J. Agr. Sci. Tech. (2015) Vol. 17: 963-976

Evapotranspiration, Yield Components, and Some Quality Attributes of Subsurface Drip Irrigated Broccoli under Three Soil-water Depletion Levels

T. Öztekin[1]*, S. Öztekin[2], and N. Geboloğlu[3]

ABSTRACT

This experiment aimed to determine evapotranspiration, and responses of some yield and quality parameters of subsurface drip irrigated broccoli (*Brassica oleraceae* L.). Treatments included water application when available soil moistures were depleted 30, 40, and 50% during both spring and autumn cultivations. Under a semi-arid climatic condition of Tokat, Turkey, the experiment was carried out with a randomized complete block design in clay and clay loam soils during, respectively, 2011 and 2012. The mean measured soil-water depletion levels of 39, 49, and 59% (irrigation treatments) yielded statistically significant results among the seasonal actual evapotranspirations with a range from 210 to 294 mm. The determined crop coefficients (Kc) during the initial growth stage of broccoli for the autumn cultivations did not follow those of standard recommendations. Furthermore, we could not find any statistically significant difference in the yield and quality components among the irrigation treatments, but among the cultivation seasons.

Keywords: Crop coefficient, Modified Penman equation, Vitamin C, Water use efficiency.

INTRODUCTION

The acreage and production of broccoli are increasing in Turkey year by year (29,076 tons according to the Turkish Summary of Agricultural Statistics for the year of 2011). In this increasing trend, higher nutritional value of broccoli due to its phenolic compounds, vitamins, and dietary fibers may have a role (Vinson *et al.*, 1998; Vallejo *et al.*, 2003; Sikora, 2008). It has high antioxidant content; and it is effective in protecting against some cancers (Kaur and Kapoor, 2002; Sikora, 2008; Yoldas *et al.*, 2008). On the other hand, water is a major factor for broccoli, limiting the plant metabolism in times of shortage. Therefore, it also affects the aforementioned attributes since the crop is sensitive to soil water stress. Thus, some deviations might be expected in the plant quality and quantity according to excess or deficit soil water conditions in the plant root zone. Furthermore, subsurface drip irrigation system managed based on soil water status and plant root depth may contribute extra saving on water resources (Camp, 1998; Reich *et al.*, 2012).

The importance of soil water in broccoli production has been documented in many studies employing various methods for irrigation scheduling such as water balance, soil moisture content, soil water tension/pressure, and plant-based methods. For instance, Toivonen *et al.* (1994) stated that the vitamin C content of broccoli varied

---

[1] Department of Biosystem Engineering, Faculty of Agriculture, Gaziosmanpaşa University, 60240 Tokat, Turkey.
[2] Middle Black Sea Transition Zone Agricultural Research Station, 60000 Tokat, Turkey.
[3] Department of Horticulture, Faculty of Agriculture, Gaziosmanpaşa University, 60240 Tokat, Turkey.
*Corresponding author; e-mail: tekin.oztekin@gop.edu.tr

inversely by the average precipitation. In the same study, it was also indicated that vitamin C content increased along with moderate water deficits (Lukicheva, 1968). On the other hand, Thompson *et al.* (2002) conducted a field experiment in southern Arizona to determine the subsurface drip-irrigated broccoli response to a range of soil water tension (low, medium, and high) during the period from 1993 through 1996. They found 10 Kpa as the optimum soil water tension in the sandy loam soil for marketable yield. They indicated that this value could change with respect to the soil texture. In addition, Zaicovski *et al.* (2008) cultivated broccoli under soil water pressures of 0.4 MPa (high water stress), 0.2 MPa (moderate water stress), and 0.04 MPa (without water stress), and they concluded that the soil water pressure did not influence significantly the fresh weight of the broccoli florets. Furthermore, Gutezeit (2004) studied the effect of three soil water regimes: the plants received 21 mm of water by irrigation until the soil moisture reached 75% of the available soil water (ASW); 42 mm after the soil moisture reached 55% *ASW*; and 63 mm after the soil moisture reached 35% *ASW* on the total biomass, and marketable yield of broccoli under two soil types (alluvial loam, loessal loam) during spring and autumn seasons. The total plant mass was significantly affected by the irrigation treatments on the loessal loam in spring and on the alluvial loam in autumn. In addition, Erdem *et al.* (2010) applied irrigation water to broccoli during the spring and autumn cultivation periods of 2007. The irrigation depths were based on the ratios of Class A pan evaporation with seven days irrigation interval. They did not find any statistically significant difference in the yield and yield components among the irrigation regimes, but they found significant differences among the cultivation periods.

The typical management allowed depletion value of 0.45 for broccoli was given by Allen *et al.* (1998) for evapotranspiration rate of about 5 mm d^{-1}. Furthermore, Doorenbos and Kassam (1979) suggest that the rate of water uptake by cruciferous crops (including broccoli) starts to reduce when the maximum evapotranspiration is 5-6 mm d^{-1} and the available soil water is depleted by approximately 35% *ASW*.

After reviewing the above literature, we could not find more information about the effects of different soil water depletion levels on the evapotranspiration, yield, and quality of subsurface drip irrigated broccoli. Therefore, we were concerned about the effects of availability of soil moisture in plant root zone on the evapotranspiration, yield, and quality of subsurface drip irrigated broccoli. The objectives of this study were to determine evapotranspiration, and some yield and quality responses of subsurface drip irrigated broccoli to: (i) a range of allowable soil-water depletion levels (WDL) in the broccoli root zone, and (ii) different growing periods (spring, and autumn).

MATERIALS AND METHODS

The experiment was carried out using spring (between the months of May and July) and autumn (between the months of September and November) plantings of broccoli in 2011 and 2012 at two different locations of the Middle Black Sea Transition Zone Agricultural Research Station, Tokat, Turkey. The research station was located 10 km west of town of Tokat. The coordinates of experimental area were 40° 19' N and 36° 27' E, at an altitude of 580 m above mean sea level. The experimental locations were almost flat (Slope< 2%) with north aspect. The average annual rainfall of Tokat city is 443 mm, mainly distributed in winter, spring, and autumn; and the average mean, maximum, and minimum annual temperatures of 12.5, 18.5, and 7°C, respectively (TSMS, 2012).

The broccoli cultivations in the autumn periods were conducted as a second crop at the winter wheat fields after harvesting wheat. The cultivations in the spring periods were also conducted at the winter wheat fields after leaving them bare during the preceding autumn periods. After deciding the two places of the experimental locations in the research station area, an area about 0.1 ha fit into the size of at least two experiments side by side in these locations, one of them (half of the area, about 0.05 ha) was used for the spring and the other one for the autumn period of the same year. Therefore, the spring and autumn experimental fields of the same year were adjacent fields. Before transplantation of broccoli seedlings, the experimental fields were plowed and then rototiller was used to break down the clods.

The soils of 2011 and 2012 experiments cropping seasons were both located on the low terraces of Yeşilırmak River and classified as Ustifluvent, and Ustorthent, respectively, according to the Soil Taxonomy (Soil Survey Staff, 1999). Some physical and chemical properties of the soils were determined according to the procedures given by Page *et al.* (1982), and Klute (1986), as presented in Table 1. According to the texture triangle of USDA, the soils of 2011 and 2012 experimental-locations were classified as clay and clay loam, respectively, slightly alkaline, mildly calcareous, salt-free, poor in organic matter and total N (between 0.12 and 0.15%), normal for phosphorus and rich in potassium contents. Considering the available nutrients in the soils and the plant requirements, the broccoli cultivations received 150 kg ha^{-1} of N (ammonium nitrate), and 180 kg ha^{-1} of P_2O_5 (granular triple superphosphate). Half of N and all of P_2O_5 fertilizers were applied to slots opened directly under the midline of north-south oriented plant rows just before transplantation of broccoli seedlings. The other half of N fertilizer was applied into plant rows by hand, mixed with soil during weed control operations by hoeing, three weeks after transplantation. Subsurface drip irrigation laterals (Wall thickness: 1.1 mm; Diameter: 16 mm, Emitter spacing: 20 cm) with double path inline emitters (Discharge rate: 4 L h^{-1}) laid out at the bottom of these

Table 1. Some physical and chemical properties of the soils at experimental sites.

Location	Depth (cm)	pH	EC[a] (µS cm^{-1})	Salt (%)	Lime (%)	OM[b] (%)	P_2O_5[c] (kg ha^{-1})	K_2O[d] (kg ha^{-1})	γ[e] (g cm^{-3})	Sand (%)	Clay (%)	Silt (%)	FC[f] (%)	PWP[g] (%)
Spring and Autumn 2011	0-30	7.8	760	0.03	10.4	1.49	84.7	999.9	1.46	21.6	46.6	31.8	30.0	16.1
	30-60	7.8	920	0.04	11.0	0.90	49.2	789.0	1.49	24.3	42.1	33.6	31.5	15.8
Spring and Autumn 2012	0-30	7.9	590	0.02	10.9	1.53	57.3	1166.7	1.53	26.1	37.1	36.8	21.5	13.7
	30-60	8.0	690	0.02	11.3	1.42	41.2	900.4	1.56	26.0	37.1	36.9	21.7	14.3

[a] Electrical conductivity; [b] Organic matter; [c] Available phosphorus; [d] Available potassium; [e] Bulk density; [f] Field capacity (% by weight), [g] Permanent wilting point (% by weight).

slots or ditches (7-9 cm depth and 10-12 cm width). In addition, transplantations were also performed into these slots or ditches before filling them by the dug soil.

The experiments were conducted in randomized block design replicated three times with three water depletion levels through effective root zone of broccoli (0 - 40 cm): WDL_1= 30% (treatment A), WDL_2= 40% (treatment B), and WDL_3= 50% (treatment C) to initiate subsurface drip irrigation of broccoli. The plot size of the experiment was 2.8×2.8 m with 1.0 m space between the plots and blocks. The broccoli cultivar Rumba was planted in the plots. After sowing the seeds into compost filled pots, the plants were grown in a controlled glasshouse until 3-5 leaf stage. In each plot, there were four rows and each row had seven plants with 0.70×0.40 m spacing. Irrigation events by a burette with an amount of 5 mm were carried out during the first two-three weeks after transplanting to overcome the transplanting shock of broccoli seedlings. The method of subsurface drip irrigation was used to irrigate the plants during the rest of the crop growth. During the experiment periods, weeds were controlled by hoeing, and insecticides were applied as needed using recommended rates during early growth.

Considering the field capacity (FC) and permanent wilting point (PWP) values of the soils in the experimental-locations for the depth of 0-30 cm (Table 1), the soil moisture levels at which irrigation was to be initiated were determined as 25.8, 24.4, and 23.1% by weight in the broccoli root zone depth for the experimental treatments of WDL_1, WDL_2, and WDL_3, respectively, for the spring and autumn of 2011; and 19.6, 18.4, and 17.6% for the experimental treatments of WDL_1, WDL_2, and WDL_3, respectively, for the spring and autumn of 2012 cropping season.

Infiltration rates of the soils of 2011, and 2012 experimental-locations were measured as 7.1, and 2.7 mm h^{-1}, respectively, with double ring infiltrometer. These rates were employed to determine emitter spacing and discharge rate when we were decide to choose the suitable drip irrigation lateral. The quality of irrigation water was C_2S_1 (EC: 0.572 dS/m, and SAR: 0.33). The plant rows in the experiment plots were irrigated with subsurface drip irrigation laterals buried about 10 cm directly under the plant rows. The irrigation water used in the experiments is carried out from the Almus dam to the research station by concrete main channels, and then it is rested to settle down the soil particles in a concrete reservoir before delivering to irrigation. Drip irrigation system of the experiments included main, sub main, and lateral PE pipes; water meter to measure volume of irrigation water for each plot; pressure regulator to reduce the system water pressure to one bar; manometer to measure system water pressure; valves to control water flow; and fine mesh screen filter to trap small amounts of sand, algae, and organic matter.

Soil moisture contents in all plots were measured gravimetrically as well as employing tensiometers (Soil Moisture Equipment Corp., USA, Model 2725), which were installed at the depths of 20, 60, and 90 cm in each plot shortly after transplantation. The tensiometers were inserted adjacent to the drip laterals midway between two plants of one of the middle plant rows to schedule irrigation (at 20 cm soil depth) and to determine downward water flow from the root zone (at 60 and 90 cm soil depths) after irrigations or notable rainfall (> 20 mm). Daily evaporation was measured from a Class A pan installed in the meteorological station, less than 200 m from the experimental plots. Tensiometer and Class A pan readings were observed daily at about 9.00 a.m. Soil moisture contents up to the maximum effective rooting depth for broccoli i.e.40 cm (Allen *et al*., 1998), were also measured gravimetrically when tensiometer readings were at target soil water depletion levels related to the corresponding tensions (62-, 72-, and 82-cbar for the experimental treatments WDL_1, WDL_2, *and* WDL_3, respectively, for the spring and autumn periods of 2011; and 51-, 61-, and 71-cbar for the same treatments in 2012. These values were employed to determine the irrigation amounts for each plot of the experiments. Soil water contents of each plot at 30 cm interval up to 90 cm soil depth were also measured every other week, after notable rainfall as well as before transplantations, and after harvests.

The transplantation and harvest dates of the experiments are given in Table 2. Five plants were taken from each of the two inside rows with the plants on each end acting as a buffer, as was the case for the two outside rows. Therefore, ten broccoli plants in the middle rows were used for all measurements. At the end of each growing season, broccoli plants were harvested at least three times by cutting plants at soil level with a knife when plants were at harvestable size (Head diameter≥ 12 cm). After harvesting, head weight and diameter, and then plant weight without head (biomass) were measured. Three heads were used to determine dry weight at 65°C in an air forced oven. Two heads were employed for the analyses of vitamin C with spectrophotometric method (Klein and Perry, 1982), pH (1:1) with pH meter, total soluble solids (TSS) with digital refractometer, and titratable acidity with titrimetric method (AOAC, 1970). The dry matter content of head was calculated as the ratio of head dry weight to fresh weight.

Seasonal evapotranspiration was computed by employing the soil water balance equation (Allen *et al.*, 1998) for the root zone depth (0-60 cm) as:

$$ET_c = I + P - D + C - R \pm \Delta S \qquad (1)$$

Where, ET_c is the actual evapotranspiration (mm); I and P are the irrigation and rainfall depths, respectively; D is deep percolation; C is the amount of capillary rise; R is the amount of runoff; and ΔS is the change in soil moisture content storage. The net irrigation water depth (m) to be applied to each plot was determined as (Anonymous, 1960):

$$I = \frac{(FC - PWP)WDL}{100} \gamma DW \qquad (2)$$

Where, I is the net irrigation water depth (m), FC is the field capacity of soil (% by weight), PWP is the permanent wilting point of soil (% by weight), WDL is the soil-water depletion level, γ is the bulk density of soil (g cm^{-3}), D is the maximum effective rooting depth of broccoli (0.4 m), and W is the percentage of the wetted area determined as 30%, based on dripper and lateral spacings. Rainfall, mean air temperature, mean wind speed, mean solar radiation, mean humidity, and atmospheric air pressure were measured by the Vantage Pro2 Weather Station (Davis Instruments, CA) in hourly base during the study; and ET_o for grass reference was computed automatically by the weather station employing the version of modified Penman equation (Pruitt and Doorenbos, 1977). Observed tansiometer readings and measured soil moisture contents below 0.6 m for each plot indicated no deep seepages (D= 0) and capillary rises (C= 0). The measured rainfall during growing periods was accepted as effective rainfall. In addition, no runoff and no horizontal water movements from/into the plots were observed during the experimental periods.

The water use efficiency (WUE, kg m^{-3}) value for each treatment was computed following Howell *et al.* (1992) as:

$$WUE = 100 \frac{CY}{ET_c} \qquad (3)$$

Where, CY is marketable yield (Mg ha^{-1}),

Table 2. The dates of harvest and transplantation of the broccoli seedlings in the experimental fields.

Year	Season	Transplantation Date	Harvest Dates
2011	Spring	May 9	July 8; 12, and 18
	Autumn	August 9	November 11, and 20
2012	Spring	May 15	July 11; 18, and 25
	Autumn	August 12	November 6, and 12

and ET_c is the seasonal actual evapotranspiration (mm). In order to relate the daily Class A pan evaporation values to daily ET_o values, pan coefficients (Kp) were determined by taking the ratio of ET_o to E_p for ten-day intervals. To determine crop coefficient (Kc) of broccoli for spring, and autumn cultivation periods separately, the measured mean ET_c averages for the treatment A, which experienced the least water stress, were divided by the values of ET_o for five-day intervals.

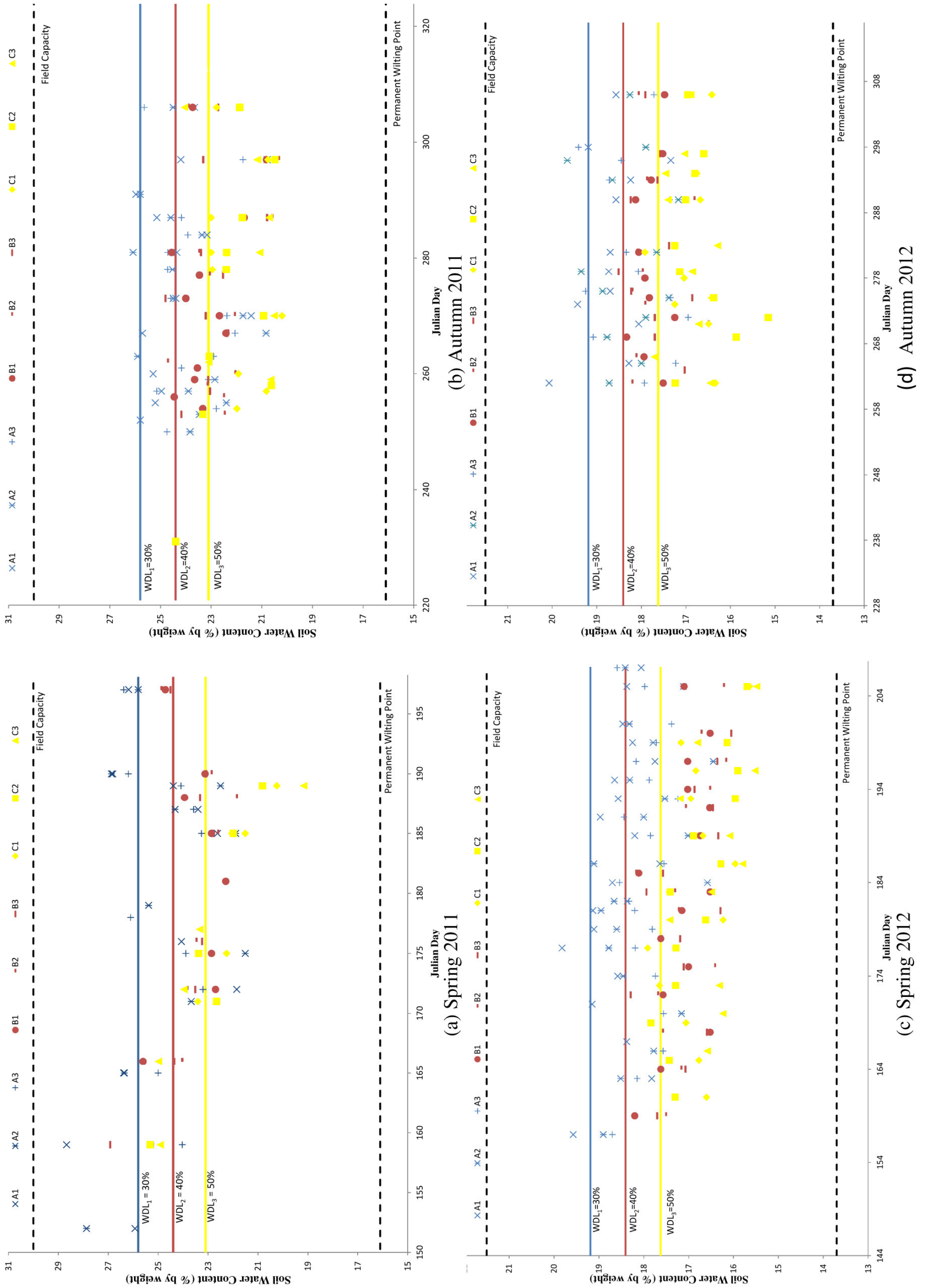
The statistical differences among the effects of different allowable soil water depletion levels on ET_c, *WUE*, yield, and quality parameters of subsurface drip irrigated broccoli were tested with Fisher's least significant difference (LSD) test ($P \leq 0.05$) using the analysis of variance (ANOVA) for a randomized complete block design with the statistical package program of MSTAT-C (Freed *et al.* 1988).

RESULTS AND DISCUSSION

The total growing periods of broccoli after transplanting were determined as 70 and 72 days for spring cultivation periods, and 104 and 97 days for autumn cultivation periods of 2011 and 2012, respectively. Due to climatic factors, the short growing periods during spring and long growing periods during autumn cultivation periods for broccoli were also stated by Erdem *et al.* (2010) and Gutezeit (2004). Furthermore, some climatic data measured at the weather station during the study and long term averages are given in Table 3. In terms of average monthly temperatures, the experimental seasons of 2011 were cooler, and those of 2012 were hotter, than those of long term averages.

While the scheduling of irrigations treatments were based on the tensiometer readings at 20 cm soil depths, soil moistures through the effective root zone of broccoli (0-40 cm) were also measured by gravimetric method when tensiometer readings indicated the time to initiate irrigations (Figure 1). The mean of measured soil moistures of each treatment replicate are presented in Table 4. There were small deviations between the actual and the targeted values of the soil moistures to initiate irrigations for each treatment. This occurred because of reasons such as checking of tensiometers daily, some deviations in calibration values of tensiometer readings at 20 cm soil depths against the soil moistures determined by gravimetric method through effective root depth, time differences therefore shading differences between calibration and usage of tensiometers in the field, etc. The mean values of standard deviations for the measured soil moistures through the two seasons of 2011 are 1.5, 1.35, and 1.8% for the treatments A, B, and C, respectively. On the other hand, the mean values of standard deviations for the measured soil moistures through the two seasons of 2012 are 0.72, 0.55, and 0.62% for the treatments A, B, and C, respectively. As a result, when we take account of the mean allowable soil water depletion levels at which irrigations were initiated through the four seasons (Table 4), the irrigations of the research treatments during the four seasons were started after the available soil moistures had been depleted by approximately 39, 49, and 59% instead of the targeted values of 30, 40, and 50% for treatments A, B, and C, respectively.

The seasonal cumulative Class A pan evaporation (E_p); the seasonal cumulative grass reference crop evapotranspiration (ET_o) estimated with the modified Penman equation Vantage Pro2 of Davis Weather Station; and the seasonal cumulative actual evapotranspiration (ET_c) of broccoli determined based on the water balance approach with the seasonal irrigation amounts of irrigation for the research treatments as well as the seasonal rainfall amounts of rainfall for each season are presented in figures such as Figure 2 for the 2011 spring season of 2011. According to the given monthly values in Table 3, the seasonal rainfalls were 83.9, 61.5, 70.4, and 78.2 mm, while the seasonal ET_o values



(a) Spring 2011

(b) Autumn 2011

(c) Spring 2012

(d) Autumn 2012

Figure 1. Soil moisture content determined by gravimetric method before irrigations of each treatment.

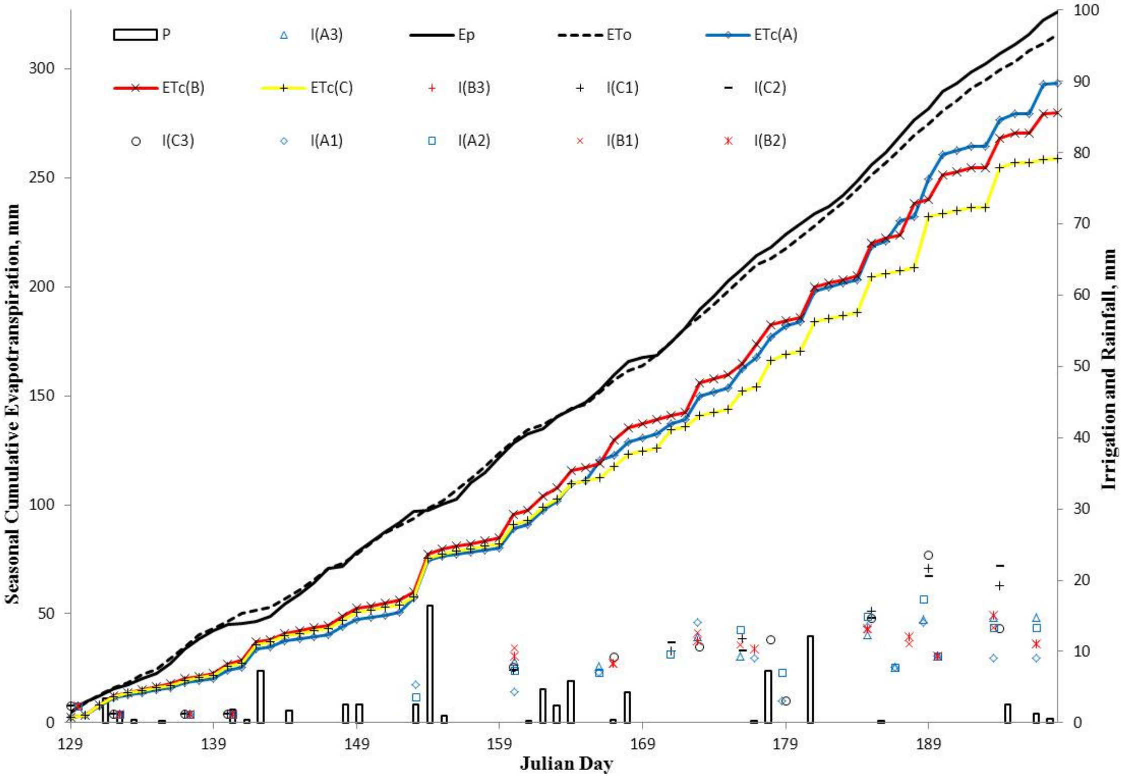


Figure 2. Measured cumulative actual evapotranspiration for treatments (ET_c), cumulative reference evapotranspiration (ET_o), and cumulative Class A pan evaporation (E_p) along with the irrigation depths applied to each plot (I) as well as precipitation (P) during spring season of 2011.

were 316, 330, 362, and 323 mm for the spring, and autumn periods of 2011, and 2012, respectively. In addition, the average seasonal irrigation amounts and the number of irrigations for the treatments are presented in Table 5. The highest seasonal irrigation amount belonged to the autumn period of 2011 because of the long hot season without rain and very dry soil conditions during the initial crop development stages of broccoli. The lower number of irrigations were applied in the spring seasons, mostly due to frequent rainfalls events.

The mean values of ET_c, head weight, *WUE*, head diameter, biomass, dry matter, vitamin C, titratable acidity, pH, and TSS for treatments and cultivation periods along with summary statistics are presented in Table 6. In general, there seemed to be a trend indicating that the ET_c, head diameter, head weight, and plant weight decreased against the increases of soil water depletion levels. The seasonal ET_c of treatments changed between 210 and 294 mm. The changes in soil water storages of replication plots were also found to contribute to these $\mathrm{ET_c}$ variations. While they changed from season to season, the ET_c values of treatments A and B were higher (20, and 10%, respectively) than that of treatment C. It is clear from Table 6 that the effects of soil water depletion levels (treatments A, B, and C) to initiate subsurface drip irrigation on ET_c for each cultivation season were statistically significant. In addition, the seasonal ET_c was also significantly affected by both soil water depletion levels and cultivation seasons.

We could not determine any statistically significant effect of soil water depletion levels on the other studied yield and quality

Table 3. Some climatic data measured at the weather station of research station during the study.

Season	Month	T[a] (°C)	P[b] (mm)	RH[c] (%)	WS[d] (km/h)	SR[e] (W/m^2)	ET_0[f] (mm)	E_P[g] (mm)
2011 Spring	May[h]	15.4	21.9	71.2	4.1	231	87.2	87.6
	June	18.9	57.3	67.9	4.0	273	140.8	146.0
	July[h]	22.3	4.6	64.8	4.9	270	93.9	92.4
2011 Autumn	August[h]	19.5	5.2	63.5	4.8	252	118.1	126.6
	September	16.7	14.0	68.8	3.7	211	112.2	140.0
	October	12.0	18.7	69.4	3.7	127	67.8	71.3
	November[h]	3.8	23.6	81.3	3.1	50	18.3	19.7
2012 Spring	May[h]	16.5	61.0	76.4	4.4	218	42.3	36.4
	June	20.7	4.0	66.4	4.1	296	157.3	172.1
	July[h]	23.0	5.4	64.4	4.1	267	158.9	153.5
2012 Autumn	August[h]	21.4	2.2	61.4	3.9	237	97.5	126.0
	September	19.3	3.6	61.7	3.4	206	118.3	133.2
	October	15.4	25.4	70.0	2.6	140	78.1	73.4
	November[h]	12.1	47.0	79.9	3.2	69	14.9	17.5
Long Period (1965-2007)	May	16.2	59.7	61.4	5.0	238		
	June	19.6	37.9	58.5	4.3	266		
	July	22.1	10.2	55.7	5.4	254		
	August	21.9	6.9	57.2	5.0	240		
	September	17.5	17.7	59.1	4.3	201		
	October	12.5	36.7	66.7	3.6	135		
	November	6.9	43.8	70.9	4.0	87		

[a] Mean temperature; [b] Total rainfall; [c] Mean Relative Humidity; [d] Mean Wind Speed; [e] Mean Solar Radiation; [f] Total reference evapotranspiration, [g] Total evaporation from Class A pan. [h] Computed for the data between the dates of transplantation/harvest and the last/first day of the months (Table 2) in which the season started or ended.

Table 4. The mean measured soil moisture content determined by gravimetric method through effective root zone of broccoli (0-40 cm) at the plots of research treatments before initiation of irrigations.

Season	Treatments with Replicates											
	A (WDL_1= 30%)				B (WDL_2= 40%)				C (WDL_3= 50)			
	A1	A2	A3	Mean	B1	B2	B3	Mean	C1	C2	C3	Mean
Spring 2011	25.0	24.6	24.6	24.7	23.7	23.6	24.0	23.8	22.6	22.8	23.0	22.8
Autumn 2011	24.7	23.9	24.2	24.3	23.3	22.8	23.2	23.1	22.2	22.1	22.0	22.1
Spring 2012	18.6	18.3	18.5	18.5	17.1	17.1	17.2	17.1	16.4	16.3	16.5	16.4
Autumn 2012	18.7	18.3	18.2	18.4	17.8	17.7	17.7	17.7	16.9	16.6	16.9	16.8

Table 5. The mean values of seasonal irrigation amounts (mm) and the mean number of irrigations for treatments.

Season	Irrigation Amounts (mm)			Number of Irrigations		
	Treatments			Treatments		
	A	B	C	A	B	C
Spring 2011	119.7	105.1	94.3	15.3	13	11
Autumn 2011	246.6	226.8	209.1	29.7	25.7	22.3
Spring 2012	152.3	123.3	118.1	25	18.7	18
Autumn 2012	130.1	106.9	97.3	31.7	29.3	26.3

Table 6. The effects of three water depletion levels and cultivation seasons on actual evapotranspiration, and some yield and quality attribute of subsurface drip irrigated broccoli.

Cultivation season	Treatments	ETc (mm)	Head weight (g)	Water use efficiency (kg m^{-3})	Head diameter (cm)	Biomass (g)	Dry matter (%)	Vitamin C (mg 100 g^{-1})	Titrable acidity (%)	pH	TSS (%)
Spring 2011	A	294^{a**}	774	9.40	18.2	1285	9.4	114.4	0.26	6.2	7.20
	B	283^{a}	745	9.40	17.8	1225	9.9	109.8	0.25	6.1	7.13
	C	259^{b}	670	9.24	16.8	1273	10.1	131.2	0.31	6.2	7.77
	Average	279^{a*}	730^{a**}	9.35^{a**}	17.6^{a**}	1261^{a*}	9.8^{b**}	118.5	0.28^{b**}	6.2^{b**}	7.37^{a**}
Autumn 2011	A	288^{a*}	265	3.28	13.1	1206	12.1	115.7	0.32	6.8	4.67
	B	260^{ab}	230	3.16	12.3	1192	14.3	101.7	0.37	6.4	5.40
	C	241^{b}	207	3.08	11.6	1188	13.2	111.9	0.33	6.5	4.60
	Average	263^{b}	234^{b}	3.17^{b}	12.3^{b}	1195^{b}	13.2^{a}	109.8	0.34^{a**}	6.6^{a**}	4.89^{b}
Spring 2012	A	291^{a**}	265	3.26	15.8	1102	9.7	104.1	0.28	6.1	9.73
	B	261^{ab}	273	3.76	15.0	997	10.0	97.4	0.27	6.0	10.20
	C	233^{b}	185	2.83	14.3	781	10.4	99.5	0.29	6.1	8.10
	Average	262^{a**}	241^{b**}	3.28^{b**}	15.0^{b**}	960^{b*}	10.0	100.3	0.28^{a*}	6.1^{b**}	9.35^{a*}
Autumn 2012	A	256^{a**}	594	8.33	17.5	1261	10.0	110.9	0.24	6.6	7.20
	B	230^{ab}	546	8.46	16.4	1229	9.8	94.3	0.26	6.6	7.53
	C	210^{b}	485	8.26	15.7	1185	10.0	117.4	0.25	6.6	7.83
	Average	232^{b}	541^{a}	8.35^{a}	16.5^{a}	1225^{a}	9.9	107.5	0.25^{b}	6.6^{a}	7.52^{b}

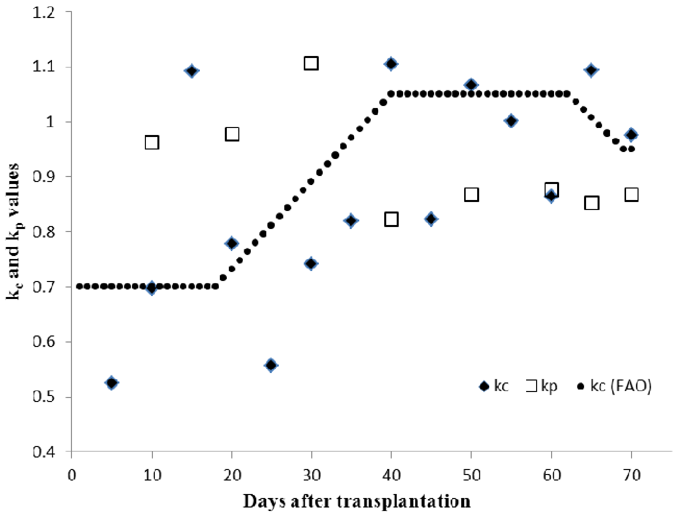
a, b: LSD groups; *: Significant at the $P< 0.05$, **: Significant at the $P< 0.01$.

attributes of broccoli. The marketable yield determined from head weight across all treatments ranged from 6.6 to 27.6 t ha^{-1}. Possibly due to narrow range of soil-water depletion levels (39-59% *WDL* against that of 25–65% *WDL* by Gutezeit (2004)) and the soil types (clay, and clay loam against alluvial loam, and loessal loam by Gutezeit (2004)) studied in this research, there was no significant differences in the studied yield and quality parameters of broccoli at each growing season. On the other hand, the *WUE* values ranged from 9.40 to 2.83 kg m^{-3}. While treatments A and B produced the highest *WUE* values in 2011 and 2012, respectively; treatment C produced the smallest *WUE* values throughout the four seasons. This result may indicate that all treatments, even treatment A, created deficit soil water conditions in the root zone of broccoli through all the four seasons. In addition, the seasonal effects of the treatments on the head weight, *WUE*, head diameter, plant weight, titratable acidity, pH, and TSS were statistically significant for both years. Similar results as indicated in the introduction section were also obtained by Erdem *et al*. (2010) in a one-year study. These results may be due to some differences in climatic and soil conditions, e.g. under clay soil condition (year of 2011), the head diameter, head weight, plant weight, and TSS of spring season were higher than those of autumn season (Table 6). However, under clay loam soil condition (year of 2012), only TSS, and titratable acidity of spring season were higher than those of autumn season.

The calculated ten- and five-day averages of *Kp* and *Kc* data, respectively, for spring, and autumn seasons are presented in Figure 3. In this figure, the *Kc* curves based on the *Kc* values recommended by Allen *et al*. (1998) are also shown. For spring cultivation period, the lowest (0.53) and the highest (1.1) *Kc* values were observed during the initial and mid-season growth stages of crop, respectively. For autumn cultivation period, the lowest (0.64) and the highest (1.20) *Kc* values were observed during the crop development and mid-season growth stages of crop, respectively. In general, the *Kc* values during the initial growth stage for the autumn season are higher than those for the spring season. This may be expected since Lopez-Urrea *et al*. (2009) indicated that the initial *Kc* must be high to account for the need for frequent watering under the high seasonal ET_o conditions for the case of late summer plantings. Therefore, the *Kc* curve by Allen *et al*. (1998) does not represent our data well, especially during initial growth stage of broccoli in the autumn season. In order to relate Class A pan evaporation to ET_o of the modified Penman equation, the determined empirical *Kp* coefficients varied between 0.82 and 1.11 for the spring, and between 0.78 and 1.14 for the autumn cultivation seasons. Possibly due to frequent rainfall events, the variations of *Kp* values during the crop development stage in the spring season, and during the whole growing season in the autumn season were high. Our results were higher than those given by Allen *et al*. (1998), possibly due to differences in the equations used to calculate ET_o, i.e. FAO Penman-Monteith against modified Penman.

CONCLUSIONS

According to the results of this study, in subsurface drip irrigated broccoli grown in clay and clay loam soils in one growing season, irrigating the crop when the available soil moisture contents of the soils were depleted approximately 39, 49, and 59% did not cause statistically significant differences in head weight, water use efficiency, head diameter, biomass, dry matter, vitamin C, titratable acidity, pH, and TSS. However, significant differences were found for all variables, except vitamin C, between the cultivation seasons (spring and autumn). Furthermore, the actual evapotranspiration values were significantly affected by the irrigation treatments and cultivation seasons.



a) Spring cultivation

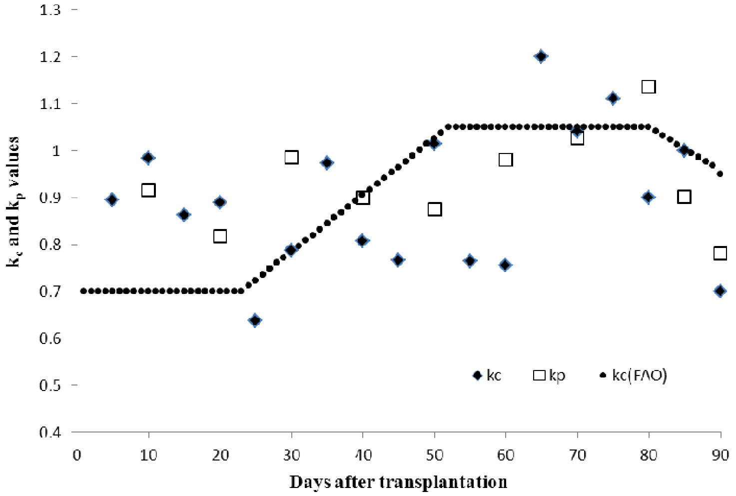


Figure 3. Class A pan coefficients (Kp), and crop coefficients (Kc) of the treatment A for spring (a) and autumn (b) cultivations along with the crop coefficients recommended by Allen *et al*. (1998).

REFERENCES

1. Allen, R. G., Pereira, L.S., Raes, D. and Smith, M. 1998. *Crop Evapotranspiration: Guidelines for Computing Crop Water Requirements: Paper No. 56.* FAO Irrigation and Drainage, FAO, Rome, Italy.
2. Anonymous. 1960. Irrigation. 15: Trickle Irrigation. 7. In: "*USDA-SCS National Engineering Handbook*", USA.
3. AOAC. 1970. *Official Methods of Analysis*. 11th Edition, Association of Official Analytical Chemists, Washington, DC, USA.
4. Camp, C.R. 1998. Subsurface Drip Irrigation: A Review. *T. ASAE*, **41**: 1353-1367.
5. Doorenbos, J. and Kassam, A. H. 1979. *Yield Response to Water: Paper No. 33.* FAO Irrigation and Drainage, FAO, Rome, Italy.

6. Erdem, T., Arın, L., Erdem, Y., Polat, S., Deveci, M., Okursoy, H. and Gültaş, H.T. 2010. Yield and Quality Response of Drip Irrigated Broccoli (*Brassica oleracea* L. var. *italica*) under Different Irrigation Regimes, Nitrogen Applications and Cultivation Periods. *Agr. Water Manage.*, **97**: 681-688.
7. Freed, R. D., Eisensmith,S. P., Everson, E. H., Webber, M., Paul, E. and Islieb, D. 1988. User's Guide to MSTAT-C a Software Program for the Design, Management, and Analysis of Agronomic Research Experiment, MSU, USA.
8. Gutezeit, B. 2004. Yield and Nitrogen Balance of Broccoli at Different Soil Noisture Levels. *Irri. Sci.*, **23**: 21-27.
9. Howell, T. A., Cuenca, R. H. and Solomon, K. H. 1992. Crop Yield Response. 5. In: "*Management of Farm Irrigation Systems*", (Eds.): Hoffman, *et al.*, ASAE, St. Joseph, MI, USA.
10. Kaur, C. and Kapoor, H. C. 2002. Anti-oxidant Activity and Total Phenolic Content of Some Asian Vegetables. *Int. J. Food Sci. Tech.*, **37**: 153-161.
11. Klein, B. P. and Perry, A. K. 1982. Ascorbic Acid and Vitamin A Activity in Selected Vegetables from Different Geographical Areas of the United States. *J. Food Sci.,* **47**: 941-945.
12. Klute, A. 1986. *Methods of Soil Analysis.* Part I. "Physical and Mineralogical Properties". 2nd Edition, ASA-SSSA Agronomy No. 9, Madison, WI.
13. Lopez-Urrea, R., Montoro, A., Lopez-Fuster, P. and Fereres, E. 2009. Evapotranspiration and Responses to Irrigation of Broccoli. *Agr. Water Manage.*, **96**: 1155-1161.
14. Lukicheva, E. L. 1968. The Changes in Some Oxidation-reduction Enzymes of Spring Wheat in Drought: English Summary. *Tr. Inst. Bot. Akad. Nauk. Azerb. Kaz. SSR*, **25**: 23-29.
15. Page, A. L., Miller, R. H. and Keeney, D. R. 1982. *Methods of Soil Analysis*. Part II. "Chemical and Microbiological Properties". 2nd Edition, ASA-SSSA Agronomy No. 9, Madison, WI.
16. Pruitt, W. O. and Doorenbos, J. 1977. Empirical Calibration: A Requisite for Evapotranspiration Formulae Based on Daily or Longer Mean Climatic Data?. *In Proceedings of the International Round Table Conference on "Evapotranspiration"*, International Commission on Irrigation and Drainage, Budapest, Hungary, 20 PP.
17. Reich, D., Godin, R., Chavez, J. L. and Broner, I. 2012. *Subsurface Drip Irrigation (SDI).* Fact Sheet No. 4.716, Colorado State University Extension, 12/01. Available at: www.ext.colostate.edu
18. Sikora, E., Cieslik, E. and Topolska, K. 2008. The Sources of Natural Antioxidants. *Acta Sci. Pol. Technol. Aliment.*, **7**: 5-17.
19. Soil Survey Staff. 1999. *Keys to Soil Taxonomy*. 8th Edition, US Department of Agriculture-Soil Conservation Service, Washington, DC, USA.
20. Thompson, T. L., Doerge, T. A. and Godin, R. E. 2002. Subsurface Drip Irrigation and Fertigation of Broccoli. I. Yield, Quality, and Nitrogen Uptake. *Soil Sci. Soc. Am. J.*, **66**: 186-192.
21. Toivonen, P. M. A., Zebarth, B. J. and Bowen, P. A. 1994. Effect of Nitrogen Fertilization on Head Size, Vitamin C Content and Storage Life of Broccoli (*Brassica oleracea* var. Italica). *Can. J. Plant Sci.*, **74**: 607-610.
22. TSMS. 2012. *Turkish State Meteorological Service*. Available at: http://www.dmi.gov.tr
23. Vallejo, F., Tomas-Barberan, F. and Garcia-Viguera, C. 2003. Health-promoting Compounds in Broccoli as Influenced by Refrigerated Transport and Retail Sale Period. *J. Agr. Food Chem.*, **51**: 3029-3034.
24. Vinson, J. A., Hao, Y., Su, X. and Zubik, L. 1998. Phenol Antioxidant Quantity and Quality in Foods: Vegetables. *J. Agr. Food Chem.*, **46**: 3630-3634.
25. Yoldas, F., Ceylan, S., Yagmur, B. and Mordogan, N. 2008. Effects of Nitrogen Fertilizer on Yield Quality and Nutrient Content in Broccoli. *J. Plant Nutr.*, **31**: 1333-1343.
26. Zaicovski, C. B., Zimmerman, T., Nora, L., Nora, F. R., Silva, J. A. and Rombaldi, C. V. 2008. Water Stress Increases Cytokinin Biosynthesis and Delays Postharvest Yellowing of Broccoli Florets. *Postharvest Biol. Tec.*, **49**: 436-439.

اثر سه سطح تخلیه رطوبت خاک روی تبخیر وتعرق ، اجزای عملکرد و بعضی صفات کیفی کلم بروکلی در آبیاری قطره ای زیر سطحی

ت. اوزتکین، س. اوزتکین، و ن. گبول اوغلو

چکیده

هدف این پژوهش تعیین تبخیر و تعرق و واکنش بعضی اجزای عملکرد کلم بروکلی (*Brassica oleraceae* L.) تحت آبیاری قطره ای زیر سطحی بود. تیمارهای آبیاری آزمایش شامل آبیاری در زمانی بود که آب دردسترس خاک در حد ۳۰٪، ۴۰٪، و ۵۰٪ ، تخلیه شده بود و تیمارهای دوره رشد هم شامل بهار و پاییز بود. آزمایش مزبور با طرح آماری بلوک های کامل تصادفی در آب و هوای نیمه خشک منطقه توکات (Tokat) در ترکیه در خاک های رسی و لومی رسی به ترتیب در طی سال های ۲۰۱۱ و۲۰۱۲ اجرا شد. میانگین واقعی (اندازه گیری شده) تخلیه رطوبتی تیمارهای آزمایشی برابر ۳۹٪، ۴۹٪ و ۵۹٪ بود و منجر به ایجاد تفاوت معنی دار در تبخیر و تعرق واقعی بین دوره های رشد در محدوده ۲۱۰ تا ۲۹۴ میلی متر شد. گفتنی است که ضریب گیاهی(Kc) به دست آمده در طی مراحل اولیه رشد کلم بروکلی برای کشت پاییزه از توصیه های استاندارد تبعیت نمی کرد. افزون بر این، هیچ گونه تفاوت معنی دار آماری از تاثیر تیمار های آبیاری روی اجزای عملکرد و کیفیت محصول به دست نیامد ولی اثر دوره رشد معنی دار بود.