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Full Length Research Paper

The effects of the regulated deficit irrigation on yield and some yield components of common bean (*Phaseolus vulgaris* L.) under semi-arid conditions

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During three consecutive years (2002 to 2004), common bean was grown to investigate the effects of the regulated deficit irrigation (RDI) on the yield and yield parameters under semi-arid conditions. Field experiments were conducted on a clay soil. The growing season of common bean was divided into two phases: (1) Vegetative stage (V); from seed germination to the beginning of flowering and (2) reproductive stage (R); from the flowering to the last fruit harvesting. The statistical design was a split-plot with three replications, where the growth stage was the main factor of variation and the irrigation was the secondary factor. The irrigation treatments consisted of all possible combinations of full irrigation (T_1 and T_5 (V_{100} and R_{100}: 100% of irrigation water (IW)/cumulative pan evaporation (CPE)) or limited irrigation (T_2: V_{75}-R_{100}, T_3: V_{50}-R_{100}, T_4: V_{25}-R_{100}, T_6: V_{100}-R_{75}, T_7: V_{100}-R_{50} and T_8: V_{100}-R_{25}) in two phases. Fresh bean yield and pod weight (PWt), pod length (PL), pod width (PWh) and number of seed per pod (NSPP) were measured. Yields of T_2, T_3, T_4, T_6, T_7 and T_8 were determined as 27.0, 35.0, 41.0, 4.0, 12.0 and 21.0% lower than the yields obtained from the control (18.36 and 18.40 t ha^{-1}) treatments, respectively. Results demonstrated that, vegetative stage was the more sensitive than the reproductive stage to the deficit irrigation. The highest irrigation water use efficiency (IWUE) and water use efficiency (WUE) were found in T_6 and T_7 treatments as 2.58 and 2.66 kg m^{-3}, respectively.

Key words: *Phaseolus vulgaris* L., class A pan, drip irrigation, deficit irrigation.

INTRODUCTION

Common bean is being consumed as a source of proteins, calories, fibers and minerals in the developing countries (Ramos et al., 1999; Singh et al., 1999). Also, since it has an ability to bind atmospheric nitrogen, it plays a significant role for the crop rotation and sustain-able cropping systems (Donald and Paulsen, 1997). Common bean is planted on an area of 0.98 million ha and has a production of 6.82 million t as fresh in the world. Turkey is ranked second to China with a produc-tion amount of 0.56 million t and a planted area of 0.07 Million ha (FAO, 2008). Besides benefits of bean to the human diet and environment, its production requires a significant amount of water due to its relatively shallow root system. Thus, the amount of irrigation applied at the developmental (vegetative and reproductive) stages, affect the bean production in that plant growth and yield are often reduced by periods of water stress (Ramos et al., 1999).

Efficient use of water in any irrigation systems is vital especially in arid and semi-arid regions. Drought occurs in many parts of the world in every year; often with devastating effects on crop production (Ludlow and Muchow, 1990; Tonkaz, 2006). As the water supply is limited worldwide, there is a need of water saving in irrigation and thus, deficit irrigation should be applied. Drip irrigation, reduces deep percolation and evaporation

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and controls water status of the soil more precisely within the crop root zone (Singandhupe et al., 2003). One choice for improving irrigation water management is to alter from furrow or sprinkler irrigation to drip irrigation. Several alternative irrigation methods have been used such as surface, drip and sprinkler irrigation systems for the production of common bean. However, recently using the drip irrigation has attracted a significant amount of attention of researchers and farmers instead of using surface and sprinkler irrigations either to increase the efficient use of water or the yield (Hanson and May, 2004). Moreover, drip irrigation reduces deep percolation and evaporation and controls water status of the soil more precisely within the crop root zone (Singandhupe et al., 2003). Numerous studies were carried out in the past for the development and evaluation of irrigation scheduling techniques under a wide range of irrigation systems and management techniques, soil, climate and crop conditions (Kang et al., 2000; Boutraa and Sanders, 2001; Wakrim et al., 2005; Zhang et al., 2006.)

The irrigation scheduling techniques is very critical to use the drip irrigation most efficiently because while excessive amount of irrigation causes a decrease in the yield, inadequate irrigation results in a water stress and a reduction in production (Sezen et al., 2005; Onder et al., 2006). Wakrim et al. (2005) reported that, even though irrigation increases the overall plant growth rate, excess water might bring about the poor grain yields in common bean. Also, this statement was in agreement with several studies which showed that, implementations of limited and excessive irrigation for common bean result in lower yield as they create stress during plant development (Nielsen and Nelson, 1998; Dapaah et al., 1999; Sezen et al., 2005). The deficit irrigation techniques, including regulated deficit irrigation (RDI), have been developed to control excessive vegetative growth or water saving. RDI is widely used in the horticultural industry since it results in the more efficient use of irrigation water and often improves the crop quality (Turner, 2001).

The meteorological-based irrigation scheduling approach, such as implementations of pan evaporation replenishment, cumulative pan evaporation (CPE) and ratio between irrigation water and CPE was employed by many researchers (Saudan et al., 2000; Ferreia and Carr 2002; Simsek et al., 2005). This was due to its simplicity, data availability and high degree of adaptability to the farmer level (Imtiyaz et al., 2000 and Simsek et al., 2005).

The objective of this study was to determine the effects of RDI on the yield and yield components of the fresh common bean in the semi-arid conditions.

MATERIALS AND METHODS

Experimental site and climatic data

This study was conducted on a clay soil at the Agricultural Experimental Research Field of the Harran University during the growth periods of 2002, 2003 and 2004. The site is situated on the 37°08' N and 38°46' E and 464 m above sea level. The soil water contents (w/w; %) of the soil at field capacity were 33.1, 33.2 and 33.7% and at permanent wilting point 21.6, 21.9 and 22.8%, in 0 to 30, 30 to 60 and 60 to 90 cm soil depths, respectively. The corresponding bulk densities were 1.41, 1.45 and 1.44 Mg m^3. The study area was located in a semi-arid climate. The soil water content was measured gravimetrically in each 0.3 m layer down to 0.9 m depth in two replicates per treatment. These measurements repeated with intervals of 12 days were done six times for each year. The lowest level of relative humidity and the highest temperature and solar radiation occur in summer months. The recorded maximum and the minimum temperatures were 32.7 and 11.7°C in August and November. The highest and lowest values of relative humidity were measured as 72.2 and 32.2% for the months of November and September, respectively (Table 1). The highest and the lowest solar radiations were measured as 24.0 and 8.8 MJ m^{-2} day^{-1} in August and November.

Crop evapotranspirations under varying irrigation regimes was calculated using the water balance model (Garrity et al., 1982).

$$ET_c=IW+P–D–R\pm\ S$$

Where, ET_c is the seasonal crop evapotranspiration (mm); IW is the total irrigation water applied (mm); P is the precipitation (mm); D is the drainage (mm); R is the run-off (mm) and S is the variation in water content (mm) of the soil profile. All terms are expressed in mm of water in the bean root zone. The effective root depth was taken as 60 cm. Run-off was taken as to be nil since no run-off was observed in drip irrigation system.

Total amount of irrigation water applied was calculated by using the following equation (Doorenbos and Pruitt, 1975):

$$IW=AxE_{pan}$$

Where, IW is the amount of irrigation water applied (L); A is the plot area (m^2) and E_{pan} is the amount of cumulative evaporation during an irrigation interval (mm).

Crop management and irrigation treatments

The experiments were conducted in the field for consecutive 3 years. Common bean cv. Gina was examined in this study. The seeds were sown in August 05, 11 and 08 in 2002, 2003 and 2004, respectively. Seeds were spaced with 25 cm in a row and 70 cm between rows, as used in traditional by the growers of this region. Each plot was 6 m in length and five rows (21 m^2). The plants were fertilized with 120, 100 and 120 kg ha^{-1} of N, P_2O_5, and K_2O_5, respectively.

The total crop duration was divided into two phenological stages in order to distinguish different plant growing stages and irrigation treatments: Vegetative stage (V); from seed germination to beginning of flowering and reproductive stage (R); from the first flowering to the end of harvesting (Tables 2 and 3). The case study involved four drip irrigation treatments applied, in two growth stages. Full irrigations (T_1 and T_5: V_{100}-R_{100} (IW/CPE ratio 100%)) were applied to the control treatments in the V and R stages, while 25, 50 and 75% limitations, were applied to the other plots and compared to the control. RDI was studied with treatments T_2: V_{75}-R_{100}, T_3: V_{50}-R_{100}, T_4: V_{25}-R_{100}, T_6: V_{100}-R_{75}, T_7: V_{100}-R_{50}, and T_8: V_{100}-R_{25} (Table 2). The CPE values were obtained by the use of class A pan evaporometer located in the experimental site. Three day CPE values were used for irrigation.

The water from water tank was delivered to the field by a submain 32 mm diameter polyethylene (PE), 16 mm diameter laterals with in-line emitters located 0.4 m apart, surface drip laterals

Table 1. Some climatic data during the experiment.

Year/month		T_a(°C)	RH(%)	E_0(mm d^{-1})	R_S(MJ m^{-2} day^{-1})	u_2(m s^{-1})
2002	August	30.5	43.7	12.2	24.0	3.0
	September	26.9	47.8	9.5	19,8	2.4
	October	21.8	48.6	4.7	14,2	2.5
	November	14.4	62.4	3.2	10.6	1.9
2003	August	32.7	32.2	10.9	22.8	2.6
	September	26.4	42.4	9.3	19.7	2.8
	October	21.5	51.5	4.0	13.9	1.7
	November	12.7	62	2.8	9.8	1.5
2004	August	30.8	40.7	11.8	23.5	2.5
	September	27.3	34.8	8.4	19.4	1.9
	October	21.7	48.7	4.3	13.1	1.6
	November	11.7	72.2	3.0	8.8	1.4
Long-run data (1929 to 2004)	August	31.1	32.1	11.9	21.4	2.7
	September	26.6	34.9	9.3	18.2	2.4
	October	20.1	44.5	4.5	13.1	1.8
	November	12.8	59.0	3.0	8.5	1.6

Average of monthly values of air temperature (T_a), relative humidity (RH), evaporation from class "A" pan (ET_0), solar radiation (R_S), and wind speed at 2 m height (u_2).

Table 2. Treatments details of irrigation regime in the different growth stages.

Treatment	Irrigation regime (CPE‡: 100, 75, 50 and 25%)	
	V	R
T_1	V_{100}	R_{100}
T_2	V_{75}	R_{100}
T_3	V_{50}	R_{100}
T_4	V_{25}	R_{100}
T_5	V_{100}	R_{100}
T_6	V_{100}	R_{75}
T_7	V_{100}	R_{50}
T_8	V_{100}	R_{25}

‡CPE: Cumulative pan evaporation.

spaced at 0.7 m intervals, one drip lateral each row and operating at a constant pressure of 152 kPa with 3.0 L h^{-1}. Irrigation water was checked by flow water meter in valves.

The harvest was conducted weekly and yield values were measured for each plot and were calculated for hectare (t ha^{-1}). Pod weight (PWt), pod length (PL) and pod width (PWh) values of the randomly chosen 50 pods and the values of the number of seed per pod (NSPP) were determined for each fruit.

Water use efficiency (WUE) and irrigation water use efficiency (IWUE)

WUE is the ratio between bean yield (t ha^{-1}) and seasonal crop

Table 3. Durations of the two growth stages (in days) of common bean in three years.

Growth stage	2002	2003	2004
V	41	40	42
R	58	58	52
Total duration	99	98	94

evapotranspiration (mm), as can be seen in the equation as follow:

$$WUE = \frac{YA}{ET_C}$$

If the yield Y_a is expressed in kg and the water use ET_c is expressed in m^3 m^{-2}, then WUE has units of kg m^{-3} on a unit water volume basis or g kg^{-1} when expressed on a unit water mass basis (Stanhill, 1986; Howell et al., 1990). IWUE is obtained by using the ratio of the yield per unit IW (mm) (equation).

$$IWUE = \frac{YA}{IW}$$

Experimental design and statistical analysis

The field experiments were set up with split plot design with three replicates, where the growth stage was the main factor of variation and the irrigation was the secondary factor. The data were analyzed using SAS statistical program (SAS Inst 1991). Analysis of variance (ANOVA) test was conducted and significant differences among treatments were determined using the TUKEY method. Square root transformation was performed for number of seed per pod to analysis of variance.

RESULTS

Effect of RDI on applied water and evapotranspiration

Irrigation treatments were initiated when the soil water content at the effective root depth decreased to 50% of the available soil water on August 26 (21 days after sowing; 21 DAS) in the first, on August 31 (20 DAS) in the second and on August 30 (22 DAS) in the third year. The sowing day was considered as 0 day (0 DAS). The final irrigation treatments were applied November 6, 2002, November 11, 2003 and November 6, 2004. A total of nineteen irrigations were applied in the first two years, while eighteen irrigations were applied in the third year. When the mean of the three years were calculated, the duration of the vegetative stage was 41 days while the duration of the reproductive stage was 56 days (Table 3). Total eight harvests were made in all the experimental years.

Table 4 shows the values of fresh bean yield, IW and ET_C. The average values of IW and ET_c were 721, 672, 623, 575, 721, 682, 642 and 603 mm and 742, 696, 651, 602, 747, 669, 607 and 558 mm for T_1, T_2, T_3, T_4, T_5, T_6, T_7 and T_8, respectively. The lowest value was determined for T_8 being applied with 75% water deficit in the reproductive stage. This was followed by the treatments on which 50 and 25% water deficit was applied. These values were higher than the values of IW and ET_c presented in the studies of Onder et al. (2006) and Sezen et al. (2005). This might be resulted from the decrease in the relative humidity, the temperature increase and evaporation ratio increase due to the semi-arid conditions in this study.

Irrigation water use efficiency and water use efficiency

IWUE and WUE values were given in Table 4. The highest IWUE was obtained as 2.58 kg m^{-3} in T_6 whereas the highest WUE was calculated as 2.66 kg m^{-3} in T_7, when the mean of the three years was examined. A direct relation was observed between the depth of the applied water and evapotranspiration. IWUE and WUE values were decreased for RDI treatments in the V stage when the applied and consumed water were decreased. However, no significant differences in IWUE and WUE values were observed for the RDI treatments belonging to the R stage. The lowest mean IWUE and WUE were measured as 1.88 and 1.80 kg m^{-3}, respectively on the T_4. Wakrim et al. (2005) determined the WUE values for common bean between 1.91 and 2.92 kg m^{-3} which was well correlated with our data. In addition, values of IWUE and WUE found by the study of Onder et al. (2006) were in agreement with our data, in that, values varied from 1.56 to 2.61 kg m^{-3} for IWUE and from 1.42 to 2.02 kg m^{-3} for WUE. The values of IWUE and WUE for the V stage were determined lower than the ones obtained for the R stage. The reason was related with the decrease in the yield in T_2, T_3 and T_4 treatments.

Sezen et al. (2005) reported that, the IWUE and WUE for Gina variety cultivated by drip irrigation were between 3.80 and 7.29 and 4.14 and 6.16 kg m^{-3} and the yield was between 12.20 and 20.60 t ha^{-1}, respectively. The higher values of IWUE and WUE had been attributed to the higher relative humidity, caused by decrease in the water consumption.

Yield-RDI relationship

As shown in Table 5, the highest mean yield was observed in control treatment as more than 18 t ha^{-1}. The yields of the T_2, T_3, T_4, T_6, T_7 and T_8 treatments were 27, 35, 41, 4, 12 and 21% lower than the yield obtained from the control treatments, respectively. The lower yield in T_2, T_3, and T_4, when compared with control treatments, can be attributed to the use of deficit of water as well as the high temperature during V stage. The V stage was defined as the period between the beginning of August and the middle of September. The mean temperatures were very high during this period and the relative humidity was very low, whereas the evaporation ratio was too high (Table 1). Nielsen and Nelson (1998) reported that, the water stress lead to the growth of the shortest plants with the least leaf area during the vegetative growth stage of black bean. In this study, thin and short plants and plants with lower number of branches were observed visually in T_2, T_3 and T_4. Water stress during the R stage in T_6, T_7, and T_8 can also lead to a significant decrease in the yield by increasing the number of aborted flowers and pods per plant. Wakrim et al. (2005) showed that, the RDI treatments resulted in the mild stress which affected significantly both plant vegetative and repro-ductive growth. Similar decreases in the yield have already been reported by Singh (1995) in common bean, Karam et al. (2005) in soybean, Cakir (2004) and Payero et al.(2006) in corn and Karam et al. (2007) in sunflower.

Application of adequate water during flowering and pod development is the most significant factor in bean irrigation. Similar responds were observed in this study for the common bean that was cultivated in the semi-arid zone. Similar trend in the yield was seen for the yield components in all irrigation treatments. Water stress combined with high temperature during flowering of the bean brought about a decrease in all yield components.

Table 4. IWUE and WUE for RDI treatments in 2002, 2003 and 2004.

Treatment	Fresh bean yield(t ha^{-1})	[a]IW(mm)	[b]ET_c(mm)	IWUE(kg m^{-3})	WUE(kg m^{-3})
2002					
T_1	18.37	786	797	2,34	2,30
T_2	13.37	734	751	1,82	1,78
T_3	12.17	683	704	1,78	1,73
T_4	10.64	631	625	1,69	1,70
T_5	18.40	786	811	2,34	2,27
T_6	17.64	743	739	2,37	2,39
T_7	16.04	700	664	2,29	2,42
T_8	14.30	656	608	2,18	2,34
2003					
T_1	17.77	690	708	2.58	2.51
T_2	12.84	643	677	2.00	1.90
T_3	11.24	595	622	1.89	1.81
T_4	10.57	548	589	1.93	1.79
T_5	17.94	690	703	2.60	2.55
T_6	17.27	652	623	2.65	2.77
T_7	15.80	613	558	2.58	2.83
T_8	13.90	575	530	2.42	2.62
2004					
T_1	18.94	687	721	2.76	2.63
T_2	13.97	640	660	2.18	2.12
T_3	12.27	593	628	2.07	1.95
T_4	11.24	545	591	2.06	1.90
T_5	18.80	687	728	2.74	2.58
T_6	17.84	651	644	2.74	2.77
T_7	16.64	615	600	2.71	2.77
T_8	15.40	578	536	2.66	2.87
Average					
T_1	18.36	721	742	2.55	2.47
T_2	13.39	672	696	1.99	1.92
T_3	11.89	623	651	1.91	1.83
T_4	10.82	575	602	1.88	1.80
T_5	18.38	721	747	2.55	2.46
T_6	17.58	682	669	2.58	2.63
T_7	16.16	642	607	2.52	2.66
T_8	14.53	603	558	2.41	2.60

[a]IW, Irrigation water; [b]ET_c, evapotranspiration.

Yield components

The effects of year, growth stages and irrigation regimes on considered yield components were significant ($P < 0.001$), whereas no significant differences were found between the year for the NSPP and between irrigation regime for PL (Table 6).

These differences could be attributed to the climate, since it was considerably cold three weeks before the last harvest time in the second year. The temperatures dropped by 10°C, compared with other years. Sudden climate change caused a drop in the yield and yield components in 2003. The values obtained in the first and the third years were similar, whereas the yield for the second year was lower than the values found in other years. The interactions between the growth stage and

Table 5. The effects of regulated deficit irrigation regimes on common bean yield and its components.

Treatment	Year	T1	T2	T3	T4	T5	T6	T7	T8
Fresh bean yield (t ha-1)	2002	18.37±0.66^{a}	13.37±0.20^{de}	12.17±0.30^{ef}	10.64±0.34^{f}	18.40±0.51^{a}	17.64±0.20^{ab}	16.04±0.09^{bc}	14.30±0.21^{cd}
	2003	17.77±0.15^{a}	12.84±0.32^{d}	11.24±0.15^{e}	10.57±0.07^{e}	17.94±0.26^{a}	17.27±0.07^{a}	15.80±0.12^{b}	13.90±0.06^{c}
	2004	18.94±0.28^{a}	13.97±0.20^{d}	12.27±0.45^{e}	11.24±0.09^{e}	18.80±0.29^{a}	17.84±0.20^{ab}	16.64±0.18^{bc}	15.40±0.40^{cd}
	Average	18.36±0.27^{a}	13.39±0.21^{e}	11.89±0.23^{f}	10.81±0.15^{g}	18.38±0.22^{a}	17.58±0.12^{b}	16.16±0.14^{c}	14.53±0.26^{d}
Pod weight (g)	2002	9.83±0.30^{a}	7.97±0.07^{bc}	7.30±0.17^{c}	6.90±0.12^{c}	9.77±0.32^{a}	9.43±0.09^{a}	8.87±0.15^{ab}	8.77±0.24^{ab}
	2003	9.33±0.03^{a}	6.73±0.22^{de}	6.17±0.29^{e}	6.10±0.10^{e}	9.47±0.12^{a}	8.70±0.31^{ab}	8.17±0.13^{bc}	7.33±0.23^{cd}
	2004	10.10±0.20^{a}	8.13±0.49^{bc}	7.40±0.30^{c}	7.17±0.12^{c}	9.93±0.26^{a}	9.70±0.35^{a}	9.20±0.26^{ab}	8.97±0.20^{ab}
	Average	9.74±0.15^{a}	7.61±0.27^{d}	6.96±0.24^{de}	6.72±0.17^{e}	9.72±0.14^{a}	9.27±0.20^{ab}	8.74±0.18b^{c}	8.36±0.28^{c}
Pod length (mm)	2002	115.50±0.98^{a}	86.37±0.20^{de}	83.43±0.59^{e}	77.37±2.09^{f}	115.10±0.73^{a}	105.50±0.98^{b}	98.03±1.18^{c}	88.57±0.68^{d}
	2003	106.80±1.78^{a}	84.70±0.75^{bc}	81.33±1.30^{c}	75.43±2.75^{c}	106.80±1.35^{a}	101.20±2.52^{a}	91.17±2.03^{b}	84.67±2.47^{bc}
	2004	118.60±2.11^{a}	94.57±1.79^{bc}	90.47±0.29^{bc}	85.60±0.61^{c}	117.80±1.68^{a}	105.10±1.04^{ab}	104.30±6.81^{ab}	97.60±1.01^{bc}
	Average	113.63±1.96^{a}	88.54±1.63^{d}	85.08±1.44^{d}	79.47±1.86^{e}	113.23±1.79^{a}	103.90±1.07^{b}	97.84±2.82^{c}	90.28±2.07^{d}
Pod width (mm)	2002	13.03±0.58^{a}	9.80±0.10^{b}	10.07±0.12^{b}	9.97±0.23^{b}	13.47±0.58^{a}	11.47±0.23^{ab}	10.80±0.59^{b}	10.37±0.23^{b}
	2003	11.07±0.69^{a}	9.80±0.15^{ab}	9.030±0.07^{b}	9.30±0.21^{ab}	11.17±0.48^{a}	10.30±0.21^{ab}	9.77±0.52^{ab}	9.63±0.27^{ab}
	2004	14.33±0.38^{a}	10.77±0.39^{cd}	10.27±0.20^{d}	10.07±0.12^{d}	14.20±0.32^{a}	12.70±0.17^{ab}	12.27±0.43^{bc}	10.77±0.60^{cd}
	Average	12.81±0.55^{a}	10.12±0.20^{cd}	9.79±0.20^{d}	9.78±0.15^{d}	12.94±0.51^{a}	11.49±0.36^{b}	10.94±0.44^{bc}	10.26±0.26^{cd}
Number of seed per pod†	2002	2.39±0.013^{a} (5.7)	2.10±0.023^{de} (4.4)	2.05±0.023^{e} (4.1)	2.02±0.030^{e} (4.05)	2.39±0.023^{a} (5.7)	2.31±0.044^{ab} (5.3)	2.27±0.030^{bc} (5.2)	2.18±0.043^{cd} (4.8)
	2003	2.32±0.063^{a} (5.4)	2.08±0.035^{cd} (4.3)	1.99±0.044^{cd} (4.0)	1.95±0.037^{d} (3.8)	2.34±0.045^{a} (5.5)	2.27±0.024^{ab} (5.2)	2.25±0.026^{ab} (5.1)	2.12±0.023^{bc} (4.5)
	2004	2.42±0.027^{a} (5.8)	2.12±0.023^{bc} (4.5)	2.03±0.021^{cd} (4.1)	1.98±0.031^{d} (3.9)	2.42±0.041^{a} (5.9)	2.38±0.007^{a} (5.7)	2.33±0.021^{a} (5.4)	2.18±0.030^{b} (4.8)
	Average	2.37±0.024^{a} (5.6)	2.10±0.015^{c} (4.4)	2.02±0.018^{d} (4.1)	1.98±0.019^{d} (3.9)	2.38±0.022^{a} (5.7)	2.32±0.022^{ab} (5.4)	2.28±0.018^{b} (5.2)	2.16±0.019^{c} (4.7)

Number of seed per pod was subjected to square root transformation. Non transformed data are represented by numbers given in brackets.

Table 6. Analysis of variance for bean yield, pod weight, pod length, pod width and number of seed per pod (mean of 2002, 2003 and 2004).

Source of variation	Degree of freedom	Mean square				
		FY	PWt	PL	PWh	NSPP
Year (Y)	2	5.665***	7.693***	630.712***	22.141***	0.029^{ns}
Y X R	6	0.345*	0.105^{ns}	8.464^{ns}	0.348^{ns}	0.006^{ns}
Growth stage (A)	1	167.445***	28.880***	1673.311***	11.045***	0.525***
Y X A	2	0.043^{ns}	0.024^{ns}	10.125^{ns}	0.755^{ns}	0.002^{ns}
Error	6	0.077	0.106	14.258	0.252	0.006
Irrigation regime (B)	3	107.211***	16.941***	2687.815^{ns}	29.585***	0.305***
Y X B	6	0.085^{ns}	0.206^{ns}	18.782^{ns}	1.484*	0.001^{ns}
A X B	3	18.595***	3.343***	216.972***	1.492*	0.054***
YXAXB	6	0.192^{ns}	0.121^{ns}	10.753^{ns}	0.366^{ns}	0.001^{ns}
Error	36	0.248	0.187	12.875	0.465	0.002
Total	71	8.02	1.622	175.301	2.557	0.026

*Significant at P < 0.05; ***significant at P < 0.001; R: replication; RDI, regulated deficit irrigation; FY, fresh yield; PWt, pod weight; PL, pod length; PWh, pod width; NSPP, number of seed per pod.

RDI were very significant at $P < 0.001$, for FY, PWt, PL and NSPP, at $P < 0.05$ for the PWh (Table 6). Table 5 represents the yield components data of treatments. Positive correlation was obtained between the yield and the values of PWt, PL, PWh and NSPP. Similarly, Lyon et al. (1995) reported that a positive correlation exists between the seed number, seed weight and the yield. The reason of the higher yield for the control treatments was due to mainly increase the vegetative growth parameters. Similar findings have been reported previously by Demirtas et al. (2010) in soybean and Onder et al. (2006) in green bean.

As expected, PWt increase had a significant effect on the yield. In addition, PWt was significantly influenced by irrigation level (Onder et al., 2006). The lowest value of the PWt was found in the T_4 on which 75% water stress was applied in the V stage as 6.72 g, when the pod weight values were examined. The yields were generally found to be decreasing, for the treatments on which RDI was applied on the V stage or R stage, as the PWt was decreased (Table 5). The PWt values of the control were observed to be higher for all the three years since water stress was not applied. RDI regime applied in the V stage caused a significant decrease in PWt, whereas no important deviation was observed in the R stage (Table 5).

When the PL was examined for the RDI regime, the values were decreased with the decreasing of irrigation water. The longest PL (113.63 and 113.23 mm) was observed in the T_1 and T_5, while the lowest PL value was measured as 79.47 mm for T_4.

RDI significantly affected the NSPP and displayed similar effects on both growing stages. When the mean values of the years were only considered, it was determined that the yield increased with increasing the NSPP. The highest and lowest NSPP were determined as 5.70 for T_5 and 3.94 for T_4 (Table 5).

Conclusions

The results of this study showed that, more positive results could be obtained for the RDI regimes in the R stage than the RDI regimes used in the V stage. It is found that bean yield is very sensitive to the water stress. Unless RDI is compulsory, it should not be applied in the V stage because the sensitivity of the plant is considerably high at this stage. However, excessive temperature was a dominant factor in the decreasing of the flowering and fruit set. Therefore, the seeding of the common bean must be done in the first or second weeks of the August. Climatic conditions particularly, cumulative pan evaporation play the most significant role among others. Therefore, irrigation techniques and programs considering climatic parameters have become very significant. The RDI regime with 25% deficit at reproductive stage could be recommended to growers without a significant decrease in the yield in semi arid zone.

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