The African Journal of Plant Science and Biotechnology ©2012 Global Science Books

Yield Components and Yield of Haricot Bean (*Phaseolus vulgaris* L.) Under Different Irrigation Frequency and Planting Density Treatments

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ABSTRACT

An experiment was undertaken to determine the yield component and yield of haricot bean (*Phaseolus vulgaris* L.) varieties in the semi-arid region of Dire Dawa, Ethiopia. The experiment was a split plot with three irrigation frequencies as main plots and a combination of three planting densities and two haricot bean varieties as subplots, all of which replicated three times. Irrigation frequencies consisted of 1, 0.67, and 0.5 irrigation water to cumulative pan evaporation (IW/CPE ratio) thereby fixing the depth of IW to 60 mm, planting densities of 15.6, 25, and 35.7 (plants m^{-2}) and two haricot bean varieties, 'Roba-1' and 'Mexican-142' were considered. Different planting densities were employed by changing planting distances within cultivation rows. Plant data on dry biomass/plant, number of branches bearing pods, number of pods/primary branch, number of pods/plant, pod length and width, number of beans/pod, number of beans/plant, 100-bean weight and harvest index at harvest were recorded. Increasing irrigation frequency from 0.5 IW/CPE to 0.67 IW/CPE and to 1 IW/CPE significantly increased all parameters. On the contrary, increasing population densities caused a significant reduction in the parameters. Averaged over planting density and variety, yield/ha and soil water depletion increased significantly with the increase in irrigation frequency. These results showed that irrigation given at 1 IW/CPE can give maximum yield of both haricot bean varieties in the semi-arid condition of Dire Dawa.

Keywords: Haricot bean, irrigation frequency, yield components, planting density

INTRODUCTION

In Ethiopia, haricot bean is grown on an area of about 166 thousand ha and ranks third in area among legumes with an average yield of 800 kg/ha. The average annual production is 132, 888 tons. In 2005, the country exported a total of 60, 000 ton haricot bean (AU 1998; Katungi *et al.* 2009). Major bean-producing regions are central, eastern, and southern parts of the country (Abebe 2009; Katungi *et al.* 2009). In central Ethiopia, farmers raise early maturing white bean crop for export as their cash crop while in the southern part, due to an extended growing period, it is intercropped with maize and/or other cereals in intercropping systems (Amare and Haile 1989; Katungi *et al.* 2009). In view of the prevalence of drought during recent years and a relatively short maturity of beans, the cultivated area under bean increased by more than 76,000 ha between 1990 and 2000. A report of EEPA (2004) indicated that a total of 174,000 tons of haricot beans were produced from 267,776 ha cropped area in 2001/02 which is almost 218 and 190% up from the 1997/98 output. Beans also yielded fairly well in areas where other pulses performed poorly due to incidence of diseases and pests (Katungi *et al.* 2009).

According to Donald (1963) and Samih (2008), as the number of plants/unit increase, competition for growth resources such as nutrients, water and light also increase. Norman (1963) observed that water, nutrients and light are the most commonly deficient factors and when the immediate supply of a single necessary factor falls below the combined demands of plants, competition begins and plants respond accordingly, termed plant plasticity (Bonaparte and Brawn 1974; Sultan 1987; Sultan 2000; Callaway *et al.* 2003). Mutual shading of leaves is considered undesirable. It reduces yield directly by reducing light available for photosynthesis and indirectly by allowing light energy to pass directly to the soil, where it may be dissipated as latent heat removing water from the root zone (Wilson and Teare 1972). These authors also indicated that small plants closed their canopies as readily as larger plants and absorbed about 90% of the incident light energy.

Loss *et al*. (1998) in faba bean and Kessler (1990) in jackbean (*Canavalia ensiformis*) observed that high sowing rates resulted in significantly earlier canopy closure, larger green area indices, more radiation absorption and dry matter accumulation, particularly during the early vegetation stages in treatments where a low plant density was established. They also showed that early canopy closure and greater dry matter production under high sowing rates caused greater suppression of weeds and aphids. In soybean, Parvez *et al*. (1989) and in faba bean, Abdel-Aziz *et al*. (1999) and Mokhtar (2001) indicated that with increasing plant density, there was an increase in plant height, while branching and node development decreased. James and Singh (1985) reported a significant curvilinear increase in yield for bean varieties with increasing planting density and significant increases in nodes/unit area with increasing plant density. However, increase in plant density leading to a significant curvilinear reduction in branches/plant and nodes/branch was observed. Bennet *et al*. (1977) in haricot bean observed only linear reductions in branches/plant and no change in number of nodes on branches as plant density increased from 17 to 63 plants/m^2. A similar finding was reported by Gesch *et al*. (2003) for *Cuphea* who described that plants in wider rows compensated for yield by pro-

Received: 1 October, 2011. Accepted: 22 March, 2012.

Original Research Paper

ducing more branches and seed pods/plant. In addition, the authors indicated that the number of filled capsules/plant was as much as 70% greater for plants in the widest compared to the narrowest row spacing.

Irrigation, defined as the application of water to soil for the purpose of supplying the moisture essential for plant growth, is primarily a means of overcoming water deficit in arid and semi-arid climatic regions and is a form of insurance for humid conditions so that an optimum supply is always available (James 1955; Hansen *et al*. 1979; Verbeten 1998). Irrigation scheduling includes three components: how much to irrigate, when to irrigate and how to irrigate. It was well established that the effect of water stress on growth and yield depends both on the degree of stress and on the stage of growth at which stress occurs (Hsiao and Acevedo 1974: Lewis *et al*. 1974). Wastgate and Peterson (1993) indicated the sensitivity of flowering stage to water deficits in soybeans. On the other hand, the sensitivity of the pod-filling stage to water deficit was reported by Andriani (1991) and Foroud *et al*. (1993) on the same crop. Siniot and Kramer (1977) and Ashley and Ethridge (1978) reported that soybean plants stressed during flower induction and flowering produced few flowers, pods and seeds than control because of a shortened flowering period and abortion of flowers.

However, such valuable information for bean varieties with varying growth habits is lacking in Ethiopia at large and in the Eastern part of the country, in particular. This information is important at this point of time when many agricultural investors in the country are producing beans for export (Simane *et al.* 1998; EARO 1999; EEPA 2004; TLII 2011). In view of the existing knowledge gap, the present study was envisaged with the specific objectives to determine the effects of irrigation frequency and planting density on growth, yield components and yield of determinate and indeterminate haricot bean varieties.

MATERIALS AND METHODS

Study site

This study was conducted in the 2001/2002 dry seasons at the experiment station of the Alemaya Universtity, Tony Farm located in Dire Dawa (41° 51' E longitude, 9° 31' N latitude and at an altitude of 1160 m.a.s.l) on the eastern escarpment of the Rift Valley, Ethiopia. The mean annual rainfall of the region is 500 mm and the mean annual maximum and minimum temperatures are 34 and 18°C, respectively. The soil of the experimental site is predominantly loamy sand to sandy loam of alluvial origin with pH ranging from 7.8 to 8.4.

Experimental design

A split plot experiment based on a randomized complete block design with three replications was used. Main plots (60 m^2) were irrigated with constant 60 mm water in each irrigation treatment. Irrigation intervals determined with IW/CPE ratio, including 1, 0.67 and 0.5 were arranged in main plots and a combination of three planting distances including of 15.6, 25, and 35.7 (plants m^{-2}) and two haricot bean varieties including 'Roba-1' and 'Mexican-142' were employed in subplots. The seeds of the two bean varieties were sown directly in the field on 1 January 2002. Each experimental subplot was arranged by 5 m long and 2 m wide with a total area of 10 m^2. For all the treatments, a uniform inter-row spacing of 40 cm was adopted. The seeds were over sown in each row beyond the treatment levels. After fifteen days, the plant density was thinned to the respective treatment levels on row basis (30, 50 and 70 plants/row). One common irrigation, with a depth of 60 mm, was given immediately after planting to ensure satisfactory seed germination and crop establishment before starting the irrigation treatments. Other cultural practices such as weeding were done when needed. Harvesting of the experiment was done on April 10, 2002.

Data collection

Data on number of branches/plant (NBP), number of branches bearing pods (NBBP), number of pods/plant (NPP), pod length (PL) and width (PW), number of beans/pod (NBPo), dry biomass/ plant (DBP), 100-bean weight (100-BW), harvest index (HI) and yield/ha (YPH) at harvest were recorded.

For soil analysis four undisturbed soil samples, two each from two soil depths 0-30 cm and 30-60 cm were taken with soil core auger for determining permanent wilting point and bulk density, as described by Baruah and Barthakur (1997). Field capacity of the experimental field was determined in the field by the method described by Hansen *et al*. (1979). A composite soil sample was also taken representing 10 surface soil samples for determining pH (hydrogen ion activity) using a 1:1 soil-to-water suspension and a glass electrode pH meter as given by Black (1965); available P with Bray-II extraction method as described by Bray and Kurtz (1945); N using the Kjeldahl digestion and distillation method as out lined by Bremner and Mulvancy (1982), organic carbon as described by Baruah and Barthakur (1997) and particle size distribution (sand, silt and clay) hydrometrically as described by Bouyoucos (1965).

Soil moisture content of the samples at the soil depths 0-30 cm and 30-60 cm was determined by gravimetric method just before sowing and irrigation and fortnightly to determine the soil water depletion from the soil using the equation cited by James *et al*. (1982) for different cycles of irrigations. Then seasonal total soil water depletion (total water used) from sowing to harvesting was calculated by summing the water depletion values of each sampling interval and depth of correction was also made for adding potential evapotranspiration values for increased water loss during first two days immediately following irrigations.

$$d = (\sum (FCi - Mi)\, BDi\, Di)/100$$

where d = soil water depletion; FCi = field capacity of the ith soil layer (% g/g); Mi = moisture content (g/g) of the ith soil layer (% g/g); Di = depth of the ith soil layer (cm); BDi = bulk density of the ith soil layer (Mg/cm^3).

Meteorological data on rainfall, and maximum and minimum temperature, relative humidity were collected from the National Meteorological Service Organization, Dire Dawa station. Daily pan evaporation reading and rainfall were recorded at the experimental site which formed the basis for scheduling the irrigation frequencies.

Statistical procedures

All the measured variables were subjected to analysis of variance (Gomez and Gomez 1984) using MSTATC computer program (Michigan State University, Crop and Soil Science Department (1991). Least Significant Difference (LSD) was used to separate the means and correlation tests were used wherever necessary for the interpretation of data at $P < 0.05$ and 0.01.

RESULTS AND DISCUSSION

Soil properties of the study area

A composite soil sample representing ten surface soil samples from the experimental field before planting was taken and analyzed for some of the soil properties in soil laboratory of the Department of Plant Sciences, Alemeya University and the results are depicted in **Table 1**. Accordingly, the soil sample recorded basic soil reaction with a pH of 8.57 as measured in 1:1 soil water suspension. The available phosphorus and nitrogen content of the sample was 0.67 ppm and 0.18%, respectively. Organic matter of the experimental area was 2.11%.

Number of branches/plant

NBP was significantly ($P < 0.05$) affected only by the main effect of varieties (**Tables 2, 3**). The determinate variety 'Roba-1' produced less NBP as compared to indeterminate

Table 1 Some soil properties of the experimental site.

Soil physical properties										Soil chemical properties			
Particle size (%)				BD (Mg/m^3)		FC (% g/g)		PWP (% g/g)		Av. P	Av. N	pH	OM
Clay	Silt	Sand	Textural class	0-30 cm	30-60 cm	0-30 cm	30-60 cm	0-30 cm	30-60cm	(ppm)	(%)		(%)
12	14	74	Sandy loam	1.37	1.45	25.3	23.43	11.5	10.0	0.67	2.18	8.57	2.11

Table 2 Analysis of Variance for yield component and yield of haricot bean.

Source	df	Agronomic Parameters										
		BP	BBP	PPB	PP	PL	PW	SP	DB	100-SW	HI	Y/ha
Replication	2	0.23	2.01	1.11	13.72	1.89	0.003	2.095	7.4	1.1	0.001	4123.4
Irrigation	2	0.64	0.53	0.99	59.20**	5.59*	0.033	5.918*	215.1*	6.2	0.015	800611.5**
Error	4	0.13	0.59	0.54	2.50	1.72	0.015	0.451	365.2	3.9	00012	6981.2
Planting density	2	0.65	3.32*	1.19	16.57	0.53	0.029*	0.752	9.7	17.1**	0.022*	43981.9**
Irrigation X Population	4	0.27	1.56	0.19	16.23	3.22	0.011	0.414	102.6	0.6	0.010	9425.5*
Variety	1	3.23*	1.16	0.83	54.40	44.68**	0.255**	3.571**	342.1**	0.2	0.028*	209066.7**
Irrigation X Variety	2	0.57	0.01	0.68	0.92	0.24	0.008	0.212	103.2	3.5	0.008	20928.2**
Planting density X Variety	2	0.14	1.14	0.72	23.56	0.35	0.001	0.575	172.0*	0.2	0.002	114983.7**
Irrigation X Planting density X Variety	4	0.66	0.83	0.10	58.18*	0.73	0.018*	0.575	60.1	2.8	0.006	26414.8**
Error	30	0.58	0.66	0.02	16.18	0.35	0.005	0.314	42.6	2.4	0.005	2701.9
CV		14.99	2033	24.33	25.17	8.13	7.83		25.4	8.39	10.58	10.97

df, degree of freedom; BP, branch/plant; BBP, branches bearing pod/plant; PPB, pods/branch; PP, pods/plant; PL, pod length; PW, pod width; SP, seed per pod; DB, dry biomass; BY, bean yield; 100-SW, 100-seed weight; HI, harvest index; **,* significant at 1% and 5% levels respectively.

Table 3 Main effect of variety, planting density and irrigation frequency on crop growth parameters: number of branch/plant (BN), Number of branch-bearing pods (BBP) and number of pods per plant (PN), pod length (PL) in cm, pod width (PW) in cm and number of seeds/pod (SP) of haricot bean.

Treatment	BN	BBP	PN	PL	PW	SP
Variety						
'Roba-1'	4.8	4.1	60.4	8.18	0.98	4.33
'Mexican-142'	5.4	3.9	64.2	6.36	0.85	3.81
$LSD_{0.01}$	0.54	Ns	Ns	0.04	0.04	0.42
Planting density						
15.6	5.3	3.9	65.5	7.41	0.95	4.30
25	5.0	4.5	67.0	7.22	0.93	3.97
35.7	5.0	3.6	59	7.18	0.87	3.93
$LSD_{0.05}$	Ns	0.6	Ns	Ns	0.05	Ns
Irrigation Frequency						
1 IW/ CPE	4.9	4.1	73.1	7.79	0.91	4.57
0.67 IW/ CPE	5.3	4.1	64.0	7.34	0.93	4.18
0.5 IW/ CPE	5.1	3.6	50.4	6.68	0.91	3.45
$LSD_{0.05}$	Ns	Ns	12.9	0.40	Ns	0.38
CV%	14.99	20.33	25.2	8.13	7.83	13.77

variety 'Mexican-142'. Mean branch numbers per plant were 4.8 and 5.4 in 'Roba-1' and 'Mexican-142', respectively. In addition, the results also indicated that, neither plant density and irrigation frequency (IF) nor their interactions had significant effect on the NBP (**Table 2**). The irrigation treatment gave inconsistent results. However, the increase in plant density showed a tendency of decrease in NBP (**Table 3**). The reason for this might be increased inter-plant competition with an increase in plant density (Kueneman *et al*. 1978). Enyi (1973), Bennet *et al*. (1977) and Loss *et al*. (1998) had also reported decrease in branches per plant at increased plant density in soybean. In addition, this study corroborated the findings of Chatterjee and Som (1991) on French bean, Naim and Jabereldar (2010) on cowpea and Ghadaksaz *et al*. (2011) on horse bean.

Number of branches bearing pods per plant

Data on NBBP showed that main effect of plant density significantly influenced the trait (**Table 2**). Plant density of 25 plants m^{-2}, which was statistically at par with the plant density of 15.6 plants m^{-2} produced significantly more branches bearing pods/plant than 35.7 plants m^{-2} (**Table 3**). Though not significant, by and large, the trend indicated that 'Roba-1' tended to produce more NBBP than 'Mexican-142'. Also increasing irrigation frequencies tended to increase the extent of this parameter, though non-significantly.

Number of pods/plant

Analysis of variance of NPP revealed the main effect of irrigation frequencies and interaction between irrigation, plant density and variety significantly affected the NPP (**Table 2**). Increasing IF significantly ($P < 0.05$) increased the NPP. The maximum NPP (73.1) was recorded at IF of 1 IW/CPE and minimum (50.4) at IF of 0.5 IW/CPE (**Table 3**). Fisher and Weaver (1974) and Sirait *et al*. (1994) on lima bean and Oljaca *et al*. (2000) on haricot bean noted higher pod number with increased irrigation. Similarly results of Gallegos and Shibata (1989) indicated that NPP was the yield component most adversely affected by the moisture stress treatments in dry bean. As indicated by Singh and Kuhad (2005), differences in pod number observed might be due to reduced flower production under moisture stress conditions, probably arising from reduced irrigation frequencies. Reduced NPP due to moisture stress might have also caused enhanced flower drop as well as pod abortion.

Though there were no statistical differences, a decreasing tendency was observed in NPP with increase in plant density. This result contradicted the findings of Biswas *et al*. (1997) and Kueneman *et al*. (1978) who reported that NPP is significantly reduced with the increase in plant densities of cowpea and dry bean, respectively. Averaged over irrigation frequencies and plant densities, NPP were relatively higher in 'Mexican-142' than 'Roba-1', the difference, however, was not significant. This result is partly in agreement with reports of Nleya *et al*. (2001) who stated that, indeterminate genotypes had more pods per plant than determinate genotypes of pinto bean.

Pod number of Mexican 142 showed no difference between different plant density treatments at 1 IW/CPE irrigation. However, at IF of 0.67 IW/CPE, 25 plants m^{-2} produced significantly lesser pods as compared to 15.6 plants m^{-2} (**Fig. 1**). The pod number at 35.7 plants m^{-2} of this variety was intermediate. At IF of 0.5 IW/0.5 IW/CPE, with increased plant density from 15.6 plants m^{-2} to 35.7 plants m^{-2}, there was a significant decrease in NPP. In case of 'Roba-1' at IF of 1 IW/CPE, increased plant density from 15.6 plants m^{-2} to 25 plants m^{-2} decreased NPP significantly from 88 to 55.9 and a plant density of 35.7 plants m^{-2} resulted in similar NPP (59.07) to that observed in plant density of 25 plants m^{-2}. On the contrary, at IF of 0.67 IW/CPE, increased plant density from 15.6 plants m^{-2} to 25 plants m^{-2} increased NPP significantly from 45.6 to 67.73

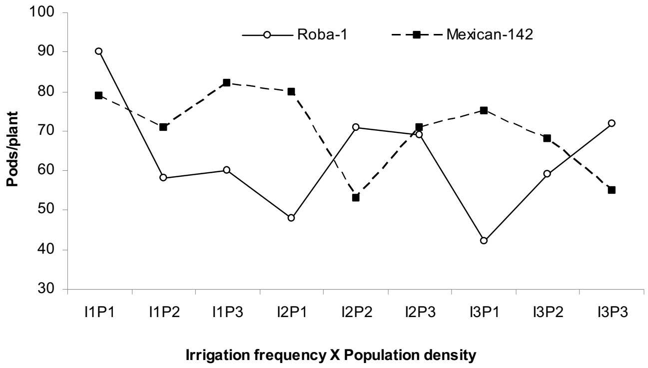

Fig. 1 Effects of irrigation frequency and planting density on number of pods/plant of Roba-1 and Mexican-142.

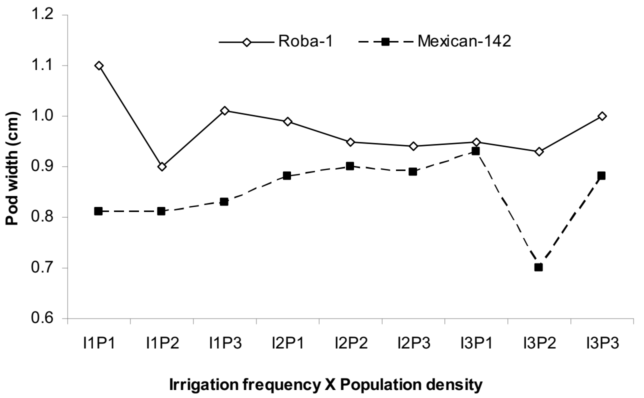

Fig. 2 Effect of irrigation frequency and planting density on pod width of two varieties of haricot bean.

and further increase in plant density did not result in any increase in pod number. Furthermore, at IF of 0.5 IW/0.5 IW/CPE, increasing plant density from 15.6 plants m^{-2} to 35.7 plants m^{-2} led to increase in NPP in 'Roba-1' (**Fig. 1**). The reason for this variation between varieties with respect to the interaction between plant density and IF for pod number could be directly associated with their genotypic variability and plasticity. On contrary to this, the main and interaction effects between irrigation frequencies, plant densities and varieties had no significant ($P < 0.05$) effect on number of pods/branch of the two haricot bean varieties, assuming that number of pod-bearing branches and number of pods/branch has a direct relationship with number of pods/plant.

Pod length and width

Both the varieties varied significantly ($P < 0.01$) with regard to PL and PW (**Table 2**). The variety 'Roba-1' gave significantly larger pods in both length and width as compared to variety 'Mexican-142' (**Table 3**). The increase in PL and PW in 'Roba-1' could be attributed to both increases in number as well as size of seeds/pod. On the other hand, increasing and/or decreasing plant density did not show any significant ($P < 0.05$) effect on PL of the two varieties of haricot bean. However, the trend of the data indicated a decreasing tendency of PL with an increase in plant density. Similar but significant decrease of PL with increased planting density of French bean and faba bean was reported by Moniruzzaman *et al.* (2009) and Turk and Tawaha (2002), respectively. Plant density was also observed to significantly affect PW. The reduced plant density increased PW. A plant density of 15.6 plants m^{-2} and 25 plants m^{-2} produced significantly greater PW than a plant density of 35.7 plants m^{-2}. This finding is in accordance with reports of Moniruzzaman *et al.* (2009), who found that planting density negatively influenced PW of French bean. However, no significant variation was observed between plant densities of 15.6 plants m^{-2} and 25 plants m^{-2} for this parameter (**Table 3**).

IF affected the PL significantly. Irrigating the field at 1 IW/CPE frequency gave the highest PL (7.79 cm) than irrigating the field at 0.67 IW/CPE and 0.5 IW/0.5 IW/CPE frequency (**Table 3**). Although the result is non significant, Jamil *et al.* (2000) and Onder *et al.* (2006) reported that increased irrigation gave high PL for mungbean and common bean, respectively. With regard to PW, interaction effect of variety, plant density and IF was significant (**Table 2**). In 'Roba-1', PW was similar irrespective of plant density at 0.67 IW/CPE and 0.5 IW/0.5 IW/CPE. However, at 1 IW/CPE irrigation, a plant density of 25 plants m^{-2} produced significantly less PW than a plant density of 15.6 plants m^{-2} and 35.7 plants m^{-2} (**Fig. 2**). In contrast, in 'Mexican-142' with increasing planting density at 1 IW/CPE and 0.67 IW/CPE, the PW was similar with a slight increase with increasing planting density. At IF given at 0.5 IW/0.5 IW/CPE, PW of 'Mexican-142' showed a significant decrease with increased plant density from 15.6 plants m^{-2} to 25 plants m^{-2}. However, further increases of plant density to 35.7 plants m^{-2} increased PW (**Fig. 2**).

Number of beans/pod

Variance data (**Table 2**) of NBPo showed that the IF and variety significantly affected NBPo. Increasing IF increased NBPo. The highest NBPo of 4.57 was recorded with IF at 1 IW/CPE followed by 4.18 at 0.67 IW/CPE and 3.45 at 0.5 IW/0.5 IW/ CPE (**Table 3**). A reduction in the number of seed/pod associated with reducing irrigation confirmed the findings of Jamil *et al.* (2000). The determinate variety 'Roba-1' produced significantly higher (4.33) NBPo than indeterminate variety 'Mexican-142' (3.81). This could be attributed to expression of varietal differences in respect of NBPo under reduced irrigation water supply. The increasing plant density decreased the NBPo, though the difference was not significant. Non significant result of number of seed per pod at different planting density of faba bean was also reported by Al-Rifaee *et al.* (2004). Similarly, El-Fieshawy and Fayed (1990) and Dahmardeh *et al.* (2010) reported that seed/pod was not affected by plant density.

Dry biomass/plant

The analysis of variance for DBP (**Table 2**) revealed that the varieties and irrigation frequencies significantly influenced the parameter. 'Mexican-142' produced 94.56 g/plant dry biomass whereas 'Roba-1' produced 92.41 g/plant biomass (**Table 4**). Similarly, Nleya *et al.* (2001) reported that indeterminate bean type produced more biomass than determinate type. Variation between dry biomass under the three planting densities considered was non-significant. This was however in contrast to the reports of Coelho and Pinto (1989) and Al-Rifaee *et al.* (2004) for faba bean and Aminifard *et al.* (2012) for sweet pepper, who observed that at final harvest, the dry matter yield of above-ground parts increased with increasing plant population.

The increased IF enhanced DBP. The significantly highest DBP of 94.78 g was recorded by IF at 1 IW/CPE followed by 93.22 g and 92.44 g in irrigation frequencies at 0.67 IW/CPE and 0.5 IW/0.5 IW/CPE, respectively. An experiment conducted by Korir *et al.* (2006) on common bean showed that biomass production/plant of haricot bean was significantly reduced due to soil moisture stress which substantiated the results of the present study. Similarly, Timsina *et al.* (1993) indicated that total dry matter accumulation of cowpea significantly decreased due to moisture stress. Gallegos and Adams (1991) and Ramirez-Vallejo and Kelly (1998), as sited by Habibi (2011), stated that drought stress can reduce biomass in bean.

Table 4 Main effects of variety, planting density and irrigation frequency on yield/ plant (Y/P) in g, 100-seed weight (100-SW) in g, DBP in g, HI and YPH.

Treatment	DB	100-SW	HI	Y/ha
'Roba-1'	92.41	18.89	0.69	893.2
'Mexican-142'	94.56	18.00	0.64	685.8
$LSD_{0.01}$	0.82	Ns	0.04	24.5
Planting density				
15.6	93.39	19.50	0.70	877.0
25	93.67	18.44	0.66	778.2
35.7	93.39	17.56	0.63	713.3
$LSD_{0.05}$	Ns	1.06	0.05	35.39
Irrigation Frequency				
1 IW/ CPE	94.78	18.44	0.69	1150.7
0.67 IW/ CPE	93.22	19.11	0.67	769.4
0.5 IW/ CPE	92.44	17.94	0.63	448.5
$LSD_{0.01}$	0.74	Ns	Ns	35.39
CV	1.17	8.39	10.58	10.97

NS- non significant difference

100-bean weight

Weight of 100-seeds was significantly ($P < 0.01$) affected by plant densities (**Table 2**). 100-BW of seeds was maximum at a plant density of 15.6 plants m^{-2}, which was statistically at par with the weight at plant density of 25 plants m^{-2}. The lowest 100-BW was at a plant density of 35.7 plants m^{-2} (**Table 4**). Similarly, Naim and Jabereldar (2010) reported an increased 100-BW of cowpea with decreased plant population. Reduced 100-BW observed at higher plant density might have resulted due to decreased PW at highest plant density which indirectly indicates the size and/or the weight of seeds. Another reason might be the decreased inter plant competition at low plant density that leads to increased plant capacity, for utilizing the environmental inputs in building great amount of metabolites to be used in developing new tissues and increasing its yield components as described by Dahmardeh *et al.* (2010). Additionally, Naim and Jabereldar (2010) described the reason for high 100-BW in a low planting space be the better availability of nutrients and better translocation of photosynthates from source to sink and may be due to higher accumulation of photosynthates in the seeds.

The effects of IF and variety treatment on 100-BW were not significant. A contrasting result was reported by Habibi (2011), who reported a reduced percent of 100-BW of white bean to moisture stress reaching 23% compared to the non-stressed condition.

Harvest index

HI is recognized by many plant breeders as an important criterion of search for high yielding genotypes (Johnson and Major 1979). Analysis of variance for HI revealed that the influence of varieties and plant density significantly affected the HI. The HI was reduced with increase in plant density. The maximum HI of 0.7 was obtained at the lowest plant density (15.6 plants m^{-2}). The higher HI with reduced plant density might be due to higher seed yield per plant at lower plant density (**Table 4**). Decreased HI due to higher plant population was reported by Naim and Jabereldar (2010). The determinate variety 'Roba-1' averaged over IF and plant density gave significantly higher HI of 0.69 over indeterminate variety 'Mexican-142' (0.64). The indeterminate growth habit of 'Mexican-142' with the associated intra-plant competition for assimilates leads to a low HI as described by Al-Rifaee *et al.* (2004) and Robertson and Filippetti (1991). This may be attributed to the genotypic differences with regard to efficiency in dry matter partitioning. IF and all interaction effects showed non significant effect on the trait.

Table 5 Yield of 'Roba-1' and 'Mexican-142' as affected by planting density.

Variety	Yield/ha		
	15.6 plants m^{-2}	25 plants m^{-2}	35.7 plants m^{-2}
'Roba-1'	865.2	851.7	962.8
'Mexican-142'	888.7	704.8	463.8
$LSD_{0.05}$	50.04		

Yield/ha

YPH was significantly ($P < 0.01$) affected by both the main effects of variety, plant density and IF as well as their interaction effects. Averaged over both varieties and plant density, increasing IF from 0.5 IW/CPE to 1 IW/CPE increased the YPH significantly from 448.5 to 1150.7 kg/ha (**Table 5**). This decrease in YPH of bean crop at reduced IF might have occurred due to reduced pod number, PL and seeds/ pod (**Table 3**) resulting from reduced water availability to the crop during both vegetative and reproductive stages. Similar results were also reported by Lanka (1991) and Nunez-Barrios (1991). Averaged over irrigation frequencies and variety increase in plant density significantly ($P < 0.01$) decreased YPH of bean crop and the largest bean yield (877.0 kg/ha) was observed due to plant density of 15.6 plants m^{-2} followed by 778.2 kg/ha due to 25 plants m^{-2} and 713.3 kg/ha due to 35.7 plants m^{-2} (**Table 5**). Reduced yield due to large planting space was not corroborated with a number of reports by Dean and Mendham (2003), Dahmardeh *et al.* (2010) on faba bean, Pawar *et al.* (2007) on French bean and Naim and Jabereldar (2010) on cowpea. Averaged over irrigation frequencies and plant densities, 'Roba-1' had a significantly ($P < 0.01$) higher yield than 'Mexican-142'.

The interaction between irrigation frequency, plant density and variety indicated that for 'Roba-1', at IF of 1 IW/CPE, 35.7 plants m^{-2} produced significantly higher YPH than 25 plants m^{-2} and 15.6 plants m^{-2} (**Fig. 3**). On the contrary, at an IF of 0.67 IW/CPE, with increased plant density from 15.6 plants m^{-2} to 35.7 plants m^{-2}, there was a significant decrease in YPH. In the case of IF of 0.5 IW/ CPE, there was no significant difference in yield/ha with an increase in plant density.

In 'Mexican-142', at an IF of 1 IW/CPE, the increase in plant density from 15.6 to 35.7 plants m^{-2} caused a significant decrease in YPH. At an IF of 0.67 IW/CPE, a plant density of 35.7 or 15.6 plants m^{-2} recorded similar yields. However, in this IF, an intermediate plant density of 25 plants m^{-2} gave significantly higher yield than the other two plant densities. The probable reason for reduced YPH of haricot bean at IF of 0.67 IW/CPE to both low and high plant density is the loss of yield advantage of a high population/unit area at the low planting density and extreme competition for resources at the high planting density. At an IF of 0.5 IW/CPE, the YPH was similar at the lowest and intermediate plant density and a further increase in plant density significantly decreased the yield (**Fig. 3**). The non-

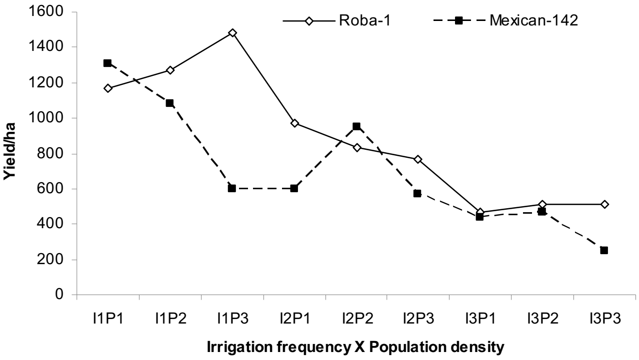

Fig. 3 Interaction effect of irrigation frequency × plant density on yield/ha of haricot bean ($LSD_{0.05}$= 86.68).

Table 6 Effect of irrigation frequency, planting density and variety on soil water depletion (water use).

Treatment	Soil water depletion (cm)		
	0-30 cm (depth)	30-60 cm (depth)	Total
Variety			
'Roba-1'	13.7	12.2	26.0
'Mexican-142'	14.6	13.4	27.9
$LSD_{0.05}$	Ns	0.99	1.60
Planting density			
15.6	14.3	12.5	26.0
25	13.7	12.9	26.9
35.7	14.4	13.0	27.8
$LSD_{0.05}$	Ns	Ns	1.55
Irrigation frequency			
1 IW/ CPE	17.1	16.8	34.2
0.67 IW/CPE	14.3	11.5	25.6
0.5 IW/CPE	11.0	10.1	20.9
$LSD_{0.01}$	1.11	1.2	1.55

Ns, Non significant

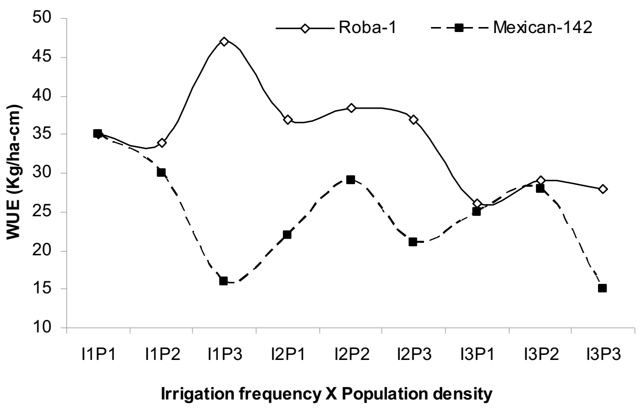

Fig. 4 Effect of irrigation frequency and plant density on water use efficiency (WUE) of haricot bean varieties.

significant difference between the lowest and intermediate plant density of haricot bean at IF of 0.5 IW/CPE, which is the most stressed treatment, was caused by the high competition for a small amount of moisture available, even at the low plant density.

Soil moisture use and water use efficiency

The main effect of IF was one soil water use at both soil depths (0-30 and 30-60). However, the main effect of variety significantly affected water use only for the 30-60 cm soil depth (**Table 6**). The highest IF (1 IW/CPE) depleted most (17.1 cm) water followed by 14.3 cm at intermediate IF (0.67 IW/CPE) and 11.0 cm at lowest IF, at a 0-30 cm soil depth. Similar trends were also obtained for 30-60 cm depth with IF. Increasing plant density significantly increased the total water use. The determinate variety 'Roba-1' depleted significantly less water than indeterminate variety 'Mexican-142' at 30-60 cm soil depth. This could be due to a deeper root system of 'Mexican-142' than 'Roba-1'. In well-drained soil, the depth of rooting is very dependent on the water supply. Hence under high IF, roots might have grown deeper. Generally, the majority of roots are concentrated in a soil depth of 0-30 cm so that water use might have been more from upper strata than the 30-60 cm soil depth. Averaged over varieties, plant densities and irrigation frequencies, soil water use was higher in a soil depth of 0-30 cm than 30-60 cm. This could be associated with the fact that soil water percolated or infiltrated downward by gravity and plants had more roots at the surface layer than at lower surfaces, leading to greater soil water depletion. Water use efficiency (WUE) of 'Roba-1' showed no difference at 1 IW/CPE, when plant density was increased from 15.6 to 25 plants m^{-2}, although a further increase in plant density to 35.7 plants m^{-2} increased WUE significantly. Increasing and/or decreasing plant density had no significant effect on WUE at 0.67 IW/CPE. At 0.5 IW/0.5 IW/CPE IF, WUE was significantly increased with an increase in plant density from 15.6 to 25 plants m^{-2}. However, a further increase in plant density to 35.7 plants m^{-2} had no significant effect. In 'Mexican-142', an opposite trend was observed in that, at IF of 1 IW/CPE, increasing plant density from 15.6 to 25 and then to 35.7 plants m^{-2} caused a significant decrease in WUE. At IF 0.67 IW/CPE, maximum WUE was observed at a plant density of 25 plants m^{-2} and the other two plant densities (15.6 and 35.7 plants m^{-2}) had a similar trend. At 0.5 IW/0.5 IW/CPE, similar results were obtained at plant densities of 15.6 and 25 plants m^{-2}. However, a further increase in plant density to 35.7 plants m^{-2} significantly decreased WUE (**Fig. 4**).

SUMMARY AND CONCLUSION

The current need of modern agricultural science is to strengthen the food security needs of the burgeoning world human population. To meet this requirement, several experiments have been done throughout the world. Development and/or introduction of high yielding varieties and expansion of irrigation network coupled with appropriate management strategies are among these. In view of this, an experiment was conducted at Tony farm, Dire Dawa, experimental field of Alemaya University, during the 2001/2002 dry '*Bega*' season to determine the effect of plant density and IF on yield components and yield of two haricot bean varieties, 'Roba-1' and 'Mexican-142' differing in growth habits. A split plot design with three irrigation frequencies (irrigations at 1 IW/CPE, 0.67 IW/CPE and 0.5 IW/0.5 IW/CPE) to main plot and a combination of three planting densities (15.6 plants m^{-2}, 25 plants m^{-2} and 35.7 plants m^{-2}) and two haricot bean varieties ('Roba-1' and 'Mexican-142') to sub plot were assigned with three replications.

The highest NBBP (4.5) was recorded at 25 plants m^{-2}, but increasing and/or decreasing plant density did not have any significant effect on NBP, and NPP. Highest NPP (73.1) was recorded at 1 IW/CPE IF. Significant interaction effects of NPP between variety, plant density and IF were observed in that with more frequent irrigation, increasing the plant density of 'Roba-1' gave a significantly reduced NPPNPP. Averaged over plant densities and irrigation frequencies, 'Mexican-142' had significantly higher NBP than 'Roba-1'. Varietal differences were also observed with respect to PL, PW and seed yield per plant, where by 'Roba-1' gave significantly higher response for all the three parameters over 'Mexican-142'. Reducing IF resulted in significantly reduced PL. Increasing plant density from 15.6 plants m^{-2} to 35.7 plants m^{-2} resulted in a significant reduction in yields/ha for both the varieties. Due to the probable reduction in water availability at reduced IF, YPH was observed to reduce significantly. Averaged over IF and plant density, the determinate variety 'Roba-1' gave significantly higher yields per hectare than the indeterminate variety 'Mexican-142'. There was also a significant interaction between variety, plant density and IF.

Total soil water depletion was found to be significantly varied due to the variation in plant density, IF and varieties. Increase in both plant density and IF increased the water use of bean crop. The soil water depletion was more in the soil depths between 0 to 30 cm than at 30-60 cm. Averaged over IF and plant density, the indeterminate variety 'Mexican-142' depleted more water at soil depth of 30-60 cm than the determinate variety 'Roba-1'.

Generally the present results confirmed the existence of variation between varieties for yields and related traits with different irrigation frequencies and plant densities. Based on the results of this study, under stressed moisture condition, the determinate variety 'Roba-1', depleted less water and produced better yield than the indeterminate variety 'Mexican-142'. For determinate variety 'Roba-1' maximum yield was obtained at higher plant density (35.7 plants m^{-2}) and at

IF given at 1 IW/CPE. For 'Mexican-142', a plant density of 15.6 plants m^{-2} at IF of 1 IW/CPE gave significantly higher yield than other IF and plant density treatments. However, further similar works have to be done over years and locations in order to confirm the result obtained in this experiment.

ACKNOWLEDGEMENTS

Authors' very special thanks and appreciation goes to Dr. Frew Mekbib and Prof. UR Pal for their support to this work. Help of Ato Zenebe Gebremedihin, Dr. Kebede Kassa, Dr. Fekadu Yohannes, Ato Tadesse, Ato Shimelis Teferi, who extended all the necessary facilities to the authors willfully, is recognizable. The authors thank Dr. Jaime A. Teixeira da Silva for improvements to grammar.

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