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DEFICIT IRRIGATION EFFECTS ON BROCCOLI (*BRASSICA OLERACEA* L. VAR. *MONET*) YIELD IN UNHEATED GREENHOUSE CONDITION

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Abstract

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The aim of this study was to determine the effect of deficit irrigation on yield for broccoli 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 broccoli as 1.00, 0.75, 0.50, 0.25 and 0.00 % (as control) of evaporation from a Class A Pan corresponding to 2 day irrigation frequency. Irrigation water applied ranged from 70 to 522 mm, and water consumption ranged from 88 to 542 mm. The effect of irrigation water level on the yield, head height, head diameter, head weight and dry matter were found to be significant. The highest yield was 29.2 t ha^{-1}. Crop yield response factor (k_y) was found as 1.04 The highest values for water use efficiency (WUE) and irrigation water use efficiency (IWUE) were found to be 6.71 and 6.50 kg m^{-3} for the $K2_{cp}$ treatment. Under the conditions that water resources are scarce, it can be recommended that $K2_{cp}$ treatment is most suitable as a water application level for broccoli irrigation by drip irrigation under unheated greenhouse condition.

Key words: Evapotranspiration, water use efficiency (WUE), yield and quality parameters, irrigation scheduling

Introduction

Greenhouse cultivation, 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 (Aldrich and Barto, 1989). Greenhouse cultivation is a steadily growing agricultural sector all over the world (Enoch and Enoch, 1999; Von Elsner et al., 2000). 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.

Broccoli which is one of the most important winter vegetable crops is mostly produced at out-

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door. Since the market values and frost damage risk of early varieties are high, broccoli is initiated to be grown in tunnels in limited extend recently. When the crop water requirements cannot be met with natural rainfall in greenhouse production, irrigation is major input. Irrigation scheduling involves preventing the soil water deficit from falling below some threshold level for a particular crop and soil condition. This may involve estimating the earliest date to permit efficient irrigation or the latest date to avoid the detrimental effects of water stress on the crop (Ritchie and Johnson, 1990). Scheduling water application is very critical to make the most efficient use of drip irrigation system, as excessive irrigation reduces yield, while inadequate irrigation causes water stress and reduces production. The optimum use of irrigation can be characterized as the rooting area, and at the same time, avoiding the leaching of nutrients into deeper soil leyers (Kruger et al., 1999). High frequency water management by drip irrigation minimizes soil as a storage reservoir for water, provides at least daily requirements of water to a portion of the root zone of each plant and maintains a high soil matric potential in the rhizosphere to reduce plant water stress. On the other hand, the intensity of the operation requires that the water supply is kept at the optimum to maximize returns to the farmer.

Approaches used to establish schedules for drip irrigation include estimates based on evapotranspiration (Bar-Yosef and Sagiv, 1982; McNeeish et al., 1985; Clough et al., 1990; Hartz, 1993), allowable soil-water depletion (Bogle et al., 1989). A widely adopted method for estimating crop consumptive water use (CWU) is the pan evaporation method, which relates evaporation from a Class A pan to CWU. These two quantities are related by what is called the pan coefficient *K*. Irrigation scheduling based on the pan coefficient *K* is one of the simplest methods where no sophisticated instrument is required. Precise values for *K* are often difficult to establish, given regional and site-specification, soil characteristics, crop physiology and cultural practices. Any recommended value of *K* for regional irrigation scheduling program must be high enough to prevent water stress arising from emergencies and specialized local situations, while remaining low enough for efficient water management (Yuan et al., 2003). Based on the US Weather Bureau Class A pan evaporation, many studies have been completed on the irrigation of cucumber (Eliades, 1988; Randal and Locascio, 1988; Ayas and Demirtas, 2009), Pepper (Demirtas and Ayas, 2009), lettuce (Yazgan et al., 2008), tomato (Locascio and Smajstral, 1996), and potato (Panigrahi et al., 2001; Ferreira and Carr, 2002). Several studies have been performed to investigate the influence of different irrigation levels on broccoli growth and yield.

The objectives of this study were to provide a guideline for broccoli growers and to determine drip irrigated broccoli response to different irrigation regimes.

Materials and Methods

Field experiment was carried out under unheated greenhouse condition in Yenişehir-Bursa ($40^{o}15^{I}09^{II}$N latitude, $29^{o}38^{I}43^{II}$E longitude and altitude of 225 m above mean sea level). A greenhouse with the size of 8 m x 40 m using plastic coverage placed in north-south direction was used for the experiment. Climate is hot and dry in summer's cold and rainy in winters. Annual mean rainfall and temperature are 482.9 mm and 13.6^{o}C, respectively. Average minimum temperature is 3.6^{o}C in December; maximum temperature is 23.3^{o}C in August (Anonymous, 2003). 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. 180 kg ha^{-1} N, 200 kg ha^{-1} DAP (18% N and 46% P_2O_5), and 200 kg ha^{-1} KNO_3 (13%N and 46% K_2O) as granular fertilizer were applied prior to sowing and a further 85 kg ha^{-1} N as urea was added three weeks later. The experimental area was chlorphtifos-ethyl sprayed 10 L ha^{-1} to

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

γ :Unit weight of soil, SL:Sandy loam, P: Phosphorus, K: Potassium.

the experimental area for insects.

The seed were sown in small pot on 18 July 2007 and seedlings were transplanted to the plots (10 August 2007) when the plants showed four to five permanent leaves. The plants were grown 0.60 m apart between the rows with 0.60 m spacing in each row. Each plot has contained 44 plants. In order to prevent the water in any one plot from affecting its neighboring plots, only the 14 plants of middle row were harvested. Head weight (g), head diameter (cm) (two repetition in both east-west and north-south directions) and head height (cm) were measured by caliper rule and calculated as the average of measured values. To determine dry matter content, the heads and leaves (two samples for each plot) were separated and dried at 65°C in a forced – air oven. Dry matter of heads and leaves was determined by the Kjeldahl method (AOAC, 2000).

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 pan coefficients ($K1_{cp}$:1.00, $K2_{cp}$:0.75, $K3_{cp}$:0.50, $K4_{cp}$:0.25, $K5_{cp}$:0.00-control). The amount of irrigation water was calculated by using the equation given below:

$$I = E_p x K_{cp} x P,$$

where E_p is the cumulative evaporation for the 2-day irrigation interval (mm) and K_{cp} is the coefficient of pan evaporation and P is the percentage of wetted area. 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. Required irrigation water was measured by flow meter device at the head of each plot.

Irrigation water was supplied from a deep well (3 L s^{-1}) 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.

Crop evapotranspiration (ET_c) was estimated using the following form of the water balance equation:

$$ET_c = (SWC_{t0} - SWC_{t1}) + IW - D,$$

Table 2

Chemical composition of irrigation water used in the experiment

Water source	$EC_{25}x10^6$ µmhos cm^{-1}	Na^+	K^+	Ca^{++}	Mg^{++}	pH	Class	SAR
		me L^{-1}						
Deep well	715	2.3	2.56	9.25	5.7	7.12	C_2S_1	0.85

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 (0.60 m) was determined by gravimetric method before irrigation water application and monitored in 30 cm depth increments to 0.90 m after irrigation for each irrigation treatments Lorenz and Maynard (1980). Monitoring the soil water content in the plots revealed that deep percolation below 0.60 m depth was negligible.

In this study, the Stewart model has contributed to define the relationships between yield and ET (Doorenbos and Kassam, 1979):

$$(1-Y_a/Y_m) = k_y(1-ET_a/ET_m)$$

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 broccoli to deficit irrigation. 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. WUE was calculated as the ratio of yield (YLD) to ET_a, given as WUE = YLD/ET_a (kg m^{-3}). IWUE was estimated by fallowing equation:

$$IWUE(kg\ m^{-3}) = \frac{YLD - YLD_{rainfed}}{IRGA},$$

where $YLD_{rainfed}$ is the yield obtained from the rainfed treatment or dryland yield and IRGA is the seasonal irrigation amount used in millimeter.

In the harvest time, 106 days after the seedlings (day of year (DOY) 106) were transplanted; the plants were fully developed and had the size, height, weight, colour and the flavour characteristics of the species. Harvested plants from each plot were evaluated immediately according to yield, head height, head diameter, head weight and dry matter.

Analysis of variance was performed on yield and yield component data using the MSTAT-C (version 2.1-Michigan State University 1991) and MINITAB (University of Texas at Austin) software. The significance of irrigation treatments were determined at the 0.05 and 0.01 probability levels, by the F-test (Steel and Torrie, 1980).

Results

Water applied and water used. After planting, 70 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 the first irrigation application. The maximum amount of water applied to the crop was 522 mm in the $K1_{cp}$ treatment while the minimum amount was 70 mm in the $K5_{cp}$ treatment during the experimental year. The amount of water applied to other treatments ranged between 138-394 mm values. Seasonal evapotranspiration (ET$_c$) was increased with the applied irrigation water. The actual evapotranspiration ranged between 88 to 542 mm values for $K5_{cp}$ and $K1_{cp}$ treatments, respectively (Table 3).

Linear relationships were observed between the crop evapotranspiration (ET$_c$) and yield (Y$_a$). The equation for the relationship was $Y = 0.0673ET - 4.6089$ with, R^2=0.95 (Figure 1).

In our study, treatment $K1_{cp}$ had the highest yield 29.2 t ha^{-1} followed by $K2_{cp}$, $K3_{cp}$, and $K4_{cp}$ irrigation treatments with 27.5 t ha^{-1}, 15.1 t ha^{-1} and 5.0 t ha^{-1}, respectively. As expected, non-irrigated treatment control $K5_{cp}$ had the lowest yield. The non irrigated treatment ($K5_{cp}$) produced 1436.8 % lower yield than the $K1_{cp}$ treatment. However $K2_{cp}$, $K3_{cp}$, and $K4_{cp}$ had 6 - 484 % less yield compared with treatment $K1_{cp}$ (Table 4).

Water deficits, particulary in the three or four week prior to harvest, lower crop yields and quality.

Table 3

Relationship between the decrease in relative water use and decrease in relative yield and yield response factor for broccoli irrigated by a drip system

Irrigation treatment	Yield, t ha^{-1}	Applied water, mm	Eta, mm	ET_a/ET_m	Y_a/Y_m	$1-(ET_a/ET_m)$	$1-(Y_a/Y_m)$	k_y
$K1_{cp}$	29.2	522	542	1	1	0	0	0
$K2_{cp}$	27.5	394	410	0.756	0.942	0.244	0.058	0.239
$K3_{cp}$	15.1	266	295	0.544	0.723	0.456	0.277	1.06
$K4_{cp}$	5	138	176	0.325	0.171	0.675	0.829	1.227
$K5_{cp}$	1.9	70	88	0.162	0.065	0.838	0.935	1.116

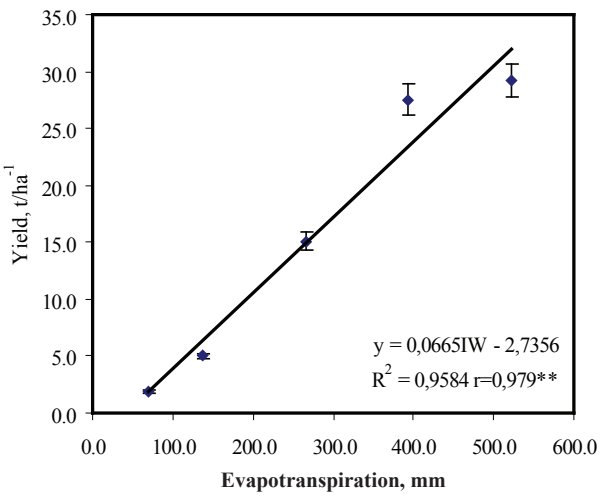

Fig. 1. The relationship between crop evapotranspiration with yield and water irrigation with yield. (The errors bars are SE of 14 plants)

Deficit irrigation had a significant effect on head height but, the values of $K1_{cp}$, $K2_{cp}$ and $K3_{cp}$ were in the same group, $K4_{cp}$ and $K5_{cp}$ treatments were placed in second group. It can be concluded that the deficit of applied irrigation water (25%) is not compatible with the reduction in head diameter. Positive linear relation was found among head height, head diameter and head weight, negative linear relation was found between dry matter and amount of water applied (IW). The equation for the relationship was *head height* = 0.0212*IW* + 8.7966 with R^2 = 0.89 (Figure 2a), *head diameter* = 0.0354*IW*+6.8555 with R^2 = 0.98 (Figure 2b), *head weight* = 2.3903*IW – 97.954* with R^2 = 0.96 (Figure 2c), and *dry matter* = -0.0483*IW*+29.08 with R^2 = 0.94 (Figure 2d), treatment.

Crop yield response factor (k$_y$). Crop yield response factor (k_y) indicates a linear relationship between the decrease in relative water consumption and the decrease in relative yield. It shows the response of yield with respect to the decrease in water consumption. In other words, it explains the decrease in yield caused by the per unit decrease in water consumption (Stewart et al., 1975; Doorenbos and Kassam, 1979). Seasonal yield response factor was determined as 1.04 for irrigation treatments (Figure 3). Values of k_y increased with increasing water deficit except in $K5_{cp}$.

Water use efficiencies. WUE and IWUE values decreased when irrigation water amount decreased. The highest WUE and IWUE was obtained from treatment $K2_{cp}$, 6.71 and 6.50 kg m^{-3} respectively. When considering IWUE values of $K1_{cp}$ and $K2_{cp}$ treatments, IWUE values of $K2_{cp}$ treatments was found higher than that of $K1_{cp}$ treatment and followed by $K3_{cp}$ (Table 5).

Discussion

In this study, irrigation treatments significantly affected yield, head height, head diameter, head weight and dry matter. Gutezeit (2004) reported that applied water of broccoli ranged between 238–445 mm. Imtiyaz et al. (2000) reported that for two years and under drip irrigation method

Table 4
Effects of irrigation treatments on broccoli marketable parameters

Irrigation treatment	Head height, cm	Head diameter, cm	Head weight, g	Dry matter, %	Yield, t ha^{-1}
$K1_{CP}$	18.5a	24.5a	1050.0a	6.3c	29.2a
$K2_{CP}$	18.0a	22.0a	990.8a	7.9c	27.5a
$K3_{CP}$	16.5a	16.5b	542.9b	13.7b	15.1b
$K4_{CP}$	11.0b	11.0c	180.6c	23.5a	5.0c
$K5_{CP}$	9.5b	9.5c	68.5d	26.8a	1.9c
Treatments	**	**	**	**	**
Blocks	ns	ns	ns	ns	ns

** Significant at the P<0.01, * Significant at the P<0.05, ns: Not significant

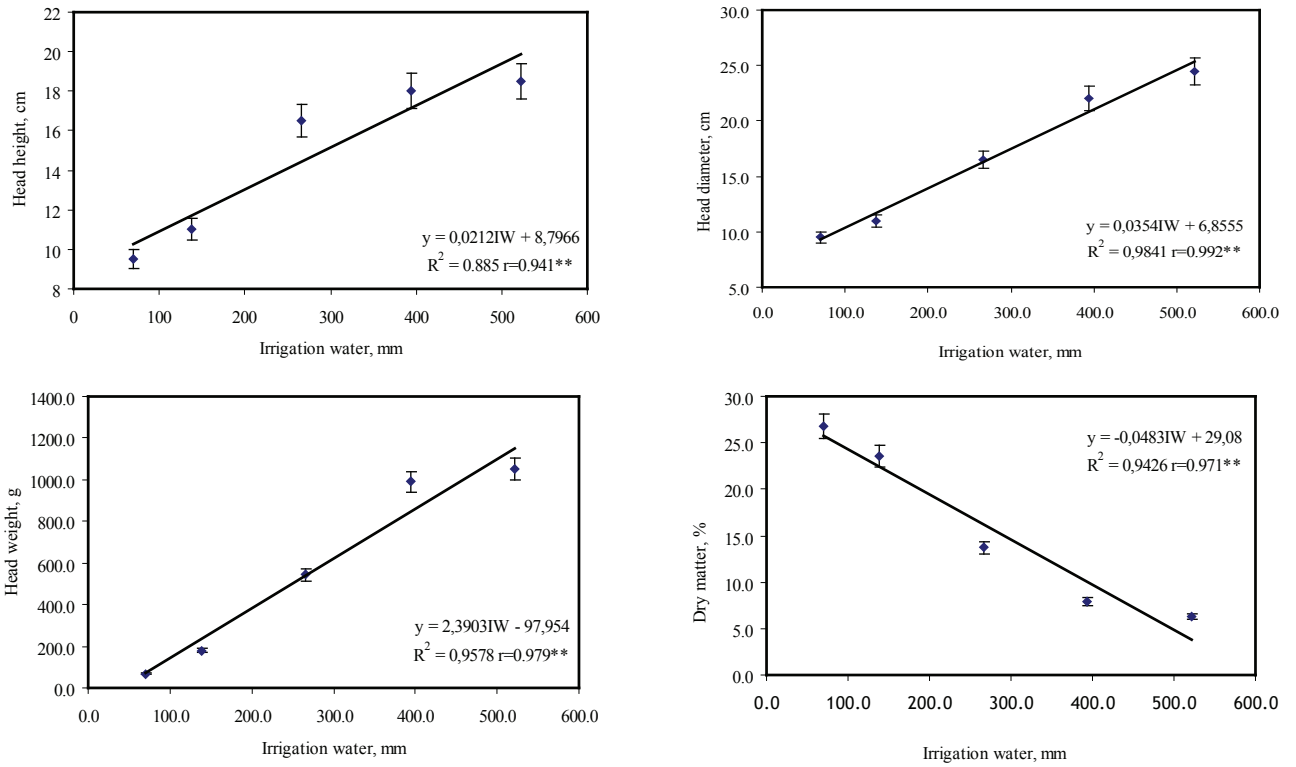

Fig. 2. Relationship between applied of irrigation water and head height, head diameter, head weight and dry matter. (The errors bars are SE of 14 plants)

avarage of water use values varied from 150 – 375 mm in different treatments in Northwestern Botswana. Erie et al. (1981) reported that broccoli water consumptive use in southern Arizona was 500 mm, not including that used for germination and stand establisment. Sanchez et al. (1996) reported that broccoli yields in southwestern Arizona were maximized with 430 mm of irrigation water applied using an overhead sprinkler system. Hegazi ve Alsadon (2001) reported that

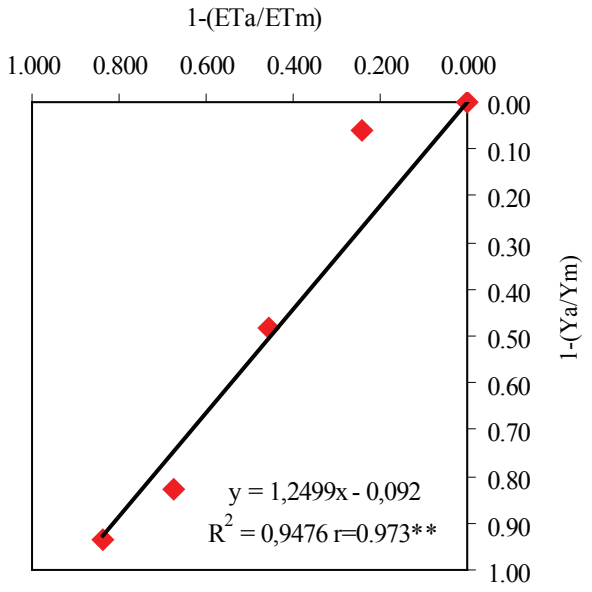

Fig. 3. Rilationship between relative yield decrease and relative crop evapotranspiration for broccoli throughout the total growing season

for two years and two irrigation methods (drip and furrow), avarage of evapotranspiration of broccoli was 402 mm/season and irrigation water applied were 435 mm for drip irrigation and 494 mm for furrow irrigation. Total seasonal evapotranspiration by broccoli varied from 233 mm to 328 mm in spring cultivation and from 276 mm to 344 mm in autumn cultivation (Erdem et al., 2010). Our results are in harmony with these earlier researches. Vittum and Flocker (1967) stressed the importance of maintaining adequate, uniform soil moisture throughout the crop cycle.

According to results, there was no effect of deficit irrigation on head height in terms of marketable value. This result was in agreement with Yoldas and Esiyok (2004).

The head diameter and head weight had a similar response to deficit irrigation like yield. All irrigation treatments had higher values than the non-irrigated ($K5_{cp}$) treatment. Our result are in agreement with Thompson et al. (2000) and Thompson et al. (2002) who stated that high irrigation treatments (soil water tension is between 10-12 kPa) generally increased yield componets of broccoli and cauliflower.

The yield ranged from 1.9 t ha $^{-1}$ to 29.2 t ha $^{-1}$. Similar results under different irrigation regimes

Table 5

Total water use efficiency (WUE) and irrigation water use efficiency (IWUE) values for broccoli irrigated by a drip system at different irrigation treatments

Irrigation treatment	Yield, t ha^{-1}	WUE, kg m^{-3}	IWUE, kg m^{-3}
$K1_{cp}$	29.2	5.39	5.23
$K2_{cp}$	27.5	6.71	6.5
$K3_{cp}$	15.1	5.12	4.96
$K4_{cp}$	5	2.84	2.25
$K5_{cp}$	1.9	2.16	0

have been obtained in the previous research (Cantore et al., 1996; Wojciechowska et al., 2005; Erdem et al., 2010).

The significant increases in dry matter were found as parallel to irrigation water deficit and the highest and lowest dry matter were found at $K5_{cp}$ and $K1_{cp}$, respectively. This may be attributed to higher head weight observed from $K1_{cp}$ treatment than those of deficit irrigation treatments. These results are similar to Yoldas and Esiyok (2004).

Conclusions

Under the conditions that water resources are scarce, it can be recommended that $K2_{cp}$ treatment is most suitable as a water application level for broccoli irrigation by drip irrigation under the unheated greenhouse condition.

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