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Effects of deficit irrigation on yield and quality of unheated greenhouse grown green bean

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Abstract
This study was conducted to determine effect of deficit irrigation on yield for green bean grown under unheated greenhouse condition. The research was carried out at the Agricultural Research Station of Yenişehir High School of Uludag University in Bursa, Turkey, in 2007. In the study, water was applied to green bean as 100, 75, 50, 25 and 0% (as control) of evaporation from a Class A Pan corresponding to 2-day irrigation frequency. Irrigation water applied to crops ranged between 40 and 579 mm, and water consumption ranged between 47 and 582 mm. Irrigation treatments significantly affected fresh bean yield, length and width of green bean, number of seeds per pod, 100 bean weight and dry pod weights percent. The highest yields were 18.88 and 11.64 t ha^{-1} for the $K1_{cp}$ and $K2_{cp}$ treatments, respectively. The lowest yield was found from $K1_{cp}$ as 3.26 t ha^{-1}. Crop yield response factor (k_y) was 1.066. The highest values for water use efficiency (WUE) and irrigation water use efficiency (IWUE) were 32.44 and 26.98 and 27.74 and 21.29 kg mm^{-1} for the $K1_{cp}$ and $K3_{cp}$ treatments, respectively. Under the conditions that water resources are scarce, it can be recommended that $K3_{cp}$ treatment is most suitable as a water application level for green bean irrigation by drip irrigation under unheated greenhouse condition.

Key words: Green bean**,** deficit irrigation, irrigation water use efficiency, yield.

Introduction

Greenhouse farming, also known as protected cultivation, is one of the farming systems widely used to provide and maintain a controlled environment suitable for optimum crop production leading to maximum profits. This includes creating an environment suitable for working efficiency as well as for better crop growth [1]. Greenhouse cultivation is a steadily growing agricultural sector all over the world [2, 3]. Greenhouse vegetable production is expanding in many world regions [2] and in particular throughout Mediterranean coastal areas [4]. The Mediterranean greenhouse vegetable system is mostly based on simple low technology plastic greenhouses located in mild winter areas, which enables the production of high-value vegetables from autumn to spring [5]. The type of structure primarily used in Turkey is the so-called Mediterranean greenhouse; low-cost, unheated plastic-covered structures and with soil-grown crops.

Since the market values of early varieties are high, some vegetables are initiated to be grown in tunnels in limited extend recently. Green bean is the one of these crops. Water management in green beans is extremely important at all stages of plant development due to its influence on stand establishment, fungal problems and pod set and quality. For this reason, the crop must be supplied with adequate water to ensure vigorous growth. Irrigation is important for its plant and pod growth [6]. At present, owing to the global expansion of irrigated areas and the limited availability of irrigation water, there is a need to optimize WUE in order to maximize crop yields under frequently occurring situations of deficit irrigation. When water deficit occurs during a specific crop development period, the yield response can vary depending on crop sensitivity at that growth stage. Therefore, timing the water deficit appropriately is a tool for scheduling irrigation where a limited supply of water is available [7]. Therefore, innovations are needed to increase the efficiency of use of the available water. There are several possible approaches. Irrigation technologies and irrigation scheduling may be adapted for more effective and rational uses of limited supplies of water. Drip irrigation method is one of the preferable to less efficient traditional surface methods[8]. For irrigation scheduling methods based on pan evaporation are widely used because of their easy applications [9]. With available pan coefficient in hand, pan evaporation (Class A Pan) can be used in the arrangement of irrigation programs. Bharat compared different pan coefficients and suggested a pan coefficient of 0.80 for optimal yield in Fort Valley, USA [10].

The objectives of this study are to: (i) determine the effect of water stress occurring during the growing season on yield and quality of green bean irrigated by a trickle system in greenhouse condition and (ii) evaluate the water use efficiency of green bean.

Materials and Methods

Field experiments were carried out under unheated greenhouse condition in Yenişehir-Bursa (40°15'09"N latitude, 29°38'43"E longitude and altitude of 225 m above mean sea level). A high tunnel with the size of 8 m x 40 m using plastic coverage placed in north-south direction was used for the experiment. Summers are hot and dry; winters are cold and rainy in the region. Annual mean rainfall and temperature are 482.9 mm and 13.6°C, respectively. Average minimum temperature is 3.6°C in December; maximum temperature is 23.3°C in August [11]. The soil of the experimental plot can be classified as sandy loam and the soil pH was 7.99-8.04. Some physical and chemical soil properties are given in Table 1.

The experiment areas were sprayed with Mankozeb and Endosulfan for control diseases, and 125 kg ha^{-1} 21% N, and 110 kg ha^{-1} 46% P_2O_5 was applied as granular fertilizer two weeks prior to sowing. A further 125 kg ha^{-1} 46% K_2O was added when the plants were 15 cm in height.

Yield quality parameters such as fresh bean length and width, number of seeds in each pod and 100 green bean weights were determined in each harvest period. The 100 green beans were randomly selected from the yield harvested from each subplot. Fresh bean pod width and length were measured by caliper rule and calculated as the average of measured values. Following the measurements of number of seeds in each pod and 100 green bean weights, samples were seperated into 1 cm parts and dried. The dry matter amount was found after oven-drying process at 75°C in 48 hours.

Irrigation water (3 L s^{-1}) was supplied from a deep well drilled in the area. Quality properties of irrigation water are given in Table 2. The water is placed in C_2S_1 class with low sodium risk, medium EC value. Since there is no recorded problem with water quality, it is well suited for irrigation.

Experimental field was planted by hand at 5 cm soil depth at 50 cm row spacing and 50 cm spacing in each row. Each plot contained 75 plants Hanzade green bean variety (*P. vulgaris* L.) planted on April 1, 2007. Yield was determined by hand harvesting the 2.5 m sections of the three adjacent center rows in each plot. Growth stage and harvest days are given Table 3.

The layout of the experiment was a completely randomized block design with three replications for each of the five irrigation treatments tested. However, replications have been distributed to the random blocks in such a way that following same range in three blocks not to disturb the existing irrigation system. Irrigation treatments consist of five different plant-pan coefficients ($K1_{cp}$ 1.00, $K2_{cp}$ 0.75, $K3_{cp}$ 0.50, $K4_{cp}$ 0.25 and $K5_{cp}$ 0.00-control). In calculation of applied water amount, pan evaporation with fundamental's given in the articles of Doorenbos and Pruit [12] was used: $IW = E_{pan} \times K_{cp}$, where IW is the amount of applied irrigation water (mm), E_{pan} the cumulative evaporation between each irrigation interval (mm), and K_{cp} is the plant-pan coefficient.

Table 3. Growth stage and harvest days of green bean.

Growth period	DOY
Sowing	91
Establishment	102
Vegetative development	123
Flowering	137
Pod filling	151
Maturity	169
I. Harvest	169
II. Harvest	176
III. Harvest	182

Evaporation between the irrigation intervals was measured with US Weather Bureau Class A Pan located in the center of greenhouse. Irrigation water was applied in the 2-day frequency and drip irrigation method was used. Laterals were laid for each plant row, and inline emitters with discharge rate of 2 L h^{-1} were spaced at 20 cm intervals on the lateral line. The system was operated at 100 kPa throughout the growing season. The control unit of the system consisted of a pump, gravel and disk filters, a flow meter, control valves, fertilizer tank, and pressure gauges.

Crop evapotranspiration (ET_c) was estimated using the following form of the water balance equation: $ET_c = (SWC_{t0} - SWC_{t1}) + IW - D$, where $(SWC_{t0} - SWC_{t1})$ is the change in volumetric soil water content between two measurement dates ; IW and D are, respectively, the total volumes of applied irrigation water and collected drainage for the period under consideration. The water content of plant root depth (0.90 m) was determined by gravimetrical method before irrigation water application [13] and monitored in 30 cm depth increments to 0.9 m after irrigation for each irrigation treatments. Monitoring the soil water content in the plots revealed that deep percolation below 0.9 m depth was negligible.

The water use-yield relationship was determined using the Stewart model in which dimensionless parameters in relative yield reduction and relative water consumption are used[14]: $\left(1 - Y_a . Y_m^{-1}\right) = k_y \left(1 - ET_a . ET_m^{-1}\right)$, where Y_a is the actual yield (t ha^{-1}), Y_m is the maximum yield (t ha^{-1}), ET_a is the actual evapotranspiration (mm) and ET_m is the maximum evapotranspiration (mm). Values of k_y indicate the response factor of green bean to deficit irrigation.

Table 1. Some chemical and physical properties of experimental field soil.

Soil depth (cm)	γ (g cm^{-3})	Soil type	Field capacity (%)	Wilting point (%)	pH	Total salt (%)	$CaCO_3$ (%)	Organic matter (%)	Available (kg da^{-1})	
									P	K
0-30	1.34	SL	19.66	11.94	7.99	0.058	5.67	2.94	1.53	38.35
30-60	1.37	SL	17.26	9.98	8.04	0.051	8.49	1.39	1.24	19.52
60-90	1.41	SL	18.10	9.22	8.29	0.042	9.83	1.21	0.91	7.88

γ unit weight of soil, SL sandy loam, P phosphorus, K potassium

Table 2. Chemical composition of irrigation water used in the experiment.

Water Source	$EC_{25}x(10^6)$	Na^+ (me L^{-1})	K^+ (me L^{-1})	Ca^{2+} (me L^{-1})	Mg^{2+} (me L^{-1})	pH	Class	SAR
Deep well	715	2.3	2.56	9.25	5.7	7.12	C_2S_1	0.85

The water use efficiency (WUE) was determined to evaluate the productivity of irrigation in the treatments. WUE and irrigation water use efficiency (IWUE) are two terms used to promote the efficient use of irrigation water at the crop production level [15]. WUE was calculated as the ratio of yield (YLD) to ET_a, given as WUE = YLD/ET_a (t ha^{-1} mm^{-1}). IWUE was estimated by following equation; IWUE(t ha^{-1} mm^{-1}) = ($YLD-YLD_{rainfed}$)/IRGA, where $YLD_{rainfed}$ is the yield obtained from the rainfed treatment or dryland yield and IRGA is the seasonal irrigation amount used in millimeter.

Yield and yield quality parameters such as fresh bean length and width, number of seeds in each pod, 100 green bean weights and dry matter were determined in each harvest period. The 100 green beans were randomly selected from the yield harvested from each subplot.

All data were subjected to analysis of variance (ANOVA) for each character using MSTAT-C (version 2.1-Michigan State University 1991) and MINITAB (University of Texas at Austin) software. The significance of irrigation treatments were compared by the Duncan test at the 0.05 and 0.01 probability levels [16].

Results and Discussion

Water applied and water used: After planting, 40 mm irrigation water was applied to all treatments to bring the soil water content in 0–60 cm soil depth up to level of field capacity. Irrigation treatments were started measuring of evaporation from Class A pan after first irrigation application. The maximum amount of water applied to the crop was 582 mm in the $K1_{cp}$ treatments while the minimum amount was 40 mm in the $K5_{cp}$ treatment during the experiment year. The amount of water applied to other treatments ranged between 177 and 437 mm values. Seasonal evapotranspiration (ET_c) increased with the applied irrigation water and ranged from 582.0 to 47 mm for $K1_{cp}$ and $K5_{cp}$ treatments, respectively (Table 4). Water use values increased with increasing K_{cp} coefficient. Water requirements of the green bean for maximum production of a 60 to 120-day crop vary between 300 and 500 mm depending on climate. Total water applied to the conventional deficit irrigation treatments for green bean ranged from 366 to 437 mm [14, 17]. Seasonal water used by green bean varied from 253 to 338 mm for different irrigation frequencies and amount in Mediterranean climate condition [18]. Üstün *et al.* reported trickle irrigated green bean water use varying from 423 to 868 mm in different treatments in Central Anatolia of Turkey [19]. Evren and Sevim reported water use values of 604 mm for green bean in eastern region of Turkey [20]. These results are in agreement with our results except $K5_{cp}$ treatments. Orgaz *et al.* measured 170 mm evapotranspiration of green bean under greenhouse condition [21]. This value is only close to ET values of $K4_{cp}$ treatment, however, this is lower than the other irrigation treatments (except $K5_{cp}$ treatments) with the rate of 242, 159 and 100%.

Irrigation levels significantly affected green bean yield as indicated by the analysis of variance given in Table 5. Highest yield averaging 18.88 kg ha^{-1} was obtained in treatment $K1_{cp}$ plots, followed by $K2_{cp}$ plots with 11.64 kg ha^{-1} (Table 6). Minimum yield was obtained from the $K5_{cp}$ (control) treatments as 3.26 kg ha^{-1}. Green bean response to irrigation levels applied with a trickle system indicated that higher the amount of applied irrigation water, the higher yield of green bean. Muirhead compared drip and furrow methods at different irrigation intervals in Australia and obtained

Table 4. Relationship between the decrease in relative water use and decrease in relative yield and yield response factor for green bean irrigated by a drip system.

Irrigation treatment	Yield (t ha^{-1})	Applied water (mm)	ETa (mm)	ETa/ETm	Ya/Ym	1-ETa/ETm	1-(Ya/Ym)	k_y
$K1_{cp}$	18.88	579	582.0	1.000	1.000	0.000	0.000	0.00
$K2_{cp}$	11.64	434	440.0	0.756	0.617	0.244	0.383	1.57
$K3_{cp}$	9.43	290	340.0	0.584	0.499	0.416	0.501	1.20
$K4_{cp}$	5.64	145	184.0	0.316	0.299	0.684	0.701	1.03
$K5_{cp}$	3.26	40	47.0	0.081	0.173	0.919	0.827	0.90

Table 5. Analysis of variance table for total green bean yield from irrigation treatments.

Variation source	d.f.	Sum of squares	Mean square	F–value	P
Replication (R)	2	1228796	614398	2.03^{ns}	0.194
IW	4	438148725	109537181	361.37^{**}	0.000
Error	8	2424947	303118		
Total	14	441802468			

** Correlation is significant at the 0.01 level, ns non-significant.

Table 6. Yield and some quality parameters of green bean in different treatments.

Irrigation treatment	Fresh bean pod width (cm)	Fresh bean pod length (cm)	Number of seeds per pod	100 green bean weight (g)	Dry pod weight percent (%)	Yield (t ha^{-1})
$K1_{cp}$	1.70a	16.0a	7.2a	882.8a	7.7e	18.88a
$K2_{cp}$	1.60ab	14.4ab	6.0b	688.4b	10.6d	11.64b
$K3_{cp}$	1.50ab	13.3bc	5.0c	544.6c	11.9c	9.43c
$K4_{cp}$	1.40b	12.1cd	4.4c	476.8d	15.8b	5.64d
$K5_{cp}$	1.20c	10.4d	3.3d	340.2e	17.7a	3.26e
Ttreatments	**	**	**	**	**	**
Blocks	**	ns	ns	**	**	ns

** Correlation is significant at the 0.01 level, ns non-significant.

maximum yield of 16.00 kg ha^{-1}, with daily drip irrigation [22]. Ustün *et al.* have reported trickle-irrigated green bean yield varying from 13.42 to 26.17 kg ha^{-1} in Central Anatolia[19]; Cağlar obtained maximum yield from Gina variety as 15.00 kg ha^{-1} with surface irrigation in the East Mediterranean region of Turkey [23]. Sezen *et al.* reported average total yield of green bean from 20.56 to 12.24 kg ha^{-1} with different irrigation frequencies and amount in Mediterranean climate conditions [18]. Gençoğlan *et al.* reported yield of green bean irrigated with the conventional deficit irrigation treatments varied from 6.86 to 10.87 kg ha^{-1} and all irrigation treatments were in different groups [17].

Quality parameters such as length and width of green bean, number of seeds per pod and 100 bean weight data and dry pod weights percent are given in Table 6. Duncan classification for fresh bean width and length, number of seeds per pod, 100 green bean weights and dry pod weights percent was carried out according to deficit irrigation treatments. Deficit irrigation had significant effect in the level of $P< 0.01$ on number of seeds in each pod, 100 green bean weights and dry pod weights percent (Table 6). According to the quality paramaters, higher K_{cp} values resulted in better quality green beans than the lower K_{cp}.

There was a highly linear relationship between the irrigation water applied and length and width of green bean, number of seeds per pod and 100 bean weight. The equations for the relationship were for pod weight = 0.0008IW + 1.2201 with R^2 = 0.99 (Fig. 1a), pod height = 0.0095IW+10.34 with R^2 = 0.99 (Fig. 1b), number of seeds = 0.006IW+3.1759 with R^2 = 0.97 (Fig. 1c), 100 green bean weight = 0.8996IW+311.44 with R^2 = 0.95 (Fig. 1d) and dry pod weight percent = –0.0134IW+16.048 with R^2 = 0.97 (Fig.1e).

Crop yield response factor (k_y): The relationship between relative yield reduction and relative evapotranspiration deficit for green bean is given in Fig. 2. The yield response factor (k_y) for green bean was 1.066 for whole growing season. Doorenbos and Kassam[14], Bahçeci [24], Sezen *et al.* [18] and Gençoğlan *et al.* [17] reported k_y values of 1.15, 1.33, 1.23 and 1.55 respectively, for total growing season.

Water use efficiencies: WUE and IWUE were different depending on the irrigation treatments (Table 7). WUE values were 32.44, 26.46, 27.74, 30.68 and 69.30 kg mm^{-1}, IWUE values were 26.98,

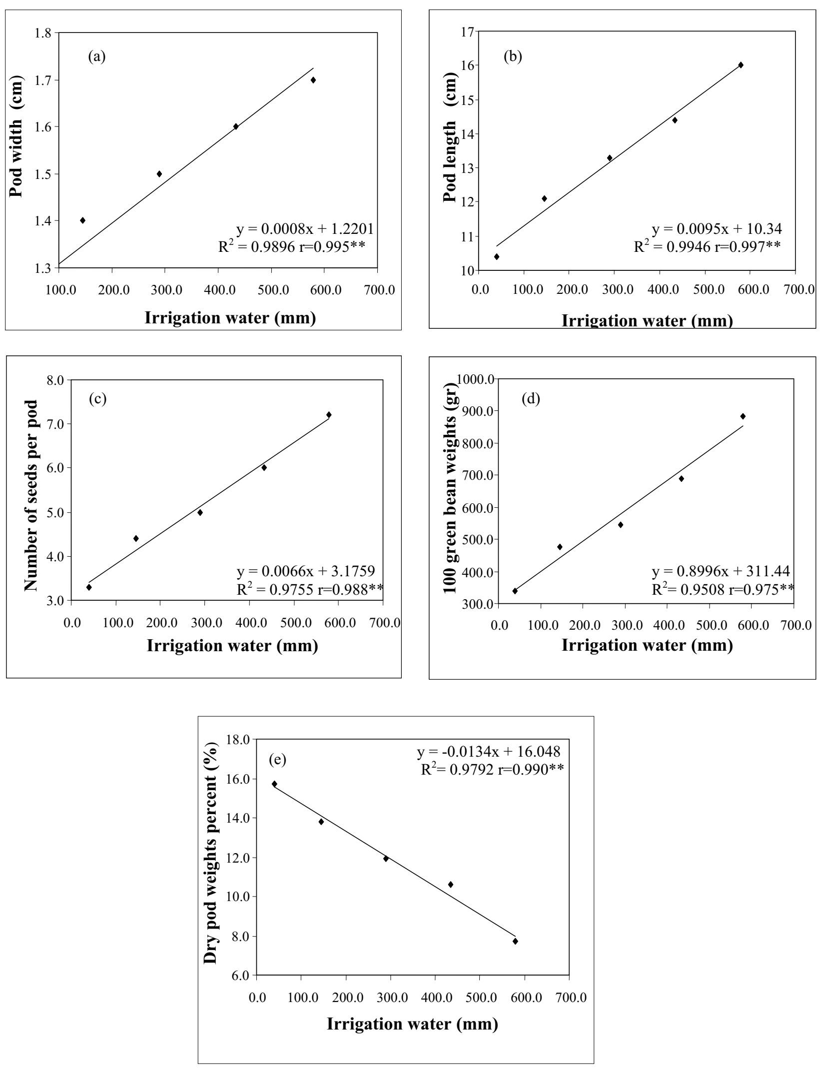

Figure 1. Relationship between applied irrigation water and quality parameters of green bean: a) irrigation water-pod weight, b) irrigation water-pod length, c) irrigation water-number of seeds per pod, d) irrigation water-100 green bean weight, e) irrigation water-dry pod weight percent.

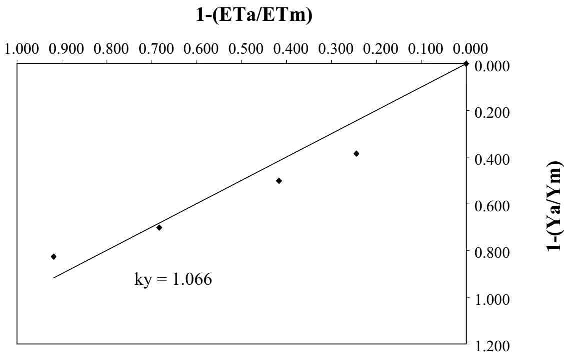

Figure 2. Relationship between relative yield reduction and relative evapotranspiration deficit for green bean.

Table 7. Total water use efficiency (IWUE) and irrigation water use efficiency (WUE) values for green bean irrigated by a drip system.

Irrigation treatments	Yield ($t\ ha^{-1}$)	IWUE ($g\ mm^{-1}$)	WUE ($g\ mm^{-1}$)
$K1_{cp}$	18.88	26.98	32.44
$K2_{cp}$	11.64	19.32	26.46
$K3_{cp}$	9.43	21.29	27.74
$K4_{cp}$	5.64	16.46	30.68
$K5_{cp}$	3.26	0.00	69.30

19.32, 21.29, 16.46 and 0.00 kg mm^{-1} for the irrigation treatments, respectively. The highest WUE was obtained in $K5_{cp}$ and minimum WUE was observed in $K2_{cp}$. In general, WUE values decreased with increasing irrigation interval. These results are similar to Stansel and Smittle [25] and Sezen *et al.* [18].

Conclusions

In this study, irrigation treatments significantly affected fresh bean yield, length and width of green bean, number of seeds per pod, 100 bean weight and dry pod weights percent. The highest yield was obtained from the $K1_{cp}$ treatment as 18.88 t ha^{-1} and the minimum yield was obtained from the $K5_{cp}$ treatment as 3.26 tha^{-1}. Yield was significantly reduced as the amount of irrigation water decreased. The rates of reduction in relative yield were 62, 100, 235 and 479% at the irrigation treatments, respectively. There was a highly linear relationship between the irrigation water applied and quality of green bean parameters. IWUE values of the $K1_{cp}$ and $K3_{cp}$ treatments were higher than in the other irrigation treatments. Under the conditions that water resources are scarce, $K3_{cp}$ treatment is suggested as a water application level for green bean irrigation by drip irrigation under unheated greenhouse condition.

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