Journal of Medicinal Plants Studies
www.PlantsJournal.com

ISSN (E): 2320-3862
ISSN (P): 2394-0530
NAAS Rating: 3.53
www.plantsjournal.com
JMPS 2021; 9(2): 24-29

Received: 15-12-2020
Accepted: 20-01-2021

Mathobo Rudzani
Limpopo Department of Agriculture and Rural Development, Private Bag X9487, Polokwane 0700, South Africa

Corresponding Author:
Mathobo Rudzani
Limpopo Department of Agriculture and Rural Development, Private Bag X9487, Polokwane 0700, South Africa

The effect of plant population on chlorophyll content and grain yield of dry bean (*Phaseolus vulgaris* L.) at Dzindi irrigation scheme in South Africa

Mathobo Rudzani

DOI: https://doi.org/10.22271/plants.2021.v9.i2a.1254

Abstract
The trial was conducted at Dzindi irrigation scheme in Vhembe District in the Limpopo Province during the 2012 growing season. It was a 3x2 factorial experiment involving three plant populations (210 000, 150 000 and 70 000 plants ha^{-1}) and two varieties of dry bean which are OPS-RS2 and Jenny with three replications. The results revealed that the interaction relationship between dry bean variety and plant population significantly influenced grain yield, 100 seed mass, number of seeds, plant height, chlorophyll content and dry matter production. The highest grain yield per plant was produced by Jenny with 70 000 plants ha^{-1}. The highest grain yield was produced by OPS-RS2 with 150 000 plants ha^{-1} (3.8 tha^{-1}) which was not significantly different to Jenny at 210 000 plants ha^{-1} and Jenny at 150 000 plants ha^{-1}. A plant population of 150 000 plants ha^{-1} was suitable for both determinate and indeterminate growth type dry beans.

Keywords: Common bean, hundred seed mass, plant density, plant height, number of seeds per plant

Introduction

Dry bean (*Phaseolus vulgaris* L.) is an important leguminous crop in the world due to its high protein content. It is regarded as the third most important food legume after soybean and peanut (Singh *et al*., 1999) [1]. In South Africa, mainly three types of beans are produced, namely red speckled beans, small white canning beans and large white kidney (Department of Agriculture, Forestry and Fisheries (DAFF), 2016) [2]. For this research, the concentration is on red speckled beans because it holds a large market in the dry bean industry in South Africa.

Determination of the optimal plant population necessary for optimal yield is a major agronomic goal (Hosseini *et al*., 2001) [3]. Plant population d plays a major role in determining expected yield in crop production. Population densities utilized for cultivation of common bean (*Phaseolus vulgaris* L.) vary from 50 000 to over 200 000 plants per hectare (Singh and Gutièrrez, 1990) [4]. Cultivars of different growth habits respond differently to varying densities (Crothers and Westermann, 1976; Nienhuis and Singh, 1985) [5, 6]. Determinate (Type I) bush beans typically require higher plant populations to maximize yield as compared to semi-vining (Type II) or vining (Type III) beans (Nienhuis and Singh, 1985) [6]. The plants tend to compete for space, light, nutrients and water as they grow bigger and older. On another case decreasing the distance between the plants results in smaller amount of the sun striking the ground decreasing the potential for weed interference (Johnson *et al*., 1998) [7]. Less amount of the sun striking the soil also reduces evaporation, thus saving water.

High plant population adversely affects plant growth and development, while suboptimal plant population results in high yield per plant but lower yield per unit area in faba bean (Singh *et al*., 1992) [8]. The increase in plant population resulted in a decrease in chlorophyll content and increase in dry matter yield in durum wheat (Jamaati-E-Somarin *et al*., 2009) [9]. Chlorophyll content decreased with increasing plant population per unit area in paprika pepper (Amnifard *et al*., 2010) [10]. The highest fruit weight per plant was observed in the 30 x 100 cm plant spacing and the lowest in the 30 x 50 cm plant spacing in paprika pepper (Amnifard *et al*., 2010) [10]. Yield per unit area tend to increase as plant population increases up to a certain point and then declines in watermelon (Akintoye *et al*., 2009) [32].

Grain yield increased linearly with an increase in plant population density and reached the highest grain yield at 450 000 plants ha^{-1} and thereafter any increase in plant population resulted in a decrease grain yield in faba bean (Khalil *et al*., 1993) [12]. Plant height increased with increasing population density in faba bean (Abdel-Aziz *et al*., 1999) [13]. A higher plant population in snap bean resulted in a lower number of pods per plant bush snap bean (Wahab *et al*., 1986) [14]. On the other hand, in faba bean, the number of pods was not affected by plant population (Dahmardeh *et al*., 2010) [15]. The objective of the study was to evaluate the effects of plant population density on chlorophyll content and grain yield.

Materials and methods

Experimental site: The experiment was planted at Dzindi irrigation scheme (23˚45`S latitude, 30˚30`E longitude) during 2012 planting season. Dzindi irrigation scheme is located 6 km south west of Thohoyandou, Thulamela municipality, Vhembe District of the Limpopo Province, South Africa. The area has an annual rainfall of about 800 mm, with 95% occurring between October and March. The daily temperatures vary from about 25 to 40 ºC in summer and between 22 to 26ºC in winter (Mzezewa *et al*., 2010) [16]. The soil at the experimental site is Hutton Suurbekom.

Treatments: The experiment was a 3x2 factorial experiment involving three plant populations (210 000, 150 000 and 70 000 plants ha^{-1}) and two varieties of dry bean (OPS-RS2 and Jenny) in a split-plot design with three replications. The recommended population is 150 000 plants ha^{-1}. Genotype Jenny has an indeterminate growth pattern, while OPS-RS2 has a determinate growth pattern. The spacing between the rows was 90 cm and within row 7.5 cm. The plot consisted of 4 rows each 4 m in length. Top-dressing was done at 30 DAP using lime ammonium nitrate (LAN-28%N) at the rate of 30 kgha^{-1}. The trial was irrigated once a week.

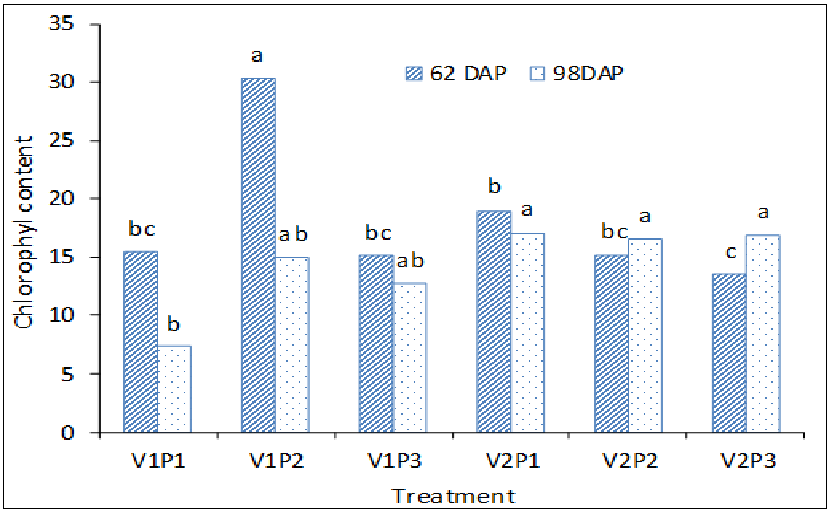
Data collection: Data was collected from the two middle rows. Number of plants germinated was determined nine days after planting. At 30, 62 and 98 days after planting (DAP) and plant height from the six plants per plot were determined. Plant height was taken as the distance from ground level to the tip of the growing point. Destructive sampling was done by harvesting six plants per treatment at 30, 62 and 98 DAPS to determine dry matter yield. After the plants were harvested, they were put in brown bags and they were dried at 75 ºC for ±48 hours.

Chlorophyll content was measured using a portable chlorophyll content meter (CCM-200, Opti Sciences, USA). The measurements were made from the top most expanded leaf (3 leaves per plot) at 20, 62 and 98 DAP. Yield data (seed yield, 100 seed mass) was collected from 1 m^2 (2 middle rows) in the middle of the plot. The number of pods per plant and number of seeds per plant were determined from 10 randomly selected plants per plot. The moisture content of the seed was determined by using a multi grain moisture meter (Dickey John, Auburn, Illinois, USA). Yield was expressed based on a 10% moisture content. Harvesting was done by hand.

Statistical procedure: Data were subjected to Analysis of Variance using General linear Model procedure of Statistical Analysis System software (SAS 9.3 – 2010) to determine the response of dry bean varieties under different plant populations. Means were compared using the Least Significant Difference test at 5 % level of probability. Correlation analysis was done using SAS to determine the relationship between parameters.

Results

The chlorophyll content was influenced by plant population at 20 DAP (Table 1). The effect of variety, variety x plant population interaction was not significant at 20DAP. The plant population P2 resulted in the significantly higher chlorophyll content (10.94) at 20 DAP. The adjustment of plant population from P2 to P1 and P3 resulted in a 17% and 19 % reduction of chlorophyll content respectively. Plant population and variety significantly influenced chlorophyll content at $p \leq 0.01$ (62 DAP) and at $p \leq 0.05$ (98 DAP). At 62 DAP the highest amount of chlorophyll content was found in Jenny under P2 (30.3) and the lowest in Jenny under P3 (13.5) (Figure 1). At 98 DAP the highest chlorophyll content was found in OPS RS2 under P2 (16.9) and the lowest in Jenny under P1 (7.3) (Figure 1).



Note: Means for bars of the same style with the same letter are not significantly different, DAP=Days after planting, P1: 210 000 plants ha^{-1}; P2: 150 000 plants ha^{-1}; P3: 70 000 plants ha^{-1}; V1: Jenny; V2: OPS-RS2.

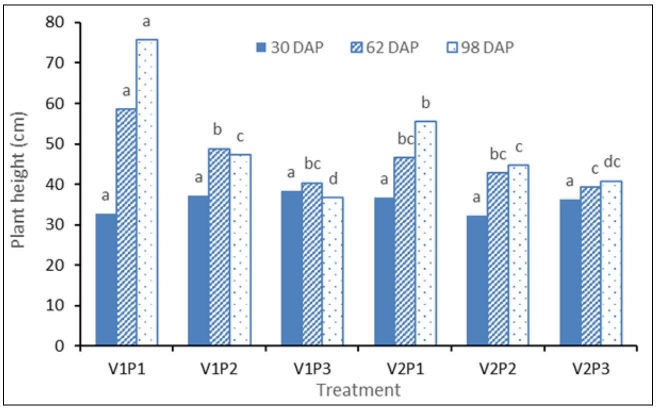
Fig 1: Effect of dry bean varieties and plant population on chlorophyll content

Table 1: Effect of dry bean varieties and plant population on chlorophyll content at 20 DAP

Treatments		Chlorophyll content
Plant population density	P1	9.10b
	P2	10.94a
	P3	8.81b
Varieties	V1	10.02a
	V2	9.21a
LSD	Plant population	1.66
	Variety	ns
	Plant population x Variety	ns

Note: LSD: Least significance difference; ns: non-significant; *: significant at p≤0.05; **: significant at p≤0.01; P1: 210 000 plants ha^{-1}; P2: 150 000 plants ha^{-1}; P3: 70 000 plants ha^{-1}; V1: Jenny; V2: OPS-RS2. Means in a column with the same letter are not significantly different.

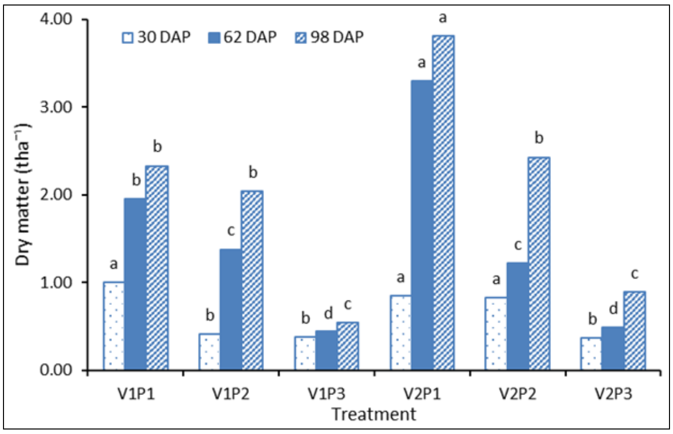
Neither of the treatment factors affected plant height at 20 DAP. The effect of interaction was highly significant on plant height at 62 DAP and 98 DAP (Figure 2). At both 62 and 98 DAP the maximum height was found in Jenny (V1) at P1 which was 58.5 and 75.67 cm respectively. The decrease in plant population of Jenny from P1 to P2 resulted in a 16% reduction of plant height, while a decrease in plant population from P1 to P3 resulted in a 31% reduction of plant height. The plant height of OPS-RS2 (V2) also tended to increase with an increase in plant density at both 62 and 98 DAPS. At 98 DAP the tallest plants were recorded for Jenny at P1 (75.67 cm).



Note: Bars of the same style with the same letter are not significantly different, DAP: Days after planting, P1: 210 000 plants ha^{-1}, P2: 150 000 plants ha^{-1}, P3: 70 000 plants ha^{-1}, V1: Jenny, V2: OPS-RS2.

Fig 2: Effect of dry bean variety and plant population on plant height

The variation in dry matter production was influenced by interaction relationship between plant population and variety at 30, 62 and 98 DAP (p≤0.01) (Figure 3). At 30 DAP both Jenny (V1) and OPS-RS2 (V2) gave the highest dry matter yield at P1 which was 1.00 tha^{-1} and 1.83 tha^{-1} respectively. The dry matter for Jenny at P1 and OPS-RS2 at P1 was not significantly different from OPS-RS2 at P2. The lowest dry matter yield was produced by OPS-RS2 at P3, which was not significantly different from the dry matter yield of Jenny at P2 and P3. At 62 DAP the variety OPS-RS2 at P1 resulted in the highest amount of dry matter yield (3.30 tha^{-1}) and the lowest dry matter yield was produced by Jenny at P3 (0.45 tha^{-1}). At 98 DAP the maximum dry matter yield was produced by OPS RS2 at P1 followed by Jenny at P1 which was statistically similar to Jenny at P2 and OPS RS2 at P2. The lowest dry matter yield was produced by Jenny at P3 which was not statistically different from OPS RS2 at P3.



Note: Bars of the same style with the same letter are not significantly different, DAP=Days after planting, P1: 210 000 plants ha^{-1}, P2: 150 000 plants ha^{-1}, P3: 70 000 plants ha^{-1}, V1: Jenny, V2: OPS-RS2.

Fig 3: Effect of dry bean variety and plant population on dry matter production

The results revealed that the effect of plant population on the number of pods per plant was highly significant (p≤0.01) (Table 2). The effects of variety as well as the interaction effect on the number of pods per plant were not significant. The highest number of pods was produced by P3 (14.09) and the lowest by P1 (8.48). The number of pods per plant was reduced by increasing plant population from P3 to P2 (7%) and P1 (40%).

The effect of plant population on number of seeds per plant was highly significant (p≤0.001) while the effect of variety was significant (p≤0.05) (Table 2). The insignificant plant population x variety interaction indicated that varieties reacted to plant population in the same way. The maximum number of seeds per plant was produced by P3 (41.83) which was not significantly different from P2 (37.57) and the lowest was produced by P1 (21.58). The number of seeds per plant at P3 and P2 were significantly higher than P1 by 48% and 42% respectively. Jenny (35.54) produced the highest number of seeds per plant than OPS-RS2 (31.78).

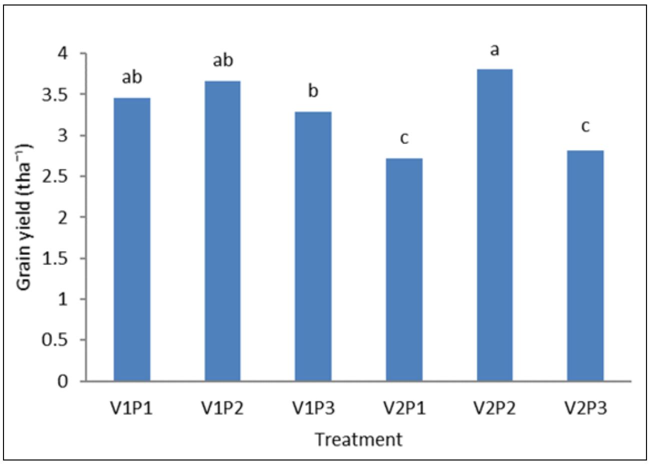
The mass of 100 seeds were significantly (p≤0.05) influenced by the interaction effect (Table 2). The 100 seed mass was the highest at P3 (211g) and it was statistically similar to P2 (200.5g). The lowest 100 seed mass was produced by P1 (184.72 g), but it was not statistically different from P2. OPS RS2 produced the highest 100 seed mass (208.37 g) and the lowest produced by Jenny (187.39 g).

Table 2: Effect of dry bean variety and plant population on number of pods, number of seeds and hundred seed for Dzindi irrigation scheme

Treatments		No. of podsplant $^{-1}$	No. of seeds plant $^{-1}$	Hundred seed mass (g)
Plant Population Density	P1	8.48c	21.58b	184.72b
	P2	13.17b	37.57a	200.50ab
	P3	14.09a	41.83a	211.40a
Variety	V1	12.07	35.54a	187.39b
	V2	11.76	31.78b	208.37a
LSD	Plant Population	0.481**	4.527**	26.99**
	Variety	ns	3.656*	7.45*
	Plant Population x Variety	ns	ns	21.40**

Note: LSD: Least significance difference; ns: non-significant; *: significant at p≤0.05; **: significant at p≤0.01; P1: 210 000 plants ha^{-1}; P2: 150 000 plants ha^{-1}; P3: 70 000 plants ha^{-1}; V1: Jenny; V2: OPS-RS2. Means in a column with the same letter are not significantly different.

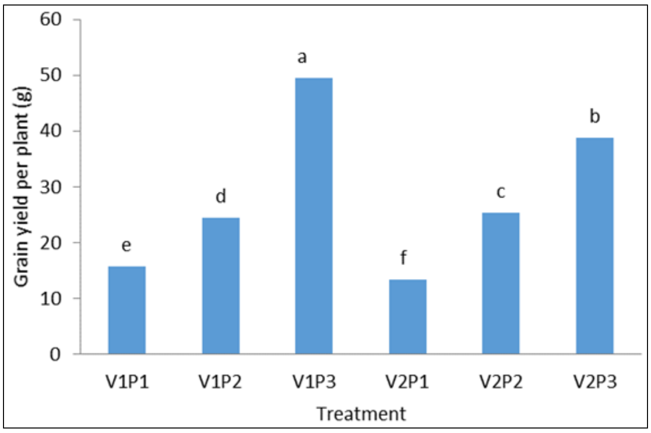
The variation in grain yield was significantly (p≤0.05) influenced by the interaction relationship between plant population and variety. The highest grain yield was achieved with OPS-RS2 (V2) at P2 (3.80 t ha^{-1}) (Figure 4). This yield was statically similar for Jenny (V1) at both P1 and P2. The adjustment of plant population of OPS-RS2 (V2) from P2 to P1 and P3 resulted in a 28% and 26% reduction in grain yield respectively. The grain yield of Jenny (V1) was statistically the same at P3 and P2. From the results it is clear that 150 000 plants ha^{-1} (P2) would be suited to both determinate and indeterminate growers. The results suggest that the best population obviously depends on the balance between available resources and the degree of competition, which is affected by the cultivar and the specific environment. However, determinate growers (example OPS-RS2 – V2) are not as adjustable to higher (P1) or lower (P3) plant populations as an indeterminate grower (example Jenny – V1) (Figure 2).



Note: Bars with the same letter are not significantly different. P1: 210 000 plants ha^{-1}; P2: 150 000 plants ha^{-1}; P3: 70 000 plants ha^{-1}; V1: Jenny; V2: OPS-RS2.

Fig 4: Effect of dry bean variety and plant population on grain yield

The interaction effect of plant population and variety was highly significant (p≤0.001) on yield per plant. The combination of Jenny (V1) and P3 resulted in a significantly higher yield per plant than its yield at P2 (50.6%) and P1 (68%) (Figure 5). This yield was significantly higher than the yield of OPS-RS2 (V2) by 21.5%. The performance of OPS-RS2 at P3 was better than at P2 and P1 by 34.7% and 65% respectively. Yield per plant increased with reduction in plant populations from P3 to P1 in both varieties.



Note: Bars with the same letter are not significantly different. P1: 210 000 plants ha^{-1}, P2: 150 000 plants ha^{-1}, P3: 70 000 plants ha^{-1}, V1: Jenny, V2: OPS-RS2.

Fig 5: Effect of dry bean variety and plant population on grain yield

There was a significantly positive correlation between grain yield per plant and pods per plant (r = 0.922, p=0.001) and number of seeds per plant (r = 0.866, p=0.001) and Chlorophyll content (r = 0.835, p = 0.001) (Table 3). Plant height was also positively correlated with yield, but the correlation was weak (Table 3), as were correlations between plant height and the other parameters. There was a significantly positive correlation between pods per plant and number of seeds (r = 0.953, *p*<0.001). There was a significantly positive correlation between pods per plant and number of seed (r = 0.953, *p*<0.001) and chlorophyll content (r = 0.772, p=0.001). Finally, there was a significantly positive association between number of seeds per plant and chlorophyll content (r = 0.672, p=0.001).

Table 3: Correlation among grain yield, yield components and growth parameters for Dzindi irrigation scheme

	Yield	Pods plant^{-1}	Seeds plant $^{-1}$	Plant height	Chlorophyll content
Yield	1	0.922***	0.866***	0.484*	0.835***
Pods plant^{-1}		1	0.953***	0.186	0.772***
Seeds plant^{-1}			1	0.154	0.672**
Plant height				1	0.118
Chlorophyll content					1

Note: *, **, ***- indicates significant difference at 0.05, 0.01 and 0.001 level of probability.

Discussion

During early stages of growth there was not much competition yet because plants were still small. Later when the plants were bigger, the competition effect was much stronger at high plant densities. The reduction of chlorophyll content at high plant density may be due to high competition for sunlight which plays a major role in the chlorophyll molecule formation. The reduction of chlorophyll content at high plant population can also be due to shading of lower leaves leading to poor light interception (Dahmardeh *et al*., 2010) [15]. The reduction of chlorophyll content at high plant population was also reported in maize (Ren *et al*., 2017) [17], snap bean (Seif *et al.* 2016) [18], paprika pepper (Aminifard *et al*., 2010) [10] and durum wheat (Jamaati-e-Somarin *et al.*, 2009) [9]. Mutual shading effect reduced chlorophyll content in sugarcane (Marchiori *et al*., 2014) [19] and in maize (Ren *et al*., 2016) [20].

The results revealed that at 20 DAP there was not much competition yet because plants were still small. Later when the plants were bigger, the competition effect was much stronger at high plant densities. The increase in plant height with an increased plant population for this study may be due to intra-plant completion for light. The increase in plant height with an increase in plant population density was also reported in faba bean (Dahmardeh *et al*., 2010; Mekkei, 2014) [15, 21].

The highest plant population density resulted in the highest dry matter yield due to improved vegetative growth due to intra-plant competition for light and space. The highest plant population resulting in the highest dry matter yield was also reported in faba bean (Gezahegn and Tesfaye, 2017) [22]. The production of high number of pods per plant for P3 may be due to less competition for light, moisture and nutrients resulting in production of more pods per plant at low plant population. The highest number of pods per plant in lower plant population was also reported faba bean (Dahmardeh *et al*., 2010; Gezahegn *et al*., 2016) [15, 23].

The higher number of seeds per plant may have resulted from less competition for nutrients, light and moisture resulting in the plant being able to produce more. Maynard and Scott (2017) [22] confirmed that at high densities plants compete for nutrients, water and light, which can result in poor seed development. The results revealed that at the highest plant population the size of the seeds were small and at the lowest plant population there were bigger seeds. The 100 seed mass of Jenny also decreased with an increase in plant density but was statistically similar. The maximum 100 seed mass in the lowest plant population was also reported in faba bean (Mekkei, 2014) [21].

From the results it is clear that 150 000 plants ha^{-1} (P2) would be suited to both determinate and indeterminate growers. The results suggest that the best population obviously depends on the balance between available resources and the degree of competition, which is affected by the cultivar and the specific environment. However, determinate growers (example OPS-RS2 – V2) are not as adjustable to higher (P1) or lower (P3) plant populations as an indeterminate grower (example Jenny – V1) (Figure 2). This suggests that Jenny (indeterminate) has a better potential to compensate for low plant stand than OPS-RS2 (determinate). The results also indicates that the lower plant population P3 for V2 could not compensate for a reduced number of plants per unit area. The increase in seed yield with higher plant populations was reported in dry beans (Grafton *et al.* 1988) [25], spotted beans (Ardakani and Farajee, 2013) [26] and sorghum (Bayu *et al*., 2005) [27]. The higher plant population resulted in higher fruit yield in pepper by Aminifard *et al*. (2010) [10]. The results indicates that the increase in the number of plants per unit area contributed to the production of extra yield per unit area leading to higher yield.

The results revealed that yield per plant increased with reduction in plant populations. This can also be due to less competition for light, water and nutrients, which leads plants being able to intercept more photosynthetically active radiation resulting in the production of more yield per plant in low plant population. Gezahegn *et al*. (2016) [23] reported that lower plant population resulted in higher yield per plant in faba bean. The highest fruit yield per plant was also found in lower plant population in paprika pepper (Aminifard *et al*., 2010) [10]. Ren *et al* (2017) [17] reported a significant reduction in yield per plant with an increase in plant population in maize. The vining ability of indeterminate beans allows for growth to compensate for low plant populations (Shirtliffe and Johnston, 2002) [28]. This could explain the large difference between Jenny at P3 versus P2 as compared to OPS-RS2 for the same plant populations.

Significant correlation between grain yield with 100 seed mass, seeds per pod and pods per plant was also reported in soybean (Daniel *et al*., 2011) [29]. Grain yield was highly correlated with the number of pods in dry bean (Bennet *et al*., 1977) [30].

Conclusions

The interaction relationship between dry bean varieties and plant populations significantly influenced the grain yield, grain yield per plant, plant height at 62 and 98 DAP, chlorophyll content and dry matter production. The highest grain yield was achieved with OPS-RS2 at 150 000 plants ha^{-1} (3.802 t ha^{-1}). The number of seeds per plant was influenced by plant population and dry bean variety. The number of pods per plant was only influenced by plant populations. There was a significantly positive correlation between grain yield per plant and pods per plant and number of seeds per plant. The plant population of 150 000 plants ha^{-1} was found to be the most suitable for both determinate and indeterminate dry bean varieties under these conditions.

Acknowledgement

The authors' wishes to express their appreciation to the Limpopo Department of Agriculture and Rural Development for funding the study, Dzindi irrigation scheme extension officer Mr Netshithuthuni C and the local farmers for the support during this study.

References

1. Singh SP, Teran H, Munoz CG, Takegami JC. Two cycles of recurrent selection for seed yield in common bean. Crop Sci 1999;39:391-397.
2. Department of Agriculture, Forestry & Fisheries (DAFF) Dry bean market value chain profile. Arcadia, South Africa. 2016; http://www.nda.agric.za/doaDev/sideMenu/Marketing/Annual%20Publications/Commodity%20Profiles/field%20crops/Dry%20Bean%20Market%20Value%20Chain%20Profiles%202012.pdf
3. Hosseini NM, Ellis RH, Yazdi-Samadi B. Effects of plant population density on yield and yield components of eight isolines of cv. Clark (*Glycine max* L.) J Agric. Sci. Technol 2001;3:131-139.
4. Singh SP, Gutièrrez JA. Effect of plant density on

selection for seed yield in two population types of *Phaseolus vulgaris* L. Euphytica 1990;51:173-178.
5. Crothers S, Westermann D. Plant population effects on the seed yield of *Phaseolus vulgaris* L. Agron. J 1976;68:958-960. http://agron.scijournals.org/cgi/content/abstract/68/6/958.
6. Nienhuis J, Singh SP. Effects of location and plant density on yield and architectural traits in dry beans. Crop Sci 1985;25:579-584.
7. Johnson GA, Hoverstad TR and Greenwald, RE Integrated weed management using narrow corn row spacing, herbicides and cultivation. Agron. J 1998;77:40-46.
8. Singh SP, Singh NP, Pandey RK Performance of faba bean varieties at different plant densities. FABIS Newsletter 1992;30:29-31.
9. Jamaati-E-Somarin S, Hassanzadeh M, Peyghami F, Zabihi-E-Mahmoodabad R. Response of durum wheat growth and chlorophyll content to nitrogen rates and plant populations. Res. J Biol. Sci 2009;4:1135-1141.
10. Aminifard MH, Aroiee H, Karimpour S, Nemati H. Growth and yield characteristics of paprika pepper (*Capsicum annum* L.) in response to plant density. Asian J Plant Sci 2010;9:276-280.
11. Taminaw Zewdie Nigatie. Review on effect of N and P fertilizer rates on yield and yield components of common bean [*Phaseolus vulgaris* (L.)] varieties. Int. J Res. Agron. 2021;4(1):32-40.
12. Khalil SA, Dissouky RF, Amer MI, El-Hady MM, Hassan MWA. Performance of yield and yield components of two faba bean (*Vicia faba* L.) cultivars as affected by two plant densities and foliar disease control in the new reclaimed land. J. Agric. Sci. Mansoura Univ 1993;18:1306-1314.
13. Abdel-Aziz EL, El-Set A, Shalaby FH. Physiological studies on response of new released faba bean varieties to different plant populations. Zagazig J Agric. Res 1999;26:1229-1244.
14. Wahab MNJ, Dabbs DH, Baker RJ. Effects of planting density and design on pod yield of bush snap bean (*Phaseolus vulgaris* L.). Can. J. Plant Sci 1986;66(3):669-675.
15. Dahmardeh M, Ramroodi M, Valizadeh J. Effect of plant density and cultivars on growth, yield and yield components of faba bean (*Vicia faba* L.). Afri. J. Bio technol 2010;9:8643-8647.
16. Mzezewa J, Misi T, Van Rensburg LD. Characterisation of rainfall at a semi-arid ecoptope in the Limpopo Province (South Africa) and its implications for sustainable crop production. Water SA 2010;36:19-26.
17. Ren B, Liu W, Zhang J, Dong S, Liu P, Zhao B. Effects of plant density on the photosynthetic and chloroplast characteristics of maize under high-yielding conditions. The Sci. Nat 2017;104:12
18. Seif YIA, Ei-Miniawy SEM, Ei-Azmq NAIA, Hegazi AZ. Response of snap bean growth and seed yield to seed size, plant density and foliar application with algae extract. AOAS 2016;61(2):187-199.
19. Marchiori PER, Machado EC. Ribeiro RV. Photosynthetic limitations imposed by self-shading in field-grown sugarcane varieties. Field Crops Res 2014;155:30-37.
20. Ren B, Cui H, Camberato JJ, Dong S, Liu P, Zhao B. Effects of shading on the photosynthetic characteristics and mesophyll cell ultrastructure of summer maize. The Sci. Nat 2016;103:67.
21. Mekkei ME. Effect of intra-row spacing and seed size on yield and seed quality of faba bean (*Vicia faba* L.) Intl. J Agric. Crop Sci 2014;7(10):665-670.
22. Gezahegn AM, Tesfaye K. Optimum inter and intra row spacing for faba bean production under Fluvisols. J Agri. Sci 2017;4:10-19.
23. Gezahegn AM, Tesfaye K, Sharma JJ, Belel MD. Determination of optimum plant density for faba bean (*Vicia faba* L.) on vertisols at Haramaya, Eastern Ethiopia. Cogent Food & Agriculture 2016;2(1):1224485.
24. Maynard ET and Scott WD Plant spacing affects yield of superstar muskmelon. J Hort. Sci 1998;33:52-54.
25. Grafton KF, Schneiter AA, Nagle BJ. Row spacing plant population and genotype x row spacing interaction effects on yield and yield components of dry bean. Agron. J 1988;80:631-634.
26. Ardakani LG, Farajee H. The effect of water stress and plant density on yield and some physiological traits of spotted bean (*Phaseolus vulgaris* L.) cultivar Talash in Yasouj region. Int. J Biosci 2013;3:175-184.
27. Bayu W, Rethman NFG, Hammes PS. Growth, yield compensation in sorghum (*Sorghum bicolor* L. Moench) as a function of planting density and nitrogen fertilizer in semi-arid areas of Northeastern Ethiopia. South-African J Plant and Soil 2005;22(2):76-83.
28. Shirtliffe SJ, Johnston AM. Yield density relationships and optimum plant populations in two cultivars of solid-seeded dry bean (*Phaseolus vulgaris* L.) grown in Saskatchewan. Can. J Plant Sci 2002;82:521-529.
29. Daniel M. Selection of Planting Pattern and Plant Population Density (PPD) for Medium and Late Maturing Soybean Varieties (G*lycine Max* (L.) Merrill) in the Tropics. Innovative Systems Design and Engineering 2011;2(4):242-249.
30. Bennet JP, Adams MW, Clifford PE. Pod yield component variation and interrelation in *Phaseolus vulgaris* L. as affected by planting density. Crop Sci 1977;17:73-75.
31. Westermann DT, Crothers SE. Plant population effects on the seed yield components of beans. Crop Sci 1977;17:493-496.
32. Akintoye HA, Kintomo AA, Adekunle AA. Yield and fruit quality of watermelon in response to plant population. Int. J Vegetable Sci 2009;15:369-380.