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Influence of irrigation systems and water treatments on growth, yield, quality and water use efficiency of bean (*Phaseolus vulgaris L.*) plants

A. A., El-Noemani, A. A.A., Aboellil and O.M. Dewedar

Water Relations and Field Irrigation Dept., National Research Centre, Dokki, Giza, Egypt

Abstract: Two Field experiments were carried out during two consecutive seasons (2012 and 2013). The experiments were conducted at Shalakan Experimental Farm of the Faculty of Agriculture, Ain Shams University, Kalubia Governorate (30.13° N, 31.4° E and 14 m above sea level). The experimental site represents the old alluvial soil of the Nile Delta. The aim of this investigation was to study the effect of irrigation treatments (40%, 60%, and 80% of available soil moisture) and drip irrigation systems (surface and subsurface) on growth, yield quality and WUE of bean crop (*Phaseolus vulgaris L.*), Contender and Bronco varieties under the Egyptian conditions.

Results exhibited that increasing irrigation up to 80% of available soil water (A.W) increased significantly vegetative growth (plant height, branches no., leaves area, and pods no. as well as dry matter of stems, leaves, pods, roots and total plant and green pods yields kg/fed. Pod length exhibited its highest significant value when plants were subjected to (80% A.W.). While, irrigation at 60 or 40% of available water (A.W.) showed the lowest values of the growth parameters of bean plants.

Generally, subsurface drip irrigation (SSDI) with 80% of available water (A.W.) increased significantly vegetative growth, yield and pod quality as well as dry matter of stem, leaves, roots, pods and total plant.

It could be concluded that in both bean varieties, the interaction influence was significant on green pods yield kg./ fed and pod thickness, whereas pod weight was not significantly affected by the interaction for the two varieties. A similar trend of the interaction in both varieties was obtained in pod quality indicating that quality parameters showed their highest significant values when bean plants were irrigated by subsurface drip irrigation system (SSDI) at 80 % of available water.

Moreover, the aforementioned characters showed their lowest interaction values parameters when bean plants were irrigated by surface drip irrigation system (SDI) at 40 % of the available water. The effect of interaction on pod weight was not significant for the two varieties as well as pod length for Contender variety.

Keywords: *Phaseolus vulgaris*, irrigation treatments, surface drip irrigation, subsurface drip irrigation, yield and quality, crop coefficient and evapotranspiration.

Introduction

Green bean *(Phaseolus vulgaris L.)* is one of the important vegetable crops grown in Egypt. The cultivated area of green beans in Egypt is 70571 feddan in both old and new lands. The productivity of green beans is 4.33 t/fed. and the total production from the cultivated area is 305560 tons[1]**.** Besides increasing the protein content of the meal, green beans have contributed to improving the protein quantity on diet because beans protein is rich in lysine.

Water is the most important factor limiting horizontal and vertical expansion in the production of different crops. Crop yield and quality are affected by available water in the soil. It is highly desirable to obtain higher yield using the least possible quantity of water. Increasing number of irrigations, levels of field capacity, irrigation amounts, pan evaporation ratios and/ or potential evapotranspiration (ETo) up to the maximum level increased growth parameters; i.e. plant height, number of branches per plant, leaf area, total plant dry matter, number of flowers and fruit setting percentage [2, 3]on peas and [4, 5]on beans.

Vegetable plants grown under the highest levels of water supply gave the highest records of green pods yield and/ or dry seeds yield, while plants grown under the low irrigation levels showed the lowest values in the same regard [3, 6, 7, 8] on peas and [5, 9, 10]on beans.

On the other hand, [2]demonstrated that cowpea yield increased by increasing irrigation level up to 60% of field capacity and then declined by the more high irrigation levels, 75 and 90% of field capacity.

Concerning the influence of irrigation on water use efficiency (WUE), [3,7]on peas, [11]on faba bean and [9]on beans, revealed that WUE in the different vegetable plants was higher under the higher or medium irrigation level while the lower irrigation level gave the lowest values of water use efficiency.

The present investigation aimed to study the effect of changing irrigation water application levels and irrigation systems (surface and subsurface drip irrigation system) on growth characters, yield and its quality and water use efficiency of bean crop.

Materials and Methods

Two field experiments were carried out during two consecutive seasons (2012 and 2013). The experiments were conducted at the Shalakan Experimental Farm of the Faculty of Agriculture, Ain Shams University, Kalubia Governorate (30.13° N, 31.4° E and 14 m above the sea level). The experimental site represents the old alluvial soil of the Nile Delta.

Sowing date was at 1st March in the two experimental seasons. Plants were sown in rows 70 cm apart and hills were spaced 10 cm apart. Thinning was practiced before the first irrigation to secure two plants per hill. Green pods were picked four times, during harvesting stage for the two growing seasons.

Soil samples were taken from different depths of the soil profile to determine the physical and chemical properties of the soil. In addition, samples from irrigation water source were taken for chemical analysis and hydro-physical properties were carried out according to the method described by[12]. Field capacity (F.C.) and permanent wilting point (P.W.P.) were determined according to[13]**.** Data are shown in Tables (1, 2 and 3).

Table (1): Soil physical properties at the experimental site (Shalakan).

Soil depth, cm	Particle size distribution, (%)				Field capacity F.C. (%)	Wilting point W.P. (%)	Available water A.W. (%)	Texture class
	Coarse sand	Fine sand	Silt	Clay				
0-15	0.8	27.8	41.6	29.8	31.46	15.1	16.36	Clay loam
15-30	0.7	27.5	41.2	30.6	31.21	15.24	15.97	Clay loam
30-45	0.6	27.9	38.5	33.0	30.72	15.76	14.96	Clay loam
45-60	0.6	28.7	37.0	33.7	30.78	16.1	14.68	Clay loam

Table (2): Soil chemical properties at the experimental site (Shalakan).

Soil depth (cm)	pH	Electrical conductivity EC (dS/m)	Soluble cations, (meq/L)				Total cations	Soluble anions, (meq/L)				Total anions
			Ca++	Mg++	Na+	K+		CO3--	HCO3-	SO4--	CL-	
0-15	7.7	0.20	0.40	0.48	0.41	0.19	1.48	0	0.63	0.36	0.49	1.48
15-30	7.6	0.20	0.46	0.35	0.51	0.18	1.50	0	0.76	0.23	0.51	1.50
30-45	7.4	0.20	0.57	0.55	0.62	0.20	1.94	0	0.79	0.40	0.75	1.94
45-60	7.2	0.21	0.48	0.66	0.67	0.16	1.97	0	0.86	0.45	0.66	1.97
Average	7.475	0.2025	0.477	0.51	0.552	0.182		0	0.76	0.36	0.6025	

Table (3): Chemical analysis of the irrigation water located at the experimental site (Shalakan).

pH	Electrical conductivity EC (dS/m)	Soluble cations, (meq/L)				Soluble anions, (meq/L)			Sodium absorption ratio (SAR), %
		Ca++	Mg++	Na+	K+	HCO3-	SO4--	CL--	
7.2	0.54	1.63	0.77	2.59	0.31	2.40	0.4	2.50	2.40

Experimental irrigation system

Two drip irrigation systems (surface and subsurface) were constructed and tested before used in the experimental location. Laterals (16 mm diameter, P.E.) and the emitters were built-in with an average discharge 4.0 L/h and 0.3 m emitter spacing. Laterals spacing were 0.70 m. In the subsurface drip irrigation system, lateral drip lines were buried at 20 cm depth under the soil surface.

Water regime treatments.

Water requirements calculated by measuring the amount of irrigation water for beans which was applied by flow meter after the measuring of it using a VIRRIB soil moisture sensor based on the theory of electromagnetic waves at 80, 60 and 40 % of available water in the soil profile.

Treatments:

Field experiments were carried out under the variation of three basic factors which were:

1. Water application rate with three levels (80 %, 60 % and 40 % of available water) were measured by using VIRRIB soil moisture sensors based on the theory of electromagnetic waves.
2. Irrigation systems (surface drip irrigation system and subsurface drip irrigation system).
3. Bean varieties (Contender and Bronco).

Therefore the total experimental area included 12 treatments, and each treatment was replicated three times.

Fertilizer program

Fertilizer requirements of bean crop were applied according to recommendations of Horticulture Research Institute, ARC, Ministry of Agriculture and Land Reclamation. The used doses of fertilizers were 200 kg/ fed. of calcium super phosphate (15.5 % P2O5), 50 kg/ fed. of ammonium sulphate (20.5 % N) and 25 kg/ fed. of potassium sulphate (48 % K2O) and were added during the seed bed preparation. While additional 50 kg/fed. of ammonium sulphate and 25 kg/fed. of potassium sulphate were added at the first irrigation. The other doses from the different fertilizers after sowing were added according to recommendations of Horticulture Research Institute, ARC, Ministry of Agriculture and Land Reclamation.

Experimental design

The applied statistical design of the experiments was split-split plot with three replications. The experimental factors were irrigation systems, water treatments, and bean varieties were assigned in main plots, sub main plots and sub-sub main plots, respectively.

Measurements and calculations

One vegetative sample of 3 plants was taken in the last pod collection for the two growing seasons. The following characters were measured:

a - Growth:

1) Plant height (cm).
2) Number of branches / plant.
3) Number of pods / plant.
4) Area of leaves / plant (cm^2).
5) Dry weight of stem (g).
6) Dry weight of leaves (g).
7) Dry weight of roots (g).
8) Dry weight of pods (g).
9) Total plant dry matter (g).

b- Pod quality characters:

1) Pod length. (mm).
2) Pod thickness. (mm).
3) Pod weight. (g).

c- Total green pods yield: yields of the different collections were summed together to estimate the total green pods yield.

d- Water use efficiency:

Water use efficiency is an indicator of effectiveness use of irrigation unit for increasing crop yield. Water use efficiencies of green pods and dry seed yields were calculated from the following equations:

WUE of green pod yield = Total green pod yield (kg/fed.)/Total applied irrigation water (m^3/fed.)

Statistical analysis:

The obtained data of the two seasons were summed together to obtain the average values which were subjected to the proper statistical analysis according to the method prescribed by[14]**.** Means were verified according to the[15]**.** To obtain overall means

Results and Discussion

1. Vegetative growth

a. Effect of irrigation systems

The effect of irrigation systems, i.e. subsurface drip irrigation (SSDI) and surface drip irrigation (SDI) on vegetative growth of bean (*Phaseolus vulgaris* L.) varieties, i.e. Contender and Bronco are exhibited in Tables (4 and 5). Data showed that in both varieties; leaves area/ plant as well as dry matter of roots were significantly affected by changing irrigation systems.

Moreover, the other studied growth criteria exhibited a different significant response to irrigation systems which varied also from one variety to another. It is worthy to mention that the significantly tallest bean plants and highest values of leaves area/plant and pods no./plant as well as dry weight of stems roots and pods were detected when SSDI were installed for Contender variety. Moreover, the same mentioned obtained trend in Contender was also detected in branches no. / plant and leaves area/ plant as well as dry matter of roots and total plant where the highest significant values were expressed by SSDI in Bronco.

b. Effect of water treatments

Data in Tables (4, 5) indicated the effect of water application rates of 80%, 60% and 40% of the available water (A.W.) on vegetative growth of bean (*Phaseolus vulgaris* L.) plants, i.e. Contender and Bronco varieties. It is clear from these tables that a quite similar trend was obtained for both varieties regarding the effect of irrigation level on the studied growth parameters.

For both varieties, leaves area, and pods no. / plants as well as dry matter of stems, pods and total plant were significantly increased by increasing water application level up to 80% of the available water (A.W.). Moreover, the lowest values in the aforementioned characters were exhibited when plants were exposed to water stress (40% of the available water). Also, plant height, branches no. /plant and dry weight of roots showed the same trend in Bronco variety, however in Contender these characters were not significantly affected by water regimes. On the other hand, data indicated generally that, the medium level of water supply at 60% of the available water (A.W.) ranked second with small differences between its characters values and those obtained by the first water treatment (80% of the available water) whereas the low level of irrigation at 40% ranked third concerning their effect on the studied growth parameters. Our results regarding plant height are in accordance with those obtained by[2,3,16] on peas and [4,5]on beans, who stated that, plant height was strongly influenced by increasing number of irrigations, levels of fields capacity, irrigation amounts, pan evaporation ratios and/ or ETo up to the maximum level.

Results could be explained as a result of enhancing cell division and enlargement which need more water supplies [17]**.**

The results previously mentioned concerning number of branches per plant are in harmony with those obtained by [3]on peas and [5]on beans, who found that number of branches per plant in peas and/ or beans was significantly increased by increasing irrigation amounts, levels of field capacity, and/ or ETo up to the maximum level.

Table (4): Effect of irrigation systems water treatments and their interaction on growth parameters of bean Contender variety plants.

Irrigation Systems9	Available water treatments %r)	Plant height (cm)	Branches No./ plant	Leaves area (cm2)/ plant	Pods No./ plant	Dry weight (g)/ plant				
						Stems	Leaves	Roots	Pods	Total plant
Subsurface drip (SSD)	80	51.7 a	8.27	2949 a	12.1 a	6.1 a	5.3 a	1.7 a	6.0 a	20.0 a
	60	48.5 a	8.07	2808 ab	11.7 a	6.0 a	6.0 ab	1.5 ab	5.5 ab	19.0 ab
	40	46.6 ab	7.53	2534 cd	10.4 ab	5.2 bc	5.3 bc	1.2 ab	5.0 bc	16.8 cd
Mean		49.0 a	7.96	2764 a	11.4 a	5.8 a	5.9	1.5 a	5.5 a	18.6
Surface drip (SD)	80	41.3 bc	7.13	2647 bc	9.7 bc	5.5 ab	5.2 a	1.2 ab	5.0 bc	18.0 bc
	60	39.3 c	6.80	2363 d	8.4 cd	5.0 bc	5.9 ab	1.1 b	4.7 bc	16.7 cd
	40	38.0 c	6.40	20 e	7.7 d	4.7 c	5.0 c	1.1 b	4.3 c	15.2 d
Mean		39.6 b	6.78	2318 b	8.6 b	5.1 b	5.7	1.1 b	4.7 b	16.6
Mean values for water treatments	80	46.5	7.7	2798 a	10.9 a	5.8 a	6.3 a	1.4	5.5 a	19.0 a
	60	4.91	7.4	2585 b	10.1 ab	5.5 a	6.0 a	1.3	5.1 ab	17.9 a
	40	42.3	7.0	2239 c	9.0 b	3.3 b	5.2 b	1.5	4.7 b	16.0 b
L.S.D. at 5% level	IS	4.8	NS	54	1.2	0.47	NS	0.2	0.6	NS
	W	NS	NS	148.3	1.32	0.47	0.85	NS	0.63	1.35
	IS X W	6.05	NS	209.70	1.87	0.67	0.83	0.52	0.89	1.91

IS = Irrigation systems, W = water treatments

Table (5): Effect of irrigation system water treatments and their interaction on growth parameters of bean Bronco variety plants.

Irrigation System	Available water treatments %	Plant height (cm)	Branches No./ plant	Leaves area/ plant (cm^2)	Pods No./ plant	Dry weight (g)/ plant				
						Stems	Leaves	Roots	Pods	Total plant
Subsurface drip (SSD)	80	51.7 a	8.27 a	2533 a	9.7 a	42.7 a	5.5	1.2 a	5.3 a	18.0 a
	60	48.5 ab	8.07 ab	2466 ab	8.8 ab	40.3 ab	5.5	1.1 ab	4.4 abc	16.8 b
	40	46.6 bc	7.53 bc	2186 c	7.4 bc	38.3 c	5.1	1.0 bc	4.2 bc	14.2 c
Mean		40.4	7.77 a	2395 a	8.6	5.0	5.4	1.1 a	4.6	16.1 a
Surface drip (SD)	80	41.3 ab	7.13 c	3225 bc	8.2 ab	41.0 ab	5.4	1.1 abc	5.1 abc	16.7 ab
	60	39.3 bc	6.80 c	2170 c	7.5 bc	39.3 b	5.3	1.0 bc	4.4 abc	15.5 b
	40	38.0 c	6.40 d	1927 d	6.2 c	36.3 c	4.9	0.9 c	3.7 c	13.4 c
Mean		38.9	6.69 b	2141 b	7.3	4.6	5.2	1.0 b	4.4	15.2 b
Mean values for water treatments	80	41.9 a	7.55 a	2429 a	8.9 a	5.5 a	5.5	1.1 a	5.2 a	17.3 a
	60	39.9 b	7.43 a	2318 b	8.2 a	5.1 a	5.4	1.1 ab	4.4 b	15.9 b
	40	37.3 c	6.70 b	2057 c	6.8 b	3.9 b	5.0	1.0 b	3.9 b	13.8 c
L.S.D. at 5% level	IS	NS	0.94	114.5	NS	NS	NS	0.06	NS	0.4
	W	1.89	0.46	110.9	1.11	0.62	NS	0.1	0.69	0.44
	IS X W	2.68	0.65	156.90	1.57	0.88	NS	0.14	0.79	1.33

IS = Irrigation systems, W = water treatments

Also, our findings concerning leaf area are in agreement with [2,3]on peas and [5]on beans who indicated that, increasing irrigation levels up to the maximum level gave the highest values of leaf area. [2]exhibited that, the reduction in number of branches owing to the low soil moisture level may be due to the reduction in the uptake of nutritional elements that caused deterrence in the physiological processes needed for plant growth.

Our findings concerning leaf area are in line with those of [2,3]on peas and [5]on beans who indicated that, increasing irrigation levels up to the maximum level gave the highest values of leaf area.

The effect of high or low level of irrigation on total plant dry matter which was detected in the present investigation is in accordance with the results of [2,3]on peas and [5]on beans who found that, higher levels of irrigation increased dry matter production markedly than under lower levels of irrigation.

The increase in dry matter of plants grown in high levels of soil moisture could be attributed mainly to the effect of water on some quantitative and qualitative changes in certain metabolic processes in the plant cell[3]**.**

Generally, it could be suggested that, increasing applied irrigation water to bean plants led to keeping higher moisture content in the soil and this in turn favored the production of dry matter content of different plant parts. This indicated the importance of water supply for increasing plant growth. On the contrary, shortening plant height and reduction in leaves area and lower dry matter under soil moisture stress may be explained that water stress caused stomatal closure and reduced minerals uptake by plants and hence affected plant growth.

c. Effect of interaction between the experimental factors

Effect of interaction between irrigation systems and irrigation regimes on vegetative growth criteria of the two bean varieties is exhibited in Tables (4, 5). Significant differences due to interaction were attained in; plant height, leaves area/ plant, pods no./plant, dry matter of stems, roots, pods and total plant for both bean varieties, the dry matter of leaves in Contender variety as well as branches no./ plant in Bronco variety, except dry matter of leaves and branches no./ plant in Bronco and Contender, respectively were not significantly affected by the interaction.

Data in Table (4) demonstrated that for Contender variety, it is worthy to mention that the highest significant interaction values of plant height, leaves area/ plant, pods no. /plant and dry matter of stems, leaves, roots, pods and total plant were attained when bean plants were irrigated by subsurface drip irrigation (SSDI) at 80% of the available water (A.W). However, the lowest significant values in the same regard were exhibited by the interaction of surface drip irrigation (SDI) and 40% of the available water (A.W). Results of the interaction for Bronco (Table 4) showed somewhat similar trend concerning the interaction influence on all of the studied growth parameters (except dry matter of leaves) which exhibited their highest significant values when bean plants were irrigated by subsurface drip irrigation (SSDI) at 80% of the available water (A.W.). The lowest significant values of the same parameters were detected also by the interaction between surface drip irrigation (SDI) and 40% of the available water (A.W). Whereas branches no. /plant and dry weight of leaves in Contender and Bronco varieties, respectively was not affected significantly by interaction.

2. Productivity and pod quality criteria

a. Effect of irrigation systems

Green pods yield/ fed of bean plants in the two irrigation systems, i.e. subsurface drip irrigation (SSDI) and surface drip irrigation (SDI) are exhibited in Tables (6, 7). Data showed that all studied parameters were not significantly influenced by different irrigation systems in both bean varieties. It is noteworthy to mention that the trend regarding the effect of irrigation systems on the different pod yield and quality parameters was similar for the two varieties. Generally, for both varieties the highest values of green pods yield/ fed., pod length, pod thickness and pod weight were attained at subsurface drip irrigation in yield and pod thickness in both varieties as well as pod length in Bronco variety. (SSDI), whereas the lowest values in the same regard were exhibited at surface drip irrigation (SDI).

It is important to conclude that subsurface drip irrigation (SSDI) increased the green pods yield Kg. / fed. by 16.49% and 4.77 % for Contender and Bronco varieties, respectively when compared with surface drip irrigation (SDI).

Table (6): Effect of irrigation systems water treatments and their interaction on yield and quality characters of bean Contender variety plants.

Irrigation Systems	Available water treatments %	Pods yield, (kg/ fed.)	Pod length (cm)	Pod thickness (mm)	Pod weight (g)	WUE (kg/ m^3)
Subsurface drip (SSD)	80	4638 a	13.0	8.9 a	4.51	5.05 a
	60	4491 ab	13.0	8.6 ab	4.43	5.12 a
	40	4070 bc	13.0	8.2 bc	3.96	4.45 b
Mean		4605	13. 1	8.6	4.30	4.87 a
Surface drip (SD)	80	4570 a	13.0	8.1 bc	4.10	4.98 a
	60	3948 c	13.0	8.2 bc	4.06	4.12 b
	40	3341 d	13.0	7.8 c	3.74	3.22 c
Mean		3953	13.0	8.0	3.97	4.11 b
Mean values for water treatments	80	4604 a	13.2	8.5 a	4.31	5.01 a
	60	4219 b	13.2	8.4 ab	4.25	4.62 b
	40	3705 c	12.7	8.0 b	3.85	3.84 c
L.S.D. at 5% level	IS	NS	NS	NS	NS	0.46
	W	335.7	NS	0.44	NS	0.36
	IS X W	474.80	NS	0.63	NS	0.52

IS = Irrigation systems, W = water treatments

Table (7): Effect of irrigation system water treatments and their interaction on yield and quality characters of bean Bronco variety plants.

Irrigation Systems	Available water treatments %	Pods yield, (kg/ fed.)	Pod length (cm)	Pod thickness (mm)	Pod weight (g)	WUE (kg/ m^3)
Subsurface drip (SSD)	80	4153 a	13 a	7.6 a	4.24	4.52 a
	60	3981 ab	13 ab	7.1 b	4.11	4.15 b
	40	3518 bc	12 ab	6.7 bc	3.81	3.84 b
Mean		3884	12.7	7.2	4.05	4.17 a
Surface drip (SD)	80	4061 ab	13 ab	7.2 b	4.01	4.42 b
	60	3817 ab	13 ab	6.5 c	3.85	3.67 b
	40	3242 c	12 b	6.0 d	3.66	2.80 c
Mean		3707	12.5	6.6	3.84	3.63 b
Mean values for water treatments	80	4107 a	13.0 a	7.4 a	4.13	4.47 a
	60	3899 a	12.7 ab	6.8 b	3.98	3.91 b
	40	3379 b	12.1 b	6.4 c	6.37	3.32 c
L.S.D. at 5% level	IS	NS	NS	NS	NS	0.46
	W	380	0.65	0.32	NS	0.37
	IS X W	537.40	1.0	0.46	NS	0.51

IS = Irrigation systems, W = water treatments

b. Effect of water treatments

Data shown in Tables (6, 7) contain the effect of water application levels at 80%, 60% and 40% of the available water (A.W.) on productivity and pod quality criteria for both bean varieties.

It is clear from the tables that there are significant differences due to variation of available water (A.W.) in yield and pod thickness in both varieties as well as pod length in Bronco variety. However, pod weight in both varieties did not show any significant response to all available water treatments.

In the two varieties, it is obvious from data that the highest values of yield (green pods) was achieved by irrigating bean plants at 80% of the available water (A.W.). Moreover, irrigation at 60% of the available water (A.W.) led to obtaining significantly medium values whereas, 40% of the available water (A.W.) showed the lowest significant values in the same concern. For Contender and Bronco varieties, increases in green pods were 24.3% and 21.5%, respectively for 80% of the available water (A.W.) comparing with 40%. Also, pod thickness showed the same trend where it exhibited its highest significant values when plants were subjected to water irrigation (80% of the available water). Moreover, irrigation at 80% of the available water (A.W.) had the same effect and showed the highest pod length value for Bronco variety but it was not significant for Contender variety. The results reported here in this investigation concerning green pods coincided with those previously obtained by [3,6,7,8]on peas and [5,9,10]on beans**,** who noticed that plants grown under the highest levels of water supply gave the highest records of green pods yield, while plants grown under the low irrigation levels showed the lowest values in the same regard.

The increment in total yield of green pods and dry seeds yield could mainly be explained as a result of increasing number of pods/plant. Besides, the sufficient supply of water may activate metabolic processes within plants, especially those which affect productivity[3]**.**

On the other hand, [2]demonstrated that cowpea yield increased by increasing irrigation level up to 60% of field capacity and then declined by the more high irrigation levels, 75 and 90% of field capacity.

c. Effect of interaction between the experimental factors

Effect of interaction between irrigation system and irrigation regimes on productivity and pod quality criteria of bean plants is exhibited in Tables (6, 7). It could be concluded that in both bean varieties, the interaction influence was significant on green pods yield kg./ fed and pod thickness, whereas pod weight was not significantly affected by the interaction for the two varieties. A similar trend of the interaction in both varieties was obtained in pod quality indicating that quality parameters showed their highest significant values when bean plants were irrigated by subsurface drip irrigation system (SSDI) at 80 % of available water.

Moreover, the aforementioned characters showed their lowest interaction values parameters when bean plants were irrigated by surface drip irrigation system (SDI) at 40 % of the available water. The effect of interaction on pod weight was not significant for the two varieties as well as pod length for Contender variety.

Generally, it was observed that the increment of water regimes increased the pods yield under the two studied irrigation systems, for the two bean varieties. For pod yield kg. / fed., it was observed that the response of Contender variety under the effect of 80 % of the available water treatment was higher than that gained by Bronco variety.

3. Effect of the experimental treatments on WUE

It is worthy to mention that in the two seasons of experimentation, WUE for green pods yield (kg/m^3) exhibited the highest significant values when bean plants were irrigated at 80 % of the available water, followed by 60 % which ranked second, and 40 % which ranked third in both bean varieties (Table 6, 7). Subsurface drip irrigation system (SSDI) was more efficient in using irrigation water in comparison with surface drip irrigation system (SDI) which showed the lowest significant values in the same regard. Regarding the interaction effect, an obvious trend was obtained indicating that the highest significant WUE values were detected when bean plants were irrigating by subsurface drip irrigation system (SSDI) at 80 % of available water. On the other hand, the lowest significant WUE values were detected when bean plants were irrigating by surface drip irrigation system (SDI) at 40 % of available water.

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