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Plant Population Effects on Ecological Characteristics of Field Bean (*Phaseolus vulgaris* L.) in Swaziland

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ABSTRACT

Field bean (*Phaseolus vulgaris* L.) is one of the major grain legumes grown in Swaziland. Though there is a recommended spacing for this pulse, small-scale farmers plant it at any convenient spacing. They do not purposely vary the spacing to evaluate any changes in yield. Knowledge of the ecological characteristics of field bean in different populations might suggest new ways of establishing and managing this pulse. This investigation was conducted in Swaziland, in the 2004/2005 cropping season, to determine the effects of different intra-row spacing on weed density, disease and insect pest incidence, soil temperature, and crop yield. Five plant populations (400,000; 200,000; 133,333; 100,000 and 66,667 plants/ha) were investigated in a randomized complete block design, replicated four times. Although increasing the field bean population did not significantly decrease weed scores, the number of weed species did decrease as the canopy closed from 3 to 6 weeks after planting (WAP). A greater number of weed species invaded the less dense plant populations. Disease incidence increased with time in all plant populations. Soil temperatures did not significantly differ among plant populations. The 400,000 plants/ha population had a significantly ($P < 0.05$) higher seed yield (695.8 kg/ha) than the recommended plant population of 200,000 plants/ha (445.5 kg/ha). Therefore, small-scale farmers are advised to plant field bean at the spacing of 50.0 cm x 5.0 cm at the rate of 400,000 plants/ha.

Keywords: Weed density, weed suppression, soil temperature, field bean, ecological characteristics.

INTRODUCTION

Field bean (*Phaseolus vulgaris* L.) is an annual crop characterized by trifoliate leaves and white or purple flowers. In Swaziland, a popular recommended variety of field bean is the speckled, seed-type known as sugar bean (Anon., 1991). It is a rich source of proteins and contains about 20% more energy on a dry mass basis than bread; it is rich in vitamins A and C (Norman, 1992). Because sugar bean is a legume, it will fix nitrogen in the soil through symbiosis. It is a short-season crop, usually maturing in 65–110 days after planting, and exhibits a rich diversity in seed characteristics, size, shape and color, growth habits and adaptative traits (van Schoonhoven & Voysest, 1993).

Field bean grows well in temperatures between 15°C and 30°C, with higher temperatures resulting in poor pod set (Norman, 1992). Soils suitable for growth of field bean are deep, well-drained, loamy soils, with a pH of 5.5 to 7.0. If the soil pH is below 5.5, liming is required, because beans are sensitive to high concentrations of aluminum and manganese (Norman, 1992). Field beans grow under an annual rainfall range of 700–1000 mm (van Schoonhoven & Voysest, 1993).

Plant population density is of great importance in the production of any crop. Attempts have been made by farmers to maximize field bean seed yield (Leakey, 1972). Quite often, small-scale farmers do not increase crop yield when they use the recommended population density, which is 200,000 plants/hectare with 10 cm between seeds (Duke, 1983). Maximizing the yield of field beans is very important; hence, it requires a review of the currently used plant population density in order to determine a population that could help to solve the problem of weed management, disease and insect pest incidence and low yield. Crop population density can influence weed density (Zimdahl, 1993). This investigation was undertaken to assess the effect of field bean population density on weed density, soil temperature, disease infestation, insect pest abundance and seed yield.

METHODS

Location and Experimental Design

This field trial was conducted at the University of Swaziland, Luyengo Campus (26°34'S, 31°12'E; 750 m above sea level; annual rainfall, 800 mm; mean annual temperature, 18°C), in the Crop Production Department Farm of the Faculty of Agriculture from December 2004 to February 2005. The soil type was the Malkerns M-set soil series that are dark, clay loam to sandy loam Oxisols (Murdoch, 1968). The experimental design was the randomized complete block design of five treatments, replicated five times. The five treatments 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. In all cases, the inter-row spacing was 50 cm; the intra-row spacing was 5.0 cm, 10.0 cm, 15.0 cm, 20.0 cm and 30.0 cm, respectively. A 100-cm space was maintained between replicates, and 50 cm separated plots within each replicate. Plot sizes were 5.5 m x 4.0 m.

Fertilizer Application and Planting

Land preparation consisted of moldboard plowing to a depth of 46 cm followed by disking with a tractor-mounted disk harrow to a depth of 20 cm. Fertilizer application was made one day before planting. A basal application was made using a compound fertilizer, N:P:K [2:3:2 (22) + Zn] at the recommended rate of 400 kg/ha (Anon., 1991). The fertilizer was applied in bands 10 cm away from the rows and was mixed with the soil. The variety of the field bean used was 'PAN 159'. Seeds were hand-planted, using two seeds/station, on 18 December 2004. To enhance germination and emergence, plots were watered to field capacity using sprinkler irrigation for the first three days after planting.

Ten days after emergence each planting station was thinned to one plant to provide the desired populations per treatment.

Data Collection

Data were collected on weed infestation, disease incidence, insect pest infestation, and soil temperature.

Weed Infestation

Weed infestation was assessed at 3 and 6 weeks after planting (WAP). Weeks 3 and 6 were chosen because they represent two important dates in the agronomic management of the field bean and the likely relationship between the crop and its weeds. Weeding is often done in this crop at about 4 weeks after planting. By assessing the parameters investigated at one week before weeding, it would be possible to compare the ecological characteristics “before” (3 wks after planting) and “after” (6 wks after planting). The first assessment at 3 WAP was followed by the first weeding at 4 WAP using hand hoes. To assess weed density, a 50-cm quadrat was used and three assessments/plot were made on each occasion. The descriptions of the range of scores (1-6) that indicated the degree of weed density were: 1, zero weeds within the quadrat; 2, sparse weed coverage of soil within the quadrat; 3, intermediate weed coverage of soil within the quadrat; 4, general weed coverage of soil within the quadrat; 5, severe weed coverage of soil within the quadrat; and 6, complete weed coverage of soil within the quadrat. This method of estimating weed density has previously been used (Daisley et al., 1988; Orluchukwu & Ossom, 1988; and Ossom et al., 2001). The weed species were also identified and classified (Botha, 2001) within the quadrat at each determination. The distribution (relative abundance) of each species within the quadrat was evaluated and expressed as a percentage of all weed species within the quadrat. Ossom et al. (2001) and Ossom (2003) have used this method to assess weed infestation in sweetpotato [*Ipomoea batatas* (L.) Lam.] and cucumber (*Cucumis sativus* L.), respectively.

Disease Incidence

Also determined at 3 and 6 WAP, disease infestation within the 50-cm quadrat was assessed and scored (1-6) as follows: 1, no disease incidence on any parts of plants within the quadrat; 2, slight incidence of disease; 3, moderate incidence; 4, slightly severe incidence; 5, severe incidence; and 6, very severe incidence of disease in all parts of plants within the quadrat. The assessment focused on disease incidence rather than on disease identification. Three determinations/plot were made at each assessment. A similar method using a descriptive key that described plants with different levels of disease and assigned a category, number, index, grade or percentage to each description had been used by Balasubramaniam et al. (1993).

Insect Pest Infestation

Using the same scale of 1-6, insect pest infestation was assessed based on sighting of insect pests or the visual assessment of damage caused by insect pests on plants within the 50-cm quadrat. The focus of the exercise was not on insect identification, but on the physical presence of insects or insect damage found. The scale of scores was as follows: 1, no insect pest or insect damage on any plant part; 2, slight incidence of insect presence or crop damage; 3, moderate incidence of insect presence or crop damage; 4, slightly severe incidence of insect presence or crop damage; 5, severe incidence of insect or crop damage; and 6, very severe incidence of insects or crop damage. As in weed and disease assessment, insect infestation was assessed at three locations/plot at 3 and 6 WAP. When scoring for weed infestation, disease incident and insect pest incident, three scores were averaged per plot and the mean was then used as the score for the respective parameters.

Soil Temperature

Soil temperature was taken every three weeks on a bright, sunny day without rain, and between 1400 and 1600 hours. The temperature was recorded using the Fisher brand bi-metal dial thermometers having a gauge diameter of 4.5 cm, a stem length of 20.3 cm, and an accuracy of ± 1.0% of dial range at any point on the dial (Ossom et al., 2001; Ossom, 2003). The temperature readings were taken at a distance of 10 cm from the plant rows, and at depths of 5 cm, 10 cm, and 15 cm. Three readings were made in each depth/plot, totaling nine readings/plot. In order to ensure that the thermometer sensor was stabilized, after inserting the thermometer into the soil, a 30-second interval was allowed to elapse before readings were taken.

Data Analysis

The statistical analysis technique applied was the analysis of variance (ANOVA) using MSTAT-C package, version 1.3 (Nissen, 1983). The least significant difference (LSD) test (Steel & Torrie, 1980) was used for mean separation at 5% probability level, unless otherwise indicated.

RESULTS AND DISCUSSION

Weed Infestation

Weed density showed no significant differences (Table 1) between field bean populations. However, all plant populations showed decreased weed density (as indicated by lower weed scores) later in the season (6 WAP) than earlier in the season (3 WAP), except for 66,667 plants/ha, which was slightly higher. This is likely because of the combined effect of weeding at 4 WAP and fewer weeds germinating later in the growing season. The highest plant population density (400,000 plants/ha) suppressed weeds (weed score, 3.3 at 6 WAP) better than the lowest plant population (66,667 plants/ha) that had weed a score of 3.5 at 6 WAP. Weed density data showed that the higher the field bean population was, weed density was also lower.

Row spacing could have a significant effect on the competition between field bean and weeds (Malik et al., 1993; Teasdale & Frank, 1983). Field bean planted in narrow rows might encourage crop competitiveness and could result in fewer and shorter weeds, resulting in improved crop yield (Malik et al., 1993; Teasdale & Frank, 1983). It has been reported that the canopy closed more rapidly as the distance between plants decreased; canopy closure shaded the soil and significantly slowed weed growth (Murdock et al., 1986; Teasdale & Frank, 1983). It is worth noting that controlling weeds prior to canopy closure is crucial in maximizing yields. Teasdale & Frank (1983) observed weeds that were allowed to emerge with field bean were only slightly suppressed. They concluded that in most cases weeds that emerged with the crop, prior to canopy closure, were likely to grow to maturity and had greater effect on yield. They further noted that when field bean were kept weed free for the first half of the growing season, weed growth was significantly reduced. Therefore, the reduction in weed scores from 3 to 6 weeks in this study can be attributed to the closing of the plant canopy and the direct result of shading the weeds. Shading leads to decreased solar radiation reaching the weeds under the crop (Keeley & Thullen, 1978; Knake, 1972), which decreases carbohydrates and energy for survival. With time, the weeds could die or at best, grow poorly and give very little competition to the crop (Ossom, 2003). Weeds that are most competitive with crops usually have a high photosynthetic rate and rapid partitioning of photosynthates into new leaf production; they have a high light saturation intensity and a low carbon dioxide compensation point (Zimdahl, 1993). The coefficient of determination (R^2) of 0.017 indicated that 1.7% of the variation in seed yield/ha of field bean could be attributed to the adverse effect of weed density at 3 WAP. Zimdahl (1993) reported crop yield reduction among the detrimental effects of weeds. It had been stressed (Woolley & Davis, 1991) that weed management often requires maintenance of weeds at appropriate infestation levels, and not complete weed eradication. Thwala (2004) also reported significant differences between weed density and cropping systems that varied crop populations. Our results agreed with the reports of Thwala (2004) and Ossom et al. (2001) regarding the decrease of weed density as the cropping season progressed.

Weed Species Distribution

Table 2 shows the influence of plant population on weed species distribution at 3 WAP. The species were distributed over nine families and 12 genera. *Richardia brasiliensis* was the most abundant weed species (17.9-36.4%) at 3 WAP; this was closely followed by *Portulaca oleracea* (9.3-22.5%) and *Oxalis latifolia* (15.1-20.7%), respectively. These weed species also had higher weed scores in all the plant populations. *Elusine africana* was the least abundant weed species in all plant populations. At 6 WAP (Table 3), a greater diversity of weeds infested the plots than at 3 WAP. The species were made up of 15 genera distributed over 10 families. The three most dominant species at 6 WAP were *Richardia brasiliensis* (29.6-37.2%), *Oxalis latifolia* (20.0-37.2%), and *Cyperus rotundus* (6.1-27.8%). The weed species that were ubiquitous in all field bean populations were *Richardia brasiliensis*, *Oxalis latifolia*, *Cyperus rotundus* L. and *Bidens pilosa*. Though no clear pattern of the number of weed species was demonstrated in each field bean population, the lowest population had the highest number of weed species (14) at 6 WAP compared with the highest population having 11 species at the same period.

Differences in weed species relative abundance could be associated with a number of ecological factors: plant population, intensity of inter- and intra-species competition for scarce resources, and ecological requirements of different species, to name a few. A low plant population initially results in more space between plants in a plot. The consequence could be that light penetration in such a plot would be greater than in a densely populated plot. With more light available between plants in the sparsely populated plots, it is likely that different weed species would readily establish as seen in the lowest bean population. The converse would be true in a densely populated plot (e.g., the 400,000 plant/ha). This might be associated with the crop's adaptive plasticity – the frequency of branching, internode increases, and direction of growth in response to light or nutrient levels (de Kroon & Hutchings, 1995; Linhart & Grant, 1996; Alpert & Simms, 2002).

The Canola Council of Canada (2005) reported that weed competition reduced canola (*Brassica rapa* L.) plant growth and leaf area resulting in increased flower, pod and seed abortion. The report further noted that the yield loss due to weeds could vary widely from year to year, depending on several factors that included density and spatial arrangement of the crop; species and density of the weeds; relative competitiveness of crop and weeds; relative time of emergence of crop and weeds, and the availability of moisture and nutrients. Amador-Ramirez (1999) reported that weed seedlings that emerged with dry bean or soon after, were a major problem because they interfered with crop growth and development more than weeds that emerge later. Much of the harm that weeds do to agricultural crops is from competition, and for many years, scientists have tried to provide a scientific explanation for plant competition (Black et al., 1969), but have not entirely succeeded.

Disease Infestation

Disease infestation did not significantly vary between the field bean populations (Table 1). However, both the recommended plant population (200,000 plants/ha) and the highest plant population (400,000 plants/ha) showed a similar degree of disease incidence (disease scores of 1.2 and 1.3, respectively). The lowest plant population (66,667 plants/ha) and 133,333 plants/ha had the same disease score of 1.3. The plant population that was 50% (100,000 plants/ha) of the recommended plant population showed the disease score of 1.4, which was not significantly higher than the recommended population.

Diseases have been reported to be the leading constraint to increased field bean production throughout the world (Kelly & Miklas, 2005). None of the levels of infestation observed in this investigation posed a serious threat to field bean production. That disease scores were not significantly different among the plant populations could be associated with the likely absence of damaging proportions of virulent pathogens in field bean plots when this investigation was conducted. This indicates that diseases did not seriously affect the crop. Probably, under the conditions of this investigation, disease incidence was not dependent on the plant population of the field bean crop. However, Anon. (2005a) reported that increased plant population significantly increased white mold (caused by *Sclerotinia sclerotiorum*) incidence in Minnesota. Disease-causing organisms have been reported (Zitter, 1987; Hoffman & Zitter, 1994) to be harbored by weeds, with the resultant decrease in crop yields. It would be expected that too many plants/ha could interfere with efficient cultural management practices in the plots. Where humid and warm weather prevails, there could be a possibility that increased plant populations could predispose a crop to higher incidence of disease infestation, especially by fungal pathogens. Such disease infestation eventually could reduce crop yield.

Insect Pest Infestation

Slightly higher insect pest incidence occurred at 6 WAP than at 3 WAP in all plant populations (Table 1). At 3 WAP, there were no significant differences in the level of insect pest incidence in all plant populations (Table 1). However, at 6 WAP, plants in the most dense plant population (400,000 plants/ha) had a significantly higher ($P < 0.05$) level of insect pest infestation (score, 4.3) than plants in the recommended plant population (200,000 plants/ha: score, 3.7). Plant populations below the recommended populations did not show any significant difference in their insect pest incidence.

The observed trend, that increasing plant population density resulted in increased insect pest incidence, was consistent with the reports of Ehrensing et al. (1997), which noted that *Scaptomyza* fly populations might buildup with increased hectares of meadowfoam (*Limnanthes alba*) cultivated. Litsinger and Moody (1976) pointed out that multiple cropping (that leads to increased plant populations/ha) could increase, or decrease the incidence of an insect or disease, or the population of its natural enemies, depending on the component species in the mixture, and the pest or disease concerned. The University of Sydney (2004) reported that "clean farming", in which there is zero tolerance for weeds and debris, destroys over wintering locations and alternative food sources such as pollen and nectar in flowering weeds, thus limiting the populations of predators and parasites. Denser crops stand (higher plant population) harboring a large number of insect pests could lead to increased damage to crop leaves, stems and yield components. Eventually, crop yield could be adversely affected if higher plant populations attracted an increased number of insect pests. However, Karel (1993) reported that flower and pod damage by insect pests decreased when plant populations increased from 66,666 to 1,333,333 plants/ha in mixed cropping that involved common beans and maize. In another study, Karel (1991) reported a reduced incidence of bean flies (*Ophiomyia phaseoli* Tryon, *O. centrosematis* de Meijere, and *Melanagromyza spencerella* Greathead) on common beans when plant population was increased from 66,666 to 533,332 plants/ha in mixed cropping. It should be borne in mind that the ecological situations in mixed cropping are often quite different from those in sole cropping, the cropping system that we used when studying field bean populations.

Soil Temperature

Soil temperature (Table 4) did not show any significant differences between field bean populations. However, temperatures at 5-cm depth were generally higher in all plant populations than temperatures at 10-cm and 15-cm depths.

The observation that soil temperature was higher at 5-cm depth than at 10- and 15-cm depths agreed with earlier observations (Ossom et al., 2001; Ossom, 2003; Thwala, 2004; Dlamini, 2005) who also reported that soil temperature was lower at greater depths. Soil temperature has been reported to influence some physiological processes including seed dormancy and germination (Relf, 1997), seedling emergence and growth (Anon., 2004). Davis et al. (1990) reported that field crops grow at a range of 5-30°C soil temperature, noting that soil temperatures above the annual soil temperature range could cause flower blast. It was reported that increased soil moisture, subsoil compaction, and decreased soil temperature may result in insufficient early season transplant root development that decreases uptake and/or immobilization of essential nutrients (Mellish, 1978; Bockus & Shroyer, 1998). The soil temperature range (25.7-28.5°C) recorded in our investigation was consistent with soil temperatures in tropical areas (Sanchez, 1976; Ossom et al., 2001; Ossom, 2003).

Among the possible reasons that might be advanced for higher soil temperatures at 5-cm depth than at lower depths are the following: greater solar radiation impacts the soil nearer the soil surface; greater microbial activities in the topsoil where the higher organic matter content might enhance microbial life; greater intensity of physiological activities (respiration, decay, and/or fermentation) caused by plant roots and other macro-organisms (flora and fauna alike) in the soil, less soil moisture compared to lower depths of the profile where the water table is deeper than at the soil surface; and reduced air circulation in the soil environment than in the atmosphere.

Field Bean Yield

Figure 1 shows the seed yield (dry mass) of field bean. There was a positive interaction ($P < 0.05$) between plant population and total seed yield and a positive correlation between plant population and seed yield. The plant population of 66,667 plants/hectare had a significantly ($P < 0.05$) lower total seed yield (270.4 kg/ha) than the 400,000 plants/ha plant population (695.8 kg/ha).

Though seed yields in this investigation were quite low compared to those of other workers (Crothers & Westermann, 1976; Ayaz et al., 2001; Clark & Carpenter, 2005), plant population density, nevertheless, contributed to the total seed yield of the crop. The results obtained in this experiment showed a positive response of higher seed yield with higher plant population densities. These results were in agreement with the findings of other workers (Crothers & Westermann, 1976; Shirtliffe & Johnston, 2002) that high plant population in *Phaseolus vulgaris* led to higher seed yield. The effect of plant population on seed yield was also consistent with the data of Ayaz et al. (2001) who reported that seed yield approximately doubled as population increased from 100,000 to 400,000 seeds sown per ha. Ayaz et al. (2001), and Herbert and Hill (1978) reported that as plant density increased, intensity of interplant competition also increased, and yield/plant would decline, although total yield/unit area might increase. Anon. (2005b) stressed that dry beans in all market classes had the potential for higher yields with narrower spacing (higher plant populations). In cowpea [*Vigna unguiculata* (L.) Walp.], such higher yield was explained to be an indication of responsiveness to higher planting densities (Ismail & Hall, 2000).

CONCLUSION AND RECOMMENDATION

While increasing the planting population density did not significantly reduce weed scores at the 0.05 level of significance, there was a trend toward fewer weeds when the field bean plant canopy closed from 3 to 6 WAP. Both the recommended plant population (200,000 plants/ha) and the highest plant population (400,000 plants/ha) showed the same degree of disease incidence. Soil temperatures were higher at 5-cm depth than at lower depths but showed no significant differences among plant populations. It is recommended that for higher seed yields, the higher population of 400,000 plants/ha (spacing, 50.0 cm x 5.0 cm) be adopted by small-scale farmers. More long-term studies should be done to clearly identify the influence of field population on the parameters investigated in this study.

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Table 1. Influence of field bean population on mean weed, disease, and insect incidence.

Field bean population/ha	Weed score 3 WAP[1]	Weed score 6 WAP[1]	Disease score 3 WAP[1]	Disease score 6 WAP[1]	Insect score 3 WAP[1]	Insect score 6 WAP[1]
400,000	4.2	3.3	1.0	1.3	2.4	4.3
200,000	4.3	3.6	1.0	1.2	2.3	3.7
133,333	4.2	3.1	1.0	1.3	2.0	3.6
100,000	3.6	3.3	1.0	1.4	2.1	3.5
66,667	3.4	3.5	1.0	1.3	1.8	3.2
Mean	3.9	3.4	1.0	1.3	2.1	3.7
$LSD^2_{(0.05)}$	0.9	0.5	NA	0.3	1.0	0.5
Significance	ns	ns	NA	ns	ns	**

[1] Weeks after planting; [2] Least significant difference; ns, not significant at $P > 0.05$
** Significant at $P < 0.01$; NA, value not available

Table 2. Effects of plant population on weed species distribution at three weeks after planting.

Family name	Scientific name	Common name	Field bean population (plants/ha) and weed species relative abundance (%)[1]				
			400,000	200,000	133,000	100,000	66,667
Amaranthaceae	*Amaranthus hybridus* L.	Common pigweed	3.4	0.8	3.3	4.6	1.3
Asteraceae	*Bidens pilosa* L.	Blackjack	10.6	10.4	8.2	6.3	12.4
Asteraceae	*Schkruhria pinnata* L.	Dwarf marigold	2.6	0.4	0.0	1.3	0.9
Commelinaceae	*Commelina benghalensis* L.	Benghal wandering Jew	4.7	5.0	3.3	2.1	7.1
Cyperaceae	*Cyperus rotundus* L.	Purple nutsedge	17.0	17.9	17.6	11.0	9.8
Oxalidaceae	*Oxalis latifolia* H.B.K.	Red garden sorrel	17.5	19.2	17.2	20.7	15.1
Poaceae	*Cynodon dactylon* L.	Bermuda grass	3.0	0.00	1.6	3.4	0.4
Poaceae	*Paspalum distichum* L.	Couch paspalum	0.0	0.0	3.3	3.0	1.3
Poaceae	*Elusine africana* L.	African goose grass	0.4	0.0	0.0	0.0	0.0
Portulaceae	*Portulaca oleracea* L.	Common purslane	20.0	22.5	21.7	18.6	9.3
Rubiaceae	*Richardia brasiliensis* Gomes.	Tropical Richardia	19.6	17.9	18.0	27.4	36.4
Tiliaceae	*Corchorus olitorius* L.	Torsa jute	1.3	5.8	5.7	1.7	5.8
Number of weed species	NA	NA	11.0	9.0	10.0	11.0	11.0
Weed score[2]	NA	NA	4.2	4.3	4.2	3.6	3.9

[1] Because of rounding up of percentages, the totals may not equal 100.0%.
[2] Other analyzed values for weeds at 3 WAP are in Table 1.
NA, Not applicable

Table 3. Effects of plant population on weed species distribution at six weeks after planting.

Family name	Scientific name	Common name	Field bean population (plants/ha) and weed species relative abundance (%)[1]				
			400,000	200,000	133,000	100,000	66,667
Amaranthaceae	*Amaranthus hybridus* L.	Common pigweed	0.0	2.5	1.3	3.5	2.5
Asteraceae	*Schkruhria pinnata* L.	Dwarf marigold	0.4	0.0	0.0	1.2	0.0
Asteraceae	*Galinsoga parviflora* L.	Gallant soldier	0.4	4.1	0.8	1.2	1.3
Asteraceae	*Bidens pilosa* L.	Blackjack	7.7	11.6	5.9	12.3	4.2
Commelinaceae	*Commelina benghalensis* L.	Benghal wandering Jew	0.4	2.1	2.9	0.0	0.4
Cyperaceae	*Cyperus rotundus* L.	Purple nutsedge	27.8	11.6	18.9	6.1	22.1
Oxalidaceae	*Oxalis latifolia* H.B.K.	Red garden sorrel	26.5	24.4	29.8	37.2	20.0
Poaceae	*Cynodon dactylon* L.	Bermuda grass	0.0	0.0	0.0	0.0	1.7
Poaceae	*Paspalum distichum* L.	Couch paspalum	0.4	0.8	0.5	0.0	2.9
Poaceae	*Digitaria senquinalis* L.	Crab finger grass	4.3	2.5	2.1	3.8	4.2
Poaceae	*Elusine africana* L.	African goose grass	0.9	1.2	0.0	0.0	5.0
Portulaceae	*Portulaca oleracea* L.	Common purslane	0.4	0.0	1.7	0.4	4.6
Rubiaceae	*Richardia brasiliensis* Gomes.	Tropical Richardia	30.8	37.2	35.7	33.3	29.6
Solanaceae	*Datura stramonium* L.	Bitter apple	0.0	1.2	0.0	0.4	0.8
Tiliaceae	*Corchorus olitorius* L.	Torsa jute	0.0	0.4	0.4	0.4	0.8
Number of weed species	NA	NA	11.0	12.0	11.0	11.0	14.0
Weed score[2]	-	-	3.3	3.6	3.1	3.3	3.5

[1] Because of rounding up of percentages, the totals may not equal 100.0%.
[2] Other analyzed values for weeds at 6 WAP are in Table 1.
NA, Not applicable

Table 4. Effects of field bean population on soil temperature (°C) at 5-cm, 10-cm, and 15-cm depths.

Field bean population/ha	Soil temperature at 5-cm depth		Soil temperature at 10-cm depth		Soil temperature at 15-cm depth	
	3 WAP[1]	6 WAP[1]	3 WAP[1]	6 WAP[1]	3 WAP[1]	6 WAP[1]
400, 000	27.8	27.8	27.3	27.2	26.3	26.4
200, 000	27.6	27.5	26.9	26.8	25.9	25.8
133, 333	27.3	27.3	27.1	27.1	26.2	26.0
100, 000	28.2	28.5	27.2	27.5	25.8	25.7
66, 667	27.7	27.9	27.5	27.3	26.1	26.3
Mean	27.7	27.8	27.2	27.2	26.1	26.1
LSD[3] $_{(0.05)}$	0.7	1.0	0.5	0.8	0.6	1.0
Significance	ns	ns	ns	ns	ns	ns

[1] Weeks after planting

[2] Least significant difference

ns, not significant ($P > 0.05$)

Figure 1. Effects of plant population on field bean seed yield.