RESEARCH ARTICLE
Legume Research- An International Journal, Volume 45 Issue 4: 469-474 (April 2022)

Effects of Plant Population Density on the Growth, Survival Rate and Yield of Common Beans (*Phaseolus* spp.) Cultivated under Tropical Climate

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10.18805/LRF-672

ABSTRACT

Background: Common beans form a key dietary protein in many developing countries, including the Pacific Island countries. It is an important source of protein for vegetarians or those who cannot afford meat. However, being such an important crop, its yield is affected for several reasons, leading to a major upset for people dependent on it. One of the major issues in tropical climatic regions such as Fiji is the lack of information on the correct spacing to achieve the accepted plant population to increase the yield per given area. Therefore, the current research was carried out to investigate the suitable plant-to-plant spacing in butter and french beans for correct plant population density for maximum yield.

Methods: Butter and french beans were selected as a research crop for this experiment with two trials and three replications. Data on plant height, stem girth, leaf chlorophyll content, plant survival rate, number of pods, pod length and pod weight were taken after thirty days of sowing and continued at an interval of ten days until sixty days after sowing.

Result: The experiment results indicate that neither the lower plant-plant spacing nor, the higher plant-to-plant spacing significantly affected the growth and yield of both butter and french bean. However, the plant survival rate under higher plant-to-plant spacing (50×25 cm) was higher; therefore, the higher plant-to-plant spacing is recommended for growing butter and french beans under the tropical climate as it allows the farmers to save around 38% of the seeds while getting similar plant growth and yield.

Key words: Butter beans, Common beans, Dietary protein, French beans, Plant-to-plant spacing.

INTRODUCTION

Vegetables are the cheapest and nutrient-rich food sources within the economic reach of the poor. It plays a vital role in the human diet since they provide carbohydrates, protein, fat, minerals, vitamins, fibers and phytochemicals (non-nutrient bioactive compounds), which are essential for making the body's immune system potent, detoxifying carcinogens, reducing muscular degeneration and protecting the body from infectious ailments (Rana and Yadav, 2018). The development of high-value crops for domestic consumption and export is seen as a priority for economic development and improved livelihoods in many Pacific Island countries (Fink *et al.*, 2013). With the sugar industry declining, the Fiji Government is exploring a dual-track policy of encouraging exports of other agricultural products while facilitating greater import substitution (Martyn, 2011). The government has identified cabbages, lettuce, tomatoes, capsicums, carrots, onions, potatoes and peas as target crops for greater production. Hotels, supermarkets and restaurants are seen as key domestic markets (Fink *et al.*, 2013). Reducing the number of vegetable imports is a policy priority of the Fijian government. However, replacing these imports with local supply faces many challenges (Martyn, 2011).

One of the major challenges the farmers face in Fiji is the lack of information on the cultural practices for most of the crops. Of these, identifying the correct spacing for cultivating crops to obtain higher yields is a major challenge. The major aim of cultural practices and plant densities are to improve the interception of light (row spacing, plant population) affecting the architecture of the canopy by modifying shoot components such as leaf orientation and insertion at the stalk, leaf size and senescence of older lower leaves (Loomis *et al.*, 1968; Tetio-Kagho and Gardner, 1988). Many researchers concluded that high plant density might lead to competitive shading within the leaf canopy architecture (Yokozawa and Hara, 1995; Hiyane *et al.*, 2010), thereby limiting interception of radiation by the middle and lower stem leaves, particularly during the silking time (Tollenaar and Wu, 1999; Maddonni, Otegui and Cirilo, 2001; Boomsma *et al.*, 2009), accelerating leaf senescence (Tetio-Kagho and Gardner, 1998; Antonietta *et al.*, 2014), reducing photosynthesis and net assimilation of individual plants.

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How to cite this article: Sundar, L.S. and Lal, A.A. (2022). Effects of Plant Population Density on the Growth, Survival Rate and Yield of Common Beans (*Phaseolus* spp.) Cultivated under Tropical Climate. Legume Research. 45(4): 469-474. DOI: 10.18805/LRF-672.

Submitted: 06-12-2021 **Accepted:** 22-01-2022 **Online:** 08-03-2022

Therefore, for a stable yield, the plants per unit area need to be distributed uniformly (Diepenbrock, 2000).

The objective of the current study was to investigate the effect of plant population density on the growth and yield of two different species of common beans. The results of this study will be used to increase the production of common beans under tropical growing conditions, thereby creating employment and improving the livelihood of resource-poor farmers.

MATERIALS AND METHODS

Study site

The study was carried out from March to July 2021 at the Instructional Agricultural Crop Farm (IACF) of the Fiji National University (FNU), College of Agriculture, Fisheries and Forestry (CAFF), Koronivia, Campus. The farm is located at an altitude of 6 m above sea level with coordinates of 18° 02′ 44″ S and 178° 31′ 55″ E. It is situated about 2.9 km from Nausori Town and has an average temperature of 28° C to 30°C (Nausori Town Council, 2020).

Experimental design and setup

A 2-factor experiment was set up in a randomized complete block design (RCBD) with three replications. Eighteen plots were prepared, with each plot having an area of 2 m^2 (1 m in width and 2 m in length). The vegetable seedlings and fertilizers were purchased from HOP TIY and Co. Pte Ltd. The golden wax variety of butter bean (*Phaseolus lunatus*) and a contender variety of french bean (*Phaseolus vulgaris*) was used in this experiment. Two rows of crops (50 cm apart) (Ministry of Agriculture, 2021) were cultivated in each plot, each having different spacing required for this experiment. The control was 50×15 cm (Ministry of Agriculture, 2021) (crop 15) spaced sowing, while the treatment was 50×20 cm (crop 20) and 50×25 cm (crop 25) spaced sown butter bean and french bean.

Soil sample collection and analysis

Five soil samples were taken from 0-200 mm depth using a soil auger. The sampling was done per plot and then mixed to make a composite soil sample before analyses. The results indicated that the average soil has low organic matter content, excessive plant-available phosphorus and excessive level of calcium and magnesium, as shown in Table 1. The nutrients required to correct the deficiencies were 161 kg/ha of phosphorous, 95.3 kg/ha of potassium, 5500 kg/ha of calcium, 940 kg/ha of magnesium, 110 kg/ha of nitrogen.

Since single superphosphate (SSP) contains 12% sulfur (S), 19% P and 21% Ca; therefore, 409 kg/ha of total superphosphate (TSP) or 970 kg of SSP were recommended as basal application. Sulfate of potash (SOP) contains 50% K and 18% S; therefore, 210 kg/ha of SOP or 161 kg/ha of muriatic of potash (MoP) were recommended. Urea which contains 46% of N, was recommended at 240 kg/ha as a split application. Lime at 1 t/ha and organic matter at 8-10 kg/ha were recommended for application, as shown in Table 2.

Harvesting and measurements

Harvesting of crops was done 30 days after sowing (DAS), DAS 40, DAS 50 and DAS 60. The plant height and pod length were recorded using a flexible measuring tape, while the vernier caliper measured the stem girth. The pods were weighed using the top-loading balance (Shimadzu UX62 00H, Shimadzu Corporation, Kyoto, Japan) with an accuracy of 0.001 g. The Soil Plant Analysis Development (SPAD) 502 chlorophyll meter (Konica Minolta, Inc., Japan) was used to measure the chlorophyll content of the three newly matured leaves of each sample. The pod number and number of survived plants were also counted.

Statistical analysis

The collected results were subjected to a two-way analysis of variance (ANOVA) using International Business Machines

Table 1: Analyzed results of soil samples as obtained from the Fiji Agricultural Chemistry Laboratory, Koronivia Research Station.

pH (water)	EC (mS/cm)	Total C (%)	Total N (%)	Olsen available P (mg/kg)	Exchangeable K	Ca (me/100g)	Mg
5.8	0.07	1.30	0.09	114	0.48	23.8	6.74

Note: Results are reported oven-dried basis.

To convert me/100 g to mg/kg, multiply results by the following factor: Ca by 200, Mg by 122, K by 391 and Na by 230.

pH- Potential of hydrogen; EC- Electrical conductivity; C- Carbon; N-Nitrogen; P- Phosphorus; K- Potassium; Ca- Calcium; Mg- Magnesium.

Table 2: Fertilizer recommendation with a 10% allowance for leaching and soil maintenance.

Fertilizer required	Recommendation application rate
Phosphate	TSP at 409 kg/ha or SSP at 970 kg/ha as basal application
Potash	SOP at 210 kg/ha or Mop 161 kg/ha
Lime (pH)	$CaCO_3$ at 1 t/ha at 4-6 weeks prior to planting
Urea	240 kg/ha as a split application
Organic matter	8-10 t/ha of poultry manure or other organic materials (mulch) supplemented with chemical fertilizers to improve soil conditions and soil biology

SPSS statistics for Windows, version 27 (International Business Machines Corporation, Armonk, NY, USA). The effects of the growing condition and the plant-to-plant spacing effects were analyzed. Means separation was performed within each crop using Duncan's multiple range test at p=0.05. All the results were expressed as means ± standard error. The graphs and charts were produced using Origin 2018 software (Origin Lab Corporation., Northampton, MA, USA) and Microsoft Excel® 2019 (Microsoft Corporation, Washington, DC, USA).

RESULTS AND DISCUSSION

Growing environment condition

The ideal growing environment conditions are needed for proper plant growth and development (OSU Extension Service, 2019). The optimum atmospheric temperature for the successful cultivation of common beans is between 20.0°C to 25.0°C (Rana and Yadav, 2018). Temperatures below 10.0°C led to poor seed germination, slow growth and delayed maturity, whereas temperatures above 30.0°C led to flower drop, ovule abortion and poor yield (Rana and Yadav, 2018; Salcedo, 2008). The experiment results indicated that no significant differences in the environment temperature recorded during both trials except at the initial and final days of the experiment. On the third day of sowing, the highest temperature (29.0°C) was recorded in trial 1, while the lowest (22.0°C) was recorded in trial 2 at DAS 59, as shown in Fig 1a. Within trial results indicated that the maximum temperature (29.0°C) was recorded in trial 1 at DAS 3, while the lowest (24.3°C) was recorded at DAS 24. In trial 2, the highest temperature (28.0°C) was recorded at DAS 5 and DAS 6, while the lowest (22.0°C) was recorded at DAS 59.

The relative humidity results also indicated no significant difference among both trials. The highest relative humidity (99.0%) was recorded in trial 1 at DAS 60 and in trial 2 at DAS 38, while the lowest relative humidity (63.0%) was recorded in trial 1 at DAS 2, as shown in Fig 1b. Within trial results indicated that the maximum relative humidity (99.0%) in trial 1 was recorded at DAS 60, while the lowest (63.0%) was recorded at DAS 2. In trial 2, the highest relative humidity (99.0%) was recorded at DAS 38, while the lowest (65.0%) was recorded at DAS 45.

Plant survival rate

The data on plant survival rate was collected and recorded throughout the experiment. The results of trial 1 indicated that the butter bean 25 and french bean 25 had the highest plant survival rate of 94% and 76%, respectively. In trial 2, similar results were obtained where butter bean 25 and french bean 25 both had the highest survival rate of 100%, as shown in Table 3. The lowest survival rate in trial 1 was observed in butter bean 15 and french bean 15, having 85% and 65%, respectively. Similar results were observed in trial 2, where the butter bean 15 and french bean 15 had the lowest survival rate of 65%, as shown in Table 3.

The result showed that the higher plant to plant spacing increases the survival rate of plants, whereas lower plant to plant spacing increases plant mortality to bring plant population in an acceptable range to avoid competition for resources. Competition occurs due to the presence of neighboring plants which reduces the availability of resources for plants, thus reducing the overall plant growth and yield (Paul and James, 2019). Competition is the key factor in maintaining the plant communities (Pant and Sah, 2020) since, during competition, the plants with lower adaptability skills are suppressed by the higher adaptive plants. Similar results were observed in this experiment for both trials, as shown in Table 3.

Plant growth

Nitrogen found in molecules such as proteins, chlorophyll, nucleic acid and amino acid is an important mineral element

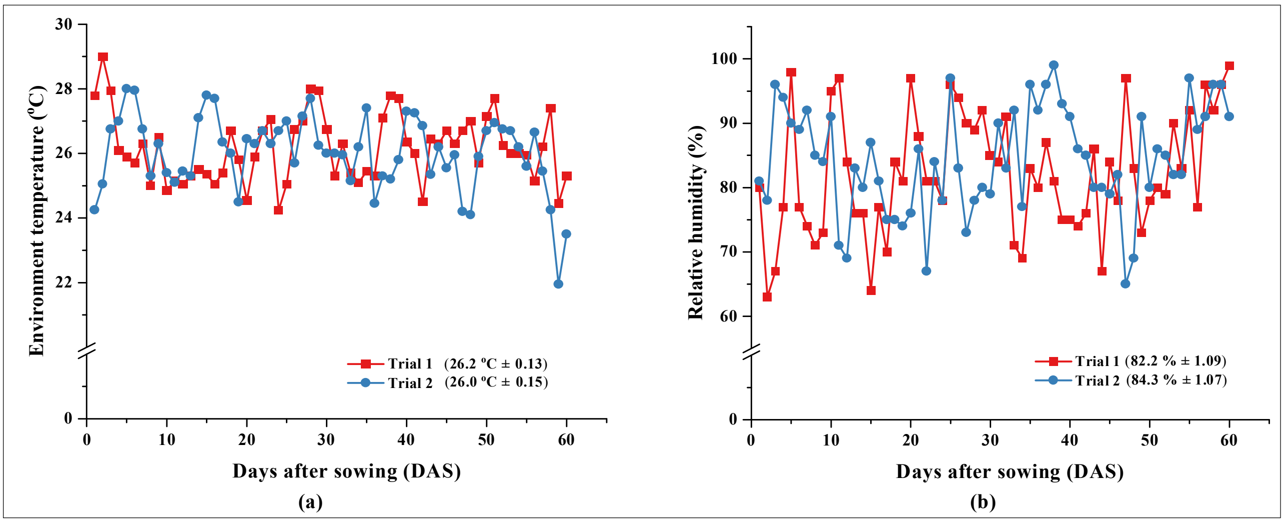

Fig 1: Growing environment temperature (°C) and relative humidity (%) measured from sowing till final harvest: (a) The average environment temperature recorded in each trial; (b) The average relative humidity recorded in each trial. Values in parentheses are mean ± standard error (n = 60).

in plants (Islam *et al*., 2016). As such, the simplest way to determine nitrogen content in plants is to determine the leaf chlorophyll content (Bausch and Diker, 2001; Fontes and de Araujo, 2006; Peng *et al*., 1996; Piekielek *et al*., 1995). The photosynthetic capacity and plant growth are also determined using chlorophyll, the essential photosynthetic pigment (Li *et al*., 2018). The easiest and non-destructive way to determine the leaf chlorophyll content and nitrogen in crops is through the handheld soil plant analysis development (SPAD) chlorophyll meter (Fiorentini *et al*., 2019; Xiong *et al*., 2015). In addition, for this experiment, the growth of the plants was further determined by measuring

Table 3: Seed rate, initial and final plant population and survival rate of butter bean and french bean measured during the experiment.

	Seed rate (seed/m^2)	Initial plant population (plants/ha)	Final plant population (plants/ha)	Survival rate (%)
		Trial 1		
Butter bean 15	26	130 000	110 000	85
Butter bean 20	20	100 000	85 000	85
Butter bean 25	16	80 000	75 000	94
French bean 15	26	130 000	85 000	65
French bean 20	20	100 000	75 000	75
French bean 25	16	80 000	65 000	76
		Trial 2		
Butter bean 15	26	130 000	85 000	65
Butter bean 20	20	100 000	85 000	85
Butter bean 25	16	80 000	80 000	100
French bean 15	26	130 000	85 000	65
French bean 20	20	100 000	75 000	75
French bean 25	16	80 000	80 000	100

Table 4: Leaf chlorophyll content, stem girth and plant height of butter and french bean grown during the experiment.

	Chlorophyll content (SPAD value)	Stem girth (mm)	Plant height (cm)
		Trial 1	
Butter bean 15	37.8±0.36[a]	6.66±0.34[a]	41.9±1.65[a]
Butter bean 20	35.8±1.04[a]	6.50±0.50[a]	45.5±1.04[a]
Butter bean 25	36.8±0.63[a]	6.74±0.41[a]	41.2±2.07[a]
		Trial 2	
Butter bean 15	37.0±0.28[a]	6.66±0.23[a]	41.1±0.42[a]
Butter bean 20	37.2±0.37[a]	6.20±0.50[a]	40.8±1.24[a]
Butter bean 25	37.7±0.26[a]	6.55±0.31[a]	37.6±2.88[a]
		Significance	
Growing time (GT)	ns	ns	*
Crop type (CT)	ns	ns	ns
GT×CT	ns	ns	ns
		Trial 1	
French bean 15	37.9±0.71[a]	5.87±0.42[a]	42.5±1.63[a]
French bean 20	37.5±0.68[a]	6.13±0.31[a]	38.8±4.96[a]
French bean 25	38.3±0.44[a]	6.62±0.16[a]	41.9±1.57[a]
		Trial 2	
French bean 15	37.7±0.10[a]	5.86±0.53[a]	43.7±3.34[a]
French bean 20	38.1±0.21[a]	6.38±0.31[a]	40.2±3.60[a]
French bean 25	38.0±0.24[a]	6.71±0.15[a]	41.5±2.19[a]
		Significance	
Growing time (GT)	ns	ns	ns
Crop type (CT)	*	ns	ns
GT×CT	ns	ns	ns

Values are mean±SE (n=4).

Means in the same column, followed by the same letter(s), are not significantly different ($p \leq 0.05$).

*** = $p<0.001$; ** = $p<0.01$; * = $p<0.05$; ns = Not significant at ($p \leq 0.05$).

Table 5: Pod number, pod length and pod weight of butter and french bean cultivated during the experiment.

	Pod number	Pod length (cm)	Pod weight (g)
	Trial 1		
Butter bean 15	53.0±7.63[a]	10.6±0.10[a]	5.79±0.44[a]
Butter bean 20	56.0±8.46[a]	10.6±0.18[a]	5.67±0.41[a]
Butter bean 25	56.1±8.76[a]	10.6±0.17[a]	6.16±0.44[a]
	Trial 2		
Butter bean 15	57.8±8.65[a]	10.7±0.21[a]	5.77±0.28[a]
Butter bean 20	59.9±8.50[a]	10.5±0.26[a]	5.68±0.36[a]
Butter bean 25	53.9±10.4[a]	10.4±0.18[a]	6.03±0.31[a]
	Significance		
Growing time (GT)	ns	ns	ns
Crop type (CT)	ns	ns	ns
GT×CT	ns	ns	ns
	Trial 1		
French bean 15	61.6±8.34[a]	11.1±0.12[a]	5.85±0.24[a]
French bean 20	62.8±9.27[a]	10.5±0.11[b]	5.99±0.26[a]
French bean 25	59.2±9.76[a]	10.7±0.20[b]	5.66±0.24[a]
	Trial 2		
French bean 15	71.0±9.07[a]	10.6±0.19[a]	5.93±0.18[a]
French bean 20	64.2±9.00[a]	10.4±0.17[a]	6.12±0.27[a]
French bean 25	60.8±10.5[a]	10.8±0.19[a]	6.45±0.25[a]
	Significance		
Growing time (GT)	ns	ns	ns
Crop type (CT)	ns	ns	ns
GT×CT	ns	ns	ns

Values are mean±SE (n=4).

Means in the same column, followed by the same letter(s), are not significantly different ($p \leq 0.05$).

*** = $p<0.001$; ** = $p<0.01$; * = $p<0.05$; ns = Not significant at ($p \leq 0.05$).

the height and stem girth (Attia and Sary, 2021; Dharmawan *et al*., 2021; Eboibo *et al*., 2018; Raihan *et al*., 2021; Sharma *et al*., 2021).

The experiment result shows no significant differences in the leaf chlorophyll content of both butter and french beans cultivated under the different plant-to-plant spacing in both trials, as shown in Table 4. The same result was obtained for stem girth and plant height of butter and french beans cultivated in both trials. The two-way ANOVA results indicate that neither the growing condition nor the plant-to-plant spacing significantly affected the leaf chlorophyll content, stem girth and plant height of butter and french bean, as shown in Table 4.

Yield and yield attributes

The yield of both butter and french beans was determined by the pod number, pod length and pod weight (Attia and Sary, 2021; Raihan, 2021). The experiment result showed no significant differences in the pod number for butter and french beans cultivated under the different plant-to-plant spacing in both trials, as shown in Table 5. The same result was obtained for pod length and pod weight of butter and french beans cultivated in both trials. The two-way ANOVA results indicated that neither the growing condition nor the plant-to-plant spacing significantly affected the pod number, pod length and pod weight of butter and french bean, as shown in Table 5.

CONCLUSION

The overall result of the experiment indicated that an increase in the plant-to-plant spacing does not significantly affect the growth and yield in both butter and french bean. However, the survival rate of plants with the plant-to-plant spacing of 50×15 cm and 50×20 cm was low compared to the survival rate of both crops with a plant-to-plant spacing of 50×25 cm. The results indicated that the growth and yield of both butter bean and french bean were not significantly different due to the loss of plants in lower spacing cultivation or under higher plant population resulting in lower competition for resources. Therefore, we can conclude from these results that higher plant-to-plant spacing (50×25 cm) is recommended for growing butter and french beans under the tropical climate as it allows the farmers to save around 38% of the seeds while getting similar plant growth and yield.

ACKNOWLEDGEMENT

The authors would like to thank Mrs. Josphine Sandya Venkataiya Kumar, Mr. Prashant Maharaj and Mr. Jagdish Prasad for their contributions in making this research successful.

Conflict of interest: None.

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