreement with the reports of Enyi (1973) who observed that soya bean developed increased leaf area as plant population increased. A larger leaf area could enhance increased photosynthesis that would contribute to improved crop yields.
LAI increased with time, higher plant populations having a significantly ($P < 0.05$) higher LAI than lower plant populations (Table 1).

Table 1. Effects of field bean population on leaf area/plant and leaf area index

Field bean population/ha	Leaf area/plant		Leaf area index	
	4 WAP[1]	7 WAP[1]	4 WAP[1]	7 WAP[1]
400,000	551.2	1143.0	2.2	4.6
200,000	443.4	1322.9	0.9	3.2
133,333	530.7	1287.9	0.7	1.7
100,000	512.5	895.6	0.5	0.9
66,667	501.3	977.1	0.3	0.7
Mean	507.8	1125.3	0.9	2.2
LSD[2] (0.01)	144.3	362.8	0.2	0.9
Significance	ns	ns	**	**

[1] Weeks after planting; ** Significant $P < 0.01$
ns, not significant

The observation that LAI was greater in the higher populations was consistent with studies on soya bean (Weber *et al.* 1966 and Enyi 1973), on corn (Williams *et al.* 1964) and on field bean (Pilbeam *et al.* 1991). Wilson and Teare (1972) stressed LAI to be the single best parameter that could be used to predict a reduction of light energy and dry matter (DM) yield of vegetation canopies. Thus, mutual shading of leaves was considered undesirable because it reduced yield by reducing light available for photosynthesis (Wilson and Teare, 1972).

There was no significant difference in RGR between plant populations in this investigation (Table 2). Generally, RGR decreased with an increase in plant population, and as the plants matured the RGR increased, except in the highest population.
The absence of significant differences found in the RGR among the different plant populations, our result is in agreement with the findings of Enyi (1973) who noted soya bean growth rate to increase with increasing plant population and with increasing leaf area. The increase in growth rate could be attributed to attempts by the plants to compete for available growth factors. Dennett and Ishag (1998) suggested that suitable parameters for predicting crop growth include the maximum RGR, and the maximum CGR for a crop intercepting all the incident radiation. In their experiments on faba bean (*Vicia faba* L.), peas (*Pisum sativum* L.), lentils (*Lens culinaris* Medic.) at three densities, Dennett and Ishag (1998) ascribed the differences in growth patterns to differences in the maximum RGR that was associated with differences in temperature.

There were no significant differences in CGR between the plant populations, but the higher populations had a higher CGR (Table 2). Higher field bean population resulting in increased CGR could have been a consequence of plant competition for scarce environmental resources. With lower CGR in lower populations, probably, there was less inter-species competition in the wider spacing. The CGR data of this study were in agreement with the observations of Enyi (1973) who reported that mean CGR increased with an increase in plant density.

Table 2. Effects of field bean population on relative growth rate, crop growth rate, net assimilation rate, and absolute growth rate.

Field bean population/ha	Relative growth rate (g/g/week)		Crop growth rate (g/m^2/week)		Net assimilation rate (g/m^2/week)	Absolute grow rate (g/week)	
	4-7 WAP[1]	7-10 WAP[1]	4-7 WAP[1]	7-10 WAP[1]	4-7 WAP[1]	4-7 WAP[1]	7-10 WAP
400,000	0.08	0.10	49.93	96.94	0.002	1.25	2.43
200,000	0.14	0.18	45.03	91.21	0.002	2.26	4.56
133,333	0.15	0.18	30.25	73.10	0.002	2.72	5.49
100,000	0.14	0.23	26.86	77.00	0.003	3.24	7.70
66,667	0.17	0.19	24.70	46.74	0.010	3.70	7.01
Mean	0.14	0.18	36.56	77.00	0.003	2.63	5.44
LSD[2] $_{(0.01)}$	0.13	0.11	45.42	79.96	0.01	2.14	2.74
Significance	ns	ns	ns	ns	ns	ns	**

[1]Weeks after planting; [2]Least significant difference;
ns, not significant ;** Significant at P <0.01

NAR did not show any significant difference between plant populations (Table 2), but there were higher NAR values at lower plant populations. Our observation that NAR increased with increasing LAI at higher plant populations, and decreased with reduced LAI values in lower plant populations was consistent with other findings (Enyi 1973). NAR was expected to be affected by LAI of the crop such that when LAI increased, NAR would also increase (Hunt, 1982).

AGR (Table 2) values showed significant difference p> 0.01 between the highest plant population (AGR, 2.4 g/wk between 7 and 10 WAP) and the lowest population (AGR, 7.0 g/wk) during the same period. The observations that higher plant populations had significantly lower AGR, and lower populations had significantly ($P < 0.01$) higher AGR, implied that field bean plants in the smaller density grew at a faster rate than the plants in the higher density. Thus, plants in the wider spacing were capable of increasing their mass/week faster than those that were grown at a closer spacing. This could be related adaptive plasticity of field bean - the frequency of branching, internode increases, and direction of growth in response to light or nutrient levels (Alpert and Simms, 2002; Grime, 1994; de Kroon and Hutchings, 1995; Dong, 1995; Linhart and Grant, 1996). Hunt (1990) described AGR to be the simplest index of plant growth; a rate of change in size, an increment in size per unit time.

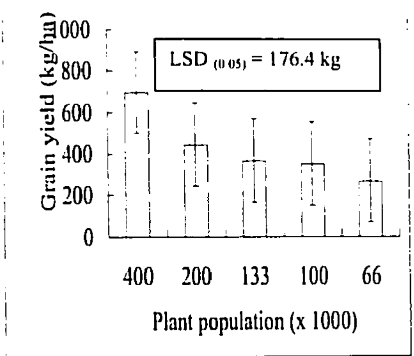
There were significant differences ($P < 0.05$) in seed yield between the population densities (Figure 1). Where field bean density was high (e.g. 400,00 plants/ha), total seed yield was consistently higher than where plant population was lower (e.g. 66,667 plants/ha). The population of 66,667 plants/ha had a significantly ($P < 0.05$) lower seed yield (270.4 kg/ha) than the 400,000 plants/ha plant population (695.8 kg/ha). There was no significant difference in seed yield between the lowest plant population and all the other plant populations.

Though seed yields were quite low compared to yields found in the literature (Crothers and Westermann, 1976; Clark and Carpenter, 2005), plant population contributed to the total seed yield of the crop. The increased seed yields due to high plant population was similarly reported for *Phaseolus vulgaris* (Crothers and Westermann, 1976; Shirtliffe and Johnston 2002; Ayaz *et al.* 2001; Herbert and Hill, 1978) It was reasoned (Herbert and Hill, 1978) that as plant density increased, the intensity of interplant competition also increased, yield/plant would decline, although total yield/unit area might increase and many components of seed yield were inversely related to population density (Ayaz *et al.*, 1999; Attiya, 1985; Mckenzie *et al.*, 1985). It has been pointed out that dry beans had the potential of higher yields with narrower spacing (higher plant populations); this was regarded as an indication of responsiveness to higher planting densities in cowpea (Anon., 2005. Ismail and Hall, 2000). Narrow row spacing and high-density planting were shown to increase the seed yield of snap beans (*Phaseolus vulgaris* L.) as reported by Mack and Hatch (1968).

CONCLUSIONS AND RECOMMENDATIONS

Higher planting densities resulted in higher CGR, higher leaf area, higher LAI and increased seed yields of field bean. In order to maximise seed yields, the spacing of 50.0 cm x 5.0 cm (400,000 plants/ha) should be used when growing *PAN 159* in Swaziland. Further research is required to identify the specific plant population at which seed yields might decline in field beans.

Figure 1. Influence of plant population on grain yield of field bean.



ACKNOWLEDGEMENTS

The authors gratefully acknowledge the financial assistance of the Crop Production Department, University of Swaziland.

REFERENCES

Alpert, P., and Simms, E. L. (2002). The relative advantages of plasticity and fixity in different environments: when is it good for a plant to adjust? *Evolutionary Ecology* 16:285-297.

Anonymous. (1991). Field Crops Production. p. 12-13. *In*: Pitts, C. W. (Ed.) Farmers' Handbook. Ministry of Agriculture and Cooperatives, Mbabane.

Anonymous. (2005). Optimum seeding rate and row spacing for dry bean under irrigation. Canada-Saskatchewan Irrigation Diversification Center. http://www.agr.gc.ca/pfra/csidc/beansr_e.htm. 02/05/05.

Attiya, H. J. (1985). The effects of plant population, growth regulators and irrigation on development and yield of spring sown field beans (*Vicia faba* L.). Ph.D. Thesis, Lincoln University, Canterbury, New Zealand.

Ayaz, S., McKenzie, B. A., Hill, G. D. (1999). Effect of plant population of four legume species on dry matter accumulation, yield and yield attributes. *Proceedings of Agronomy Society of New Zealand* 29: 9-15.

Ayaz, S., McNeil, D. L., McKenzie, B. A. and Hill, G. D. (2001). Population and sowing depth effects on yield components of grain legumes. http://www.regional.org.au/au/a sa/2001/5/c/mcneil.htm. 02/05/05.

Buruchara, R. (Undated). Background information on common beans (*Phaseolus vulgaris* L). http://www.africancrops.net/crops1/beans/. 15/07/05.

Centro Internacional de Agricultura Tropical, CIAT. (2001). Common bean: The nearly perfect food. http://www.ciat.cgiar.org/ciatinfocus/beans.htm. 15/07/05.

Clark, L. J., and Carpenter, E. W. (2005). 2002 Cooperative dry bean nursery. http://cals.arizona.edu/pubs/crops/az1322/az13223a.pdf. 30/4/05.

Crothers, S. E., and Westermann, D. T. (1976). Plant Population Effects on Seed Yield of *Phaseolus vulgaris* L. *Agronomy Journal* 686: 958-960.

de Kroon, H. and Hutchings, M. J. (1995). Morphological plasticity in clonal plants: the foraging concept reconsidered. *Journal of Ecology* 83: 143–152.

Dennett, M. D., and Ishag, K. H. M. (1998). Use of the expolinear growth model to analyse the growth of Faba bean, peas and lentils at three densities: Predictive use of the model. *Annals of Botany* 82: 507-512.

Dong, M. (1995). Morphological responses to local light conditions in clonal herbs from contrasting habitats, and their modification due to physiological integration. *Oecologia* 101: 282–288.

Edje, O. T. (1995). Response of maize and beans on association to placement method of kraal manure. *UNISWA Journal of Agriculture* 4: 18-27.

Edje, O. T., and Osiru, D. S. O. (1988). Methods for determining leaf area in some crop plants. Cassava-based cropping systems Research I. Contributions from the First Annual Meeting of the collaborative grouping cassava-based cropping systems Research. International Institute of Agriculture, Ibadan, Nigeria.

Enyi, B. A. C. (1973). Effect of plant population on growth and yield of soya bean (*Glycine max*). *Journal of Agricultural Science, Cambridge* 81: 131-138.

Grime, J. P. (1994) The role of plasticity in exploiting environmental heterogeneity. *In*: M. M. Caldwell and R. W. Pearcy (Eds.) *Exploitation of Environmental Heterogeneity in Plants: Eco- physiological Processes Above- and Below-ground.* Academic Press, San Diego.

Herbert, S. J., and Hill, G. D. (1978). Plant density and irrigation studies on lupin. I. Growth analysis of *Lupinus angustifolius* cv. 'WAU11B'. *New Zealand Journal of Agricultural Research* 21: 467-474.

Hunt, R. (1978). Plant growth analysis. Edward Arnold, London.

Hunt, R. (1982). Plant growth curves. Edward Arnold, London.

Hunt, R. (1990). Basic growth analysis. Unwin Hyman, London.

Ismail, A. M., and Hall, A. E. (2000). Semidwarf and standard-height cowpea responses to row spacing in different environments. *Crop Science* 40: 1618-1623.

Karel, A. (1991). Effects of plant populations and intercropping on the population patterns of bean flies on common beans. *Environmental entomology* 20: 354-357.

Kelly, J. D. (2000). International agriculture and rural development: An investment with mutual benefits for the United States and developing countries. Bean/Cowpea CRSP Midcourse 2000 Workshop, East Lansing, Michigan, April 2000.

Lindemann, W. C., C. R. Glover, C. R. (2003). Nitrogen fixation by legumes. Cooperative Extension Service, Guide A-129. http://www.cahe.nmsu.edu/pubs/_a/a-129.pdf. 13/07/05.

Linhart, Y. B. and Grant, M. C. (1996). Evolutionary significance of local genetic differentiation in plants. *Annual Review of Ecology and Systematics* 27: 237–277.

Mack, H. J. and Hatch, D. L. (1968). Effect of plant arrangement and population density on yield of bush snap beans. *Proceedings in American Society of Horticultural Science* 92: 418 – 425.

McKenzie, B. A., Sherrell, C., Gallagher, J. N., and Hill, G. D. (1985). Response of lentils to irrigation and sowing date. *Proceedings of Agronomy Society of New Zealand* 15: 47-50.

Murdoch, G. (1968). Soils and land capability of Swaziland. Swaziland Ministry of Agriculture, Mbabane.

Ndawula-Senyimoba, N. B. (1972). Estimation of leaf area of trifoliate legumes using a non-destructive linear measurement. *East African Agricultural Forum* 37: 192-196.

Nelson, W. L., and Barber, S. A. (1964). Nutrient deficiencies in legumes for grain and forage. pp. 143-170. *In*: Hunger signs in crops. Sprague, H. B. (Ed.). David McKay Co. Inc.

Nissen, O. (1983). MSTAT-C: A microcomputer program for the design, management, and analysis of agronomic research experiments. Michigan State University, East Lansing.

Norman, J. C. (1992). Tropical vegetable crops. Arthur H. Stockwell Ltd., Elms Court.

Pilbeam, C. J., Hebblethwaite, P. D., Nyongesa, T. E., and Ricketts, H. E. (1991). Effect of plant indeterminate forms of winter faba beans (*Vicia faba* L.) growth and development. *Journal of Agricultural Science, Cambridge* 116: 385-393.

Shirtliffe, S. J., and Johnston, A. M. (2002). Yield-density relationships and optimum plant populations in two cultivars of solid-seeded, dry bean (*Phaseolus vulgaris* L.) grown in Saskatchewan. *Canadian Journal of Plant Science* 82; 521-529

Tsubo, M., Mukhala, E., Ogindo, H. O., and Walker, S. (2003). Productivity of maize-bean intercropping in a semi-arid region of South Africa. *Water SA* 29: (4) 381-388.

Walker, S., Ogindo, H. O., and Tsubo, M. (2004). Quantifying risk for maize-bean intercrop production in the semi-arid region of southern Africa. Proceedings of the 4th International Crop Science Congress Brisbane, Australia, 26 September - 1 October 2004. http://www.cropscience.org.au/icsc2004/poster/2/6/842_ogindoho.htm. 4/8/05.

Weber, C. R., Shibles, R. M., and Byth, D. E. (1966). Effects of plant population and two spacing on soybean development and production. *Agronomy Journal* 58: 99-102.

Williams, W. A., Loomis, R. S., and Lepley, C. R. (1964). Vegetative growth of corn as affected by population density. 1. Productivity in relation to interception of solar radiation. Journal of Crop Science 5: 211-215.

Wilson, V. E., and Teare, I. D. (1972). Effect of between and within-row spacing on components of lentil yield.
Journal of Crop Science 12: 507-510