

Water-Yield Relationships in Deficit Irrigated Cabbage

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Abstract

This trial was realized in Yenisehir Vocational School between 2007 and 2008 on the purpose of study out the influence of lack of water in four growth periods of cabbage. In this trial, fourteen irrigation treatments was formed considering the growth periods (establishment, vegetative, yield formation and ripening) of cabbage (*Brassicaceae Oleracea var. capitata L. Grandslam F1*) and the results obtained from these treatments were evaluated. According to the content of the treatments, the water amount to the plants varied between 0 and 524 mm in the 2007 year, and between 0 and 536 mm in the 2008 year. Water consumption of cabbage in the 2007 year ranged between 200 and 795 mm and in the 2008 year ranged between 190 and 802 mm. Yield, head weight, diameter, height and dry matter ratio were determined statistically important. In 2007 and 2008 years, the maximal yield were found as 74.2 t ha⁻¹ and 72.4 t ha⁻¹ in the E₁₀₀V₁₀₀Y₁₀₀R₁₀₀ treatments, while the minimal yield were found as 2.0 t ha⁻¹ and 4.0 ha⁻¹ in the E₀V₀Y₀R₀ treatments, respectively. Water- yield relationship factor (k_y) in 2007 and 2008 years were found as 0.96 and 0.97, respectively.

Key words: Cabbage, deficit irrigation, WUE and IWUE values, yield and quality parameters of cabbage, irrigation planning.

Introduction

Van Straten et al., (2010) stated that the greenhousing is worldwide the fastest growing sector of all agricultural production activities. There are two essential causes for this. First, the plant grows in greenhouse differently from the external environment, in this way supplying some way of abri from the direct effect of the external environment. This allows the production of crops at that specific place. Second, the greenhouse allows to be produced of many crops. This situation permits the grower to direct the farming in a preferable aspect. It causes to more crop yield, extended production period, less use of chemicals, better quality. The value added per decare in greenhouse crops is much more than that in field agriculture.

The world's the biggest cabbage producers are China, India and Russia with 33 400 000, 9 000 000 and 3 500 000 tons, respectively (**FAOSTAT, 2014**). Russia is the largest cabbage consuming country. Turkey is one of the significant cabbage producer with 785 791 tons in the world (**FAOSTAT, 2016**). The cabbage is considered to be of European origin and grows along the North Sea, the English Channel and Northern Mediterranean. Lahana is preferred because of its various advantages such as the growth of the various climate and soil conditions, its easy of production and storage and its high food value. The cabbage is eaten up as cuisine dish in our country along with salad, raw, wrap and pickle (**Vural et al., 2000**). **Sezen, (2005)** found that surface irrigation doesn't suggest because of the low of irrigation efficiency result from drainage and salinity in plantations. Irrigation with less amount of water is important such as sprinkler and drip irrigations. There is a need for more efficient irrigation systems support to improve agricultural targets and irrigation efficiency. Moreover, irrigation water by drip irrigation is used more effective and over-irrigation causes yield losses. Thus, irrigation method is really crucial with regard to irrigation planning (**Anonymous, 2005**).

Irrigation planning aims of the soil water deficit to not falling below the critical level for a specific soil and crop condition. This may enable to avoid the harmful effect of water stress by means of estimating the earliest date (**Ritchie and Johnson, 1990**). Irrigation water is used effectively thanks to drip irrigation system. Extreme irrigation lowers yield, while insufficient irrigation reduces production and brings about water stress.

Irrigation planning with drip irrigation relies on approaches related to evapotranspiration estimations (**Bar-Yosef and Sagiv, 1982; McNeeish et al., 1985; Clough et al., 1990; Hartz, 1993**) and permissible soil-water consumption (**Bogle et al., 1989**). K values usually difficult to create accurately. Because regional conditions, soil properties, crop physiology and cultural practices affects to K values. A suggested K value for irrigation planning must be high enough to avoid the water stress caused by the needs and specific local situations. It remains low enough for effective water management (**Yuan et al., 2003**)

Some studies have been made to research the effect of deficit irrigation on cabbage. The purposes of this trial were to obtain a prospectus for cabbage growers and to determine drip irrigated cabbage response to deficit irrigation modes in Bursa conditions. As a result, drip irrigation method preferred in the study.

Material and Methods

The trial was realized in Yenisehir Vocational School, Bursa in 2007 and 2008 years. For practical purposes, plastic greenhouse (8 m x 40 m) was used. In the study place, winters

are cold and summers are hot. The average annual rainfall and temperature values for the region where the greenhouse experiments were made in 2007 and 2008 were 482,9-630,7 mm and 13,6-12,9 °C respectively. While the average minimum temperature for 2007 and 2008 were -6,6 - (-5,9) °C between January and December, the average maximum temperature in August was measured as 32,9 and 34,6 °C (**Anonymous, 2010**). The soil of study place was sandy clay and pH value of soil ranged between 7.86 and 8.05. The specific features of the soil are given in Table 1.

A suitable well for irrigation was used as the water source in the trial area and the quality of irrigation water was determined as C₁S₁. 3x15 NPK manure was utilized to trial plots while the cabbages were being planted, and 75 kg of 3x15 NPK manure per decare were utilized. The urea form of the nitrogen was applied to the plots together with water. 25 kg manure (% 46 N) per decare in vegetative period was applied as the first manure application, while 25 kg manure (% 46 N) per decare was applied along with irrigation water during the yield formation period. Furthermore, during the vegetative and yield formation periods the generative growth of plant was supported by using 25 kg of magnesium nitrate manure per decare (11 – 0 – 0 + 16 MgO - Nitrogen % 11 and MgO % 16). The cabbage seedlings were transplanted into the trial pots on August 03, 2007 and on August 01 2008 years, respectively. Seedlings were planted on the same line and at a distance of 60 cm between the plant lines. The specific parameters of cabbage are yield, head weight, diameter, height and dry matter ratio. The four heads harvested from the middle of the plots were weighed and head weight were determined by the averages of these values. Head diameter and height were calculated by measuring with a scale/ruler. The dry matter ratio of the cabbage was calculated by drying the leaves of the fruit in a drying oven for 48 hours and at 65°C. The trial design was formed by randomly distributing fourteen different treatments on three different blocks. The size of trial plots was 4 m² (2.0 m x 2.0 m) and the intervals between blocks and plots were 2.0 m and 0.75 m, respectively. Each plot had 9 plants and 0.60 m apart between the rows with 0.60 m spacing in each row. The detail of one of the trial plot is shown in Figure 1.

In growth periods of the cabbage (establish, vegetative, yield formation and ripening) were formed fourteen deficit irrigation treatments based on full or deficit irrigation applications, 0.75-50-0.25% of the deficit irrigations were applied in different growth periods of the plant (establishment, vegetative, yield formation and ripening), while in the fully irrigated treatments, all of this water was applied. In line with this planning, irrigation treatments were planned like this: E₁₀₀V₁₀₀Y₁₀₀R₁₀₀, E₇₅V_{YR}, E₅₀V_{YR}, E₂₅V_{YR}, EV₇₅YR, EV₅₀YR, EV₂₅YR, EVY₇₅R, EVY₅₀R, EVY₂₅R, EVYR₇₅, EVYR₅₀, EVYR₂₅, E₀V₀Y₀R₀ (Table 2.).

In the trial, the plants were irrigated drip irrigation method and water was provided from an irrigation well. The specific features of the irrigation water utilized in the study are given in Table 3. The water has low-sodium risk, has a medium EC and is in C₂S₁ class. In growth periods of plant, the damp contains of the soil was followed before and after irrigation with a gravimetric method in every 30 cm till 120 cm depth.

ET, was calculated by means of water balance equation (Eq. 1)¹¹.

$$ET = I + P - R_f - D_p \pm \Delta S \quad (1)$$

Where, ET represents the evapotranspiration, I shows the irrigation water (mm), P is the precipitation, R_f is the surface flow (mm), D_p is deep drainage (mm) and ΔS is the between two soil water changing in effective root depth (mm/90 cm). Before planting seedlings, water was used to the tomato with the drip irrigation method. Total precipitation (P) and surface flow (R_f) was omitted and the soil moisture between the depths of 90 to 120 cm of the soil is accepted as the deep drainage (D_p). However, during the growing period, soil moisture changes between 90 and 120 cm were not followed and the deep drainage was accepted as “0”. In this trial, the relationships between yield and ET is defined by the Steward Model (Eq.2) (Stewart et al., 1975; Doorenbos and Kassam, 1979). The equation can be showed as

$$\left(1 - \frac{Y_a}{Y_m}\right) = ky \left(1 - \frac{ET_a}{ET_m}\right) \quad (2)$$

Where Y_m (t/ha) and Y_a (t/ha) are maximal and real yield, respectively, ET_m (mm) and ET_a (mm) are maximal and real evapotranspiration, respectively. The yield response factor is shown as k_y . WUE values were determined to assess irrigation efficiency in treatments. WUE and IWUE terms refer to contribution of irrigation water to effective use of plant production stages (Bos, 1980). The ratio of yield (YLD) to ET_a expressed as WUE and it is demonstrated as $WUE = YLD/ET_a$ (kg/m^3). IWUE was predicted by the following equation;

$$IWUE(th a^{-1}) = \frac{YLD - YLD_{rainfed}}{IRGA} \quad (3)$$

Where YLD is yield and $YLD_{rainfed}$ is the yield found from the rainfed treatment, IRGA is the seasonal water amount (mm). The damp content of the soil till 90 cm depth was calculated before the seedlings were planted into the soil. All treatments were completed in the level of field capacity. In 2007 year, irrigation was started on August 10, 2007 and in 2008 year was started on August 08 and irrigation was done every 7 days. The irrigation water for the four growth stages are given in Table 4. Crop evapotranspiration for the different growth stages are given in Table 5.

Product efficiency and quality parameters are evaluated. Variance analysis was done with the values of product productivity and productivity components by using MSTAT-C and MINITAB software (Steel and Torrie, 1980).

Results

In 2007 and 2008 years, maximal irrigation water was found in $E_{100}V_{100}Y_{100}R_{100}$ treatment as 524 – 536 mm and minimal irrigation water was found in $E_0V_0Y_0R_0$ treatment as 0 – 0 mm, respectively. Plant water consumption of the cabbage (ET_c) went up with the increment in the water amount. In $E_{100}V_{100}Y_{100}R_{100}$ and $E_0V_0Y_0R_0$ treatments, it was found as 200–795 mm in 2007 year and as 190 – 802 mm in 2008 year, respectively. The irrigation water and yield values are given in Table 6.

Linear relationships between ET_c with Y_a , and IW with Y_a were observed for 2007 year. The relationship equation is as follows; $Y_a = 0.1166ET_c - 16.57$ with $R^2 = 0.95$ and $Y_a = 0.1343IW + 2.0828$ with $R^2 = 0.92$ (Fig 2 and Fig 3).

Linear relationships between ET_c with (Y_a), and IW with Y_a were observed for 2008 year. The relationship equation is as follows; $Y_a = 0.1343ET_c - 2.0828$ with $R^2 = 0.92$ and $Y_a = 0.1274IW + 3.1626$ with $R^2 = 0.93$ (Fig 3 and Fig 4).

As for that the trial results, irrigation applications considerably influenced the yield (Fig. 2 and Fig. 3), and when they were assessed as the values of 2007 and 2008, the maximal values of yield were found as 74.2 t ha^{-1} and 72.4 t ha^{-1} in $E_{100}V_{100}Y_{100}R_{100}$ treatment (Table 8 and Table 9).

When $E_{100}V_{100}Y_{100}R_{100}$ treatment was made comparison with the other irrigation treatments, yield losses were determined as 0.5%, 2.6%, 5.0%, 8.5%, 10.4%, 11.2%, 16.9%, 18.2%, 24.5%, 35.4%, 41.6%, 46.6% and 3610.0% in 2007 year and 0.6%, 1.4%, 2.4%, 6.6%, 7.1%, 21.7%, 13.3%, 19.3%, 25.0%, 25.7%, 39.0%, 43.7% and 1710.0% in 2008 year. In the trial, it was study out that deficit irrigation has an important effect on yield and quality parameters at $P < 0.05$ level.

While a positive straight line relationship was obtained between the water amount and the yield, head weight, diameter, height; a negative straight line relationship was obtained between the irrigation amount and dry matter ratio. As for that the relationship, these results were determined: head weight (2007) = $0.01IW + 0.3464$, $R^2 = 0.96$ and head weight (2008) = $0.0099IW + 0.271$, $R^2 = 0.94$ (Fig. 4.a.); head diameter (2007) = $0.0447IW + 3.6228$, $R^2 = 0.84$ and head diameter (2008) = $0.043 + 4.8106$, $R^2 = 0.85$ (Fig. 4.b). Head height (2007) = $0.0399IW + 4.6067$, $R^2 = 0.88$ and head height (2008) = $0.0404IW + 5.4357$, $R^2 = 0.90$ (Fig. 4.c.); dry matter ratio (2007) = $-0.012IW + 13.876$, $R^2 = 0.92$ and dry matter ratio (2008) = $-0.0124 + 14.072$, $R^2 = 0.90$ (Fig. 4.d.).

Crop yield response factor (k_y)

Crop yield response facto (k_y) is defined as the linear relationship between relative crop evapotranspiration and relative yield decrease. This is accepted to be the response of the yield to the relative crop evapotranspiration. In another saying, it indicates the decrease in the yield corresponding to each level of deficit in water consumption. Seasonal crop yield factors (k_y) were determined as 0.96 (2007 year) and 0.97 (2008 year) (fig.5). The increase in k_y value is due to the increase in the water deficiency. This result shows that the seasonal crop yield factors are a bit low in the period of cabbage but it is accordant with the crop yield factors in the every growth periods given in literature. The difference of results may refer to the differences between the empirical, soil conditions, climatic.

Water use efficiencies

WUE and IWUE values of the 2007 and 2008 years, when the trial was performed, were obtained different allied to the treatments (Table 10). The maximal WUE values for 2007-2008 years were found as 0.09, 0.10, 0.10 – 0.09, 0.09, 0.10 and 0.09, 0.09, 0.10 – 0.09, 0.09, 0.09 kg mm^{-1} from $E_{75}V_{YR}$, $E_{50}V_{FYR}$, $E_{25}V_{YR}$ and $E_{75}V_{FYR}$, $E_{50}V_{FYR}$, $E_{25}V_{FYR}$ treatments, respectively. IWUE values for 2007-2008 years were found as 0.14, 0.14, 0.14 – 0.14, 0.15, 0.16 kg.mm^{-1} and 0.14, 0.14, 0.15 – 0.14, 0.15, 0.14 kg.kg.mm^{-1} respectively. When WUE and IWUE values were taken into consideration, the maximal WUE and IWUE values

were obtained from establishment and vegetative periods and the lowest value was obtained from yield formation and ripening periods. In another saying, the maximal yield was found and the most water was saved with deficit irrigation only in the establishment and early vegetative periods of the cabbage.

Discussion

In our trial, irrigation treatments considerably influenced yield, head height, diameter, weight and dry matter. Total water amounts range from 380 to 500 mm subject to the length of growing season and climate (Doorenbos and Kassam, 1979). Kumar and Sahu (2013) reported that the total depth of water for cabbage applied were 107 and 268 mm, respectively. Agrawal et al. (2018) determined that water used for cabbage varied from 189 to 710 mm. Kiziloglu et al. (2007) specified that 449.4 mm irrigation amount and 932 mm evaporation were applied to the plants in whole growth period. Wahome et al. (2009) stated that water applied for cabbage varied from 420 to 491 mm in different treatments and two mulch materials. Sammis and Wu (1989) found that the irrigation amount ranged from 0.42 to 1.94 mm and plots were arranged in the form of a tree repeated gradient irrigation. Abdel et al. (1994) reported that irrigation water was applied 3.6 and 9 mm day⁻¹ during the growth period of cabbage (*Brassica oleracea* var. *capitata* L.) and irrigation frequencies were preferred 1 and 3 days in winter conditions of Oman in the Gulf region. Smittle et al. (1994) notified that the water applied for cabbage changed from 71 to 182 mm. In the same study, pan evaporation values varied from 131 to 270 mm. Bucks et al. (1973) indicated that the consumptive use requirement (380 mm of water) for high production of cabbage was about the same for all irrigation methods. Sammis et al. (1988) reported that the plant consumptions of lettuce and Chinese cabbage were 205 mm and 209 mm, respectively. Kiziloglu et al. (2008) specified that the total evapotranspiration for red cabbage in Turkey conditions was 937 mm. In the first year of the trial, a total of 524 mm of the amount of irrigation water was applied to the E₁₀₀V₁₀₀Y₁₀₀R₁₀₀ treatment which was applied in full water and 536 mm in the second year. In addition, the plant water consumption of cabbage was determined as 795 and 802 mm in 2007 and 2008 years for E₁₀₀V₁₀₀Y₁₀₀R₁₀₀ treatment. The results of the irrigation amounts and crop water consumption values of the trial were compatible with previous studies (Bucks et al., 1973; Doorenbos and Kassam, 1979; Sammis et al., 1988; Sammis and Wu, 1989; Smittle et al., 1994; Abdel et al., 1994; Kiziloglu et al., 2007; Kiziloglu et al., 2008; Wahome et al., 2009; Kumar and Sahu, 2013; Agrawal et al., 2018).

The cabbage yield for 2007 and 2008 years ranged between 74.2-2.0 and 72.4-4.0 t ha⁻¹, respectively. The results of our study shows that the influence of deficit irrigation on yield was quite important. According to the yield results, all treatments were ranked as the different statistical groups. It is concluded that the amount of irrigation water applied to different phenological periods of the plant was important on the yield value of the plant. This result is in agreement with those of (Doorenbos and Kassam, 1979; Nortje and Henrico, 1988; Sammis et al., 1988; Jangandi et al., 2000; Beltrao et al., 2000; Bogoescu, 2000; Imtiyaz et al., 2000; Salo et al., 2002; Tiwari et al., 2003; Wahome et al., 2009; Sturm et al., 2010; Himanshu et al., 2012; Kumar and Sahu, 2013; Xu and Leskovar, 2014; Seciu et al., 2016; Agrawal et al., 2018).

At all of treatments except for $E_{100}V_{100}Y_{100}R_{100}$, yield was significantly lowered as irrigation water amount decreased. As determined in yield, the quality values of the cabbage (head weight, diameter, height and dry matter) have given a similar response to deficit irrigation. As expected, the non-irrigated ($E_0V_0Y_0R_0$) treatment had lower values than all irrigation treatments. Head weight, diameter ve height values were not included in different statistical groups. This situation is that the amount of irrigation water had a good few effect on head weight, diameter and height. However, the amount of irrigation water had no significant effect on head weight, diameter and height. This situation can be attributed to the fact that plant water consumption wasn't high during plant growing period. These values are similar to those of previous studies (**Janes, 1950; Wahome et al., 2009; Himanshu et al., 2012; Kushwah and Dwivedi, 2013; Kumar and Sahu, 2013; Xu and Leskovar, 2014; Agrawal et al., 2018**). Since all treatments in the trial had lower than $E_{100}V_{100}Y_{100}R_{100}$ treatments. The minimal dry matters were found at $E_{100}V_{100}Y_{100}R_{100}$ treatments while the minimal dry values were observed at $E_0V_0Y_0R_0$ treatments in 2007 and 2008 years of the study. We may infer that important increments in dry matter may be provided by the rising level of irrigation water deficiency. The results obtained from the trial are in conformance with those of (**Janes, 1950; Abdel et al., 1994; Bogoescu, 2000; Wahome et al., 2009**).

The maximal WUE and IWUE values for 2007 and 2008 years found as 0.16-0.15 and 0.15-0.15, respectively. The maximal WUE and IWUE values were found in establishment and vegetative periods and the lowest value was obtained from yield formation and ripening periods. When the findings of several researchers compared with the results of our study, the findings were found to be same to (**Doorenbos and Kassam, 1979; Sammis et al., 1988; Himanshu et al., 2012; Kushwah and Dwivedi, 2013; Agrawal et al., 2018**). These values were influenced climate, variety and soil structure. As explained by **Davis et al. (2008)**, it may be attributed to the variety and applied cultural practices handling under different climate and geographical conditions. Crop yield response factor (k_y) for 2007 and 2008 year were calculated as 0.96 and 0.97 for cabbage, respectively. The specified values of k_y (0.96-0.97) which is lesser than 1.00 shows that cabbage is susceptible to the water. Research values who studied on similar issues also matches up with k_y factor (**Doorenbos and Kassam, 1979; Sammis et al., 1988; Himanshu et al., 2012; Kushwah and Dwivedi, 2013; Agrawal et al., 2018**).

Results

According to the results of the study, irrigation water were applied 524 and 536 mm in $E_{100}V_{100}Y_{100}R_{100}$ treatment applied to full irrigation in 2007 and 2008 years. The plant water consumption of cabbage was determined as 795 and 802 mm in 2007 and 2008 years for $E_{100}V_{100}Y_{100}R_{100}$ treatment. Crop yield response factors (k_y) for the different plant growth periods (Establishment, vegetative, yield formation and ripening) were found as 0.47, 0.84, 1.23, 1.28 in 2007 year and 0.49, 0.88, 1.25, 1.26 in 2008 year. Crop yield response factor (k_y) for the total growth period was found as 0.96 in 2007 year and as 0.97 in 2008 year. The highest crop yield response factor values were obtained from the ripening and yield formation periods. These values for 2007 and 2008 years were calculated as 1.28-1.23 and 1.26-1.25, respectively. The highest crop yield response factors (k_y) obtained from ripening and yield formation periods showed that the cabbage was susceptible to water in these periods. The highest yield decreases in all plant growth periods were in ripening and yield formation, while the lowest yield

decreases were in establishment and vegetative periods. In our trial, it was studied out that irrigation treatments considerable influences yield, head diameter, weight, height and dry matter ratio. In 2007 and 2008 years, the maximal yield was 73.3 t h^{-1} and it was found in $E_{100}V_{100}Y_{100}R_{100}$ treatment. The minimal yield was found as 3.0 h^{-1} in $E_0V_0Y_0R_0$ treatment. The yield decreased significantly due to the irrigation water deficiency. The relative decreases in yield in 2007 and 2008 were %0.5, %2.6, %5.0, %8.5, %10.4, %11.2, %16.9, %18.2, %24.5, %35.4, %41.6, %46.6, %3610.0 and %6.0, %1.4, %2.4, %6.6, %7.1, %21.7, %13.3, %19.3, %25, %25.7, %39, %43.7, %1710, respectively. WUE and IWUE values of establishment and vegetative periods were the lowest values. In water deficiency conditions, the establishment and vegetative periods of cabbage are the most suitable periods for deficit irrigation and the yield and quality value decreases was the lowest during these periods.

As a result, of a possible deficit irrigation in a semi-humid climate condition, it is necessary to plan carefully and it is possible to say that the levels and times of the deficit irrigation were significantly effective on cabbage yield. In cabbage irrigation, if the deficit irrigation treatment is obligatory, water deficiency should be planned only for establishment and vegetative periods. The water deficiency shouldn't be applied in other plant growth periods and irrigations during ripening period should be exactly applied. In addition, in the irrigation planning to be done in similar climatic conditions may be benefited from crop yield response factor (ky) values. The results used to determine the amount of reduction in yield in response to the water deficiency to be applied to the plant may be used in studies related to cabbage.

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

Soil Depth (cm)	Soil Type	Unit weight (gr/cm ³)	Field Capacity (%)	Wilting point (%)	pH	Total salt (%)	CaCO ₃ (%)	Organic matter (%)
0-30	SL	1.34	29.73	21.74	7.99	0.037	16.5	2.92
30-60	SL	1.37	27.26	19.37	8.04	0.031	29.5	1.39
60-90	SL	1.58	33.92	23.72	7.86	0.034	31.5	1.08
90-120	SL	1.50	36.30	27.73	8.05	0.032	33.0	0.94

Table 2. Experimental treatments

Irrigation treatments	Growth Stages			
	Establishment	Vegetative	Yield Formation	Ripening
E100V100Y100R100	+	+	+	+
E75VYR	+ %25 su kısıntısı	+	+	+
E50VYR	+ %50 su kısıntısı	+	+	+
E25VYR	+ %75 su kısıntısı	+	+	+
EV75YR	+	+ %25 su kısıntısı	+	+
EV50YR	+	+ %50 su kısıntısı	+	+
EV25YR	+	+ %75 su kısıntısı	+	+
EVY75R	+	+	+ %25 su kısıntısı	+
EVY50R	+	+	+ %50 su kısıntısı	+
EVY25R	+	+	+ %75 su kısıntısı	+
EVYR75	+	+	+	+ %25 su kısıntısı
EVYR50	+	+	+	+ %50 su kısıntısı
EVYR25	+	+	+	+ %75 su kısıntısı
E0V0Y0R0		-	-	-

+: Water application in the specified period, -: Without irrigation

Table 3. Chemical composition of irrigation water used in the experiment

Water Source	EC _{25X} (10 ⁶)	Na ⁺	K ⁺	Ca ²⁺	Mg ²⁺	PH	Class	SAR
		(me L ⁻¹)						
Deep well	715	2.3	2.56	9.25	5.7	7.12	C ₂ S ₁	0.85

Table 4. The amount of irrigation water applied for the different growth stages according to the treatments

Konular	Irrigation Water (mm)									
	Establishment		Vegetative		Yield Formation		Ripening		Total	
	2007	2008	2007	2008	2007	2008	2007	2008	2007	2008
E100V100Y100R100	40	60	140	150	170	160	174	166	524	536
E75VYR	30	45	140	150	170	160	174	166	514	521
E50VYR	20	30	140	150	170	160	174	166	504	498
E25VYR	10	15	140	150	170	160	174	166	494	487
EV75YR	40	60	105	112	170	160	174	166	489	498
EV50YR	40	60	70	75	170	160	174	166	454	461
EV25YR	40	60	35	38	170	160	174	166	419	424
EVY75R	40	60	140	150	128	120	174	166	482	496
EVY50R	40	60	140	150	85	80	174	166	439	456
EVY25R	40	60	140	150	43	40	174	166	397	416
EVYR75	40	60	140	150	170	160	130	124	480	494
EVYR50	40	60	140	150	170	160	87	83	437	453
EVYR25	40	60	140	150	170	160	44	42	394	412
E0V0Y0R0	0	0	0	0	0	0	0	0	0	0

Table 5. Crop evapotranspiration for the different growth stages according to to the treatments

Konular	Crop Evapotranspiration (mm)									
	Establishment		Vegetative		Yield Formation		Ripening		Total	
	2007	2008	2007	2008	2007	2008	2007	2008	2007	2008
E100V100Y100R100	50	65	195	190	210	212	340	335	795	802
E75VYR	50	65	194	187	202	210	333	335	779	797
E50VYR	46	60	186	182	195	193	327	329	754	764
E25VYR	43	56	183	178	191	186	320	316	737	736
EV75YR	53	67	165	175	204	207	323	307	745	756
EV50YR	50	65	115	120	201	203	332	325	698	713
EV25YR	52	62	60	62	197	197	330	330	639	651
EVY75R	42	56	125	148	230	220	320	306	717	730
EVY50R	40	53	171	180	155	145	335	335	701	713
EVY25R	40	53	174	182	78	73	331	332	623	640
EVYR75	43	52	132	138	165	160	325	302	665	652
EVYR50	40	50	130	150	194	192	250	185	614	577
EVYR25	40	50	138	183	207	202	145	132	530	567
E0V0Y0R0	40	50	45	45	50	45	50	50	185	190

Table 6. Relationship between the decrease in relative water use and decrease in relative yield and yield response factor for cabbage irrigated by a drip system in 2007 and 2008

Irrigation Treatment	Yield (t ha ⁻¹)	Applied Water (mm)	ETa (mm)	ETa/ETm	Ya/Ym	1-(ETa/Etm)	1-(Ya/Ym)	ky	ky
E100V100Y100R100	74,2	524	795	1,000	1,000	0,000	0,000	0,000	0,000
E75VYR	73,8	514	779	0,980	0,995	0,020	0,005	0,268	0,470
E50VYR	72,3	506	754	0,948	0,974	0,052	0,026	0,497	
E25VYR	70,7	494	737	0,927	0,953	0,073	0,047	0,647	
EV75YR	68,4	489	745	0,937	0,922	0,063	0,078	1,243	0,844
EV50YR	67,2	454	698	0,878	0,906	0,122	0,094	0,773	
EV25YR	66,7	419	639	0,804	0,899	0,196	0,101	0,515	
EVY75R	63,5	482	717	0,902	0,856	0,098	0,144	1,470	1,226
EVY50R	62,8	439	701	0,882	0,846	0,118	0,154	1,299	
EVY25R	59,6	397	623	0,784	0,803	0,216	0,197	0,909	
EVYR75	54,8	480	665	0,836	0,739	0,164	0,261	1,599	1,281
EVYR50	52,4	437	614	0,772	0,706	0,228	0,294	1,290	
EVYR25	50,6	394	530	0,667	0,682	0,333	0,318	0,954	
EoVoYoRo	2,0	0	200	0,252	0,027	0,748	0,973	1,300	1,300

Irrigation Treatment	Yield (t ha ⁻¹)	Applied Water (mm)	ETa (mm)	ETa/ETm	Ya/Ym	1-(ETa/Etm)	1-(Ya/Ym)	ky	ky
E100V100Y100R100	72,4	536	802	1,000	1,000	0,000	0,000	0,000	0,000
E75VYR	72,0	521	797	0,994	0,994	0,006	0,006	0,886	0,488
E50VYR	71,4	498	764	0,953	0,986	0,047	0,014	0,292	
E25VYR	70,7	487	736	0,918	0,977	0,082	0,023	0,285	
EV75YR	67,9	498	756	0,943	0,938	0,057	0,062	1,084	0,876
EV50YR	67,6	461	713	0,889	0,934	0,111	0,066	0,597	
EV25YR	59,5	424	651	0,812	0,822	0,188	0,178	0,946	
EVY75R	63,9	496	730	0,910	0,883	0,090	0,117	1,308	1,252
EVY50R	60,7	456	713	0,889	0,838	0,111	0,162	1,456	
EVY25R	57,9	416	640	0,798	0,800	0,202	0,200	0,991	
EVYR75	57,6	494	652	0,813	0,796	0,187	0,204	1,093	1,260
EVYR50	52,1	453	577	0,813	0,720	0,187	0,280	1,499	
EVYR25	50,4	412	597	0,744	0,696	0,256	0,304	1,189	
EoVoYoRo	4,0	0	190	0,237	0,055	0,763	0,945	1,238	1,238

Table 7. Crop water production functions obtained for each growth stage and total growing season in 2007 and 2008

Year	Period	Production Functions
2007	E	$(1-Y_a/Y_m)=0.47 (1-E_t a/E_t m)$, $R^2= 0.9837$
	V	$(1-Y_a/Y_m)=0.84 (1-E_t a/E_t m)$, $R^2= 0.9134$
	Y	$(1-Y_a/Y_m)=1.23 (1-E_t a/E_t m)$, $R^2= 0.9999$
	R	$(1-Y_a/Y_m)=1.28 (1-E_t a/E_t m)$, $R^2= 0.9513$
	Seasonal	$(1-Y_a/Y_m)=0.96 (1-E_t a/E_t m)$, $R^2= 0.9530$
2008	E	$(1-Y_a/Y_m)=0.49(1-E_t a/E_t m)$, $R^2= 0.9916$
	V	$(1-Y_a/Y_m)=0.88 (1-E_t a/E_t m)$, $R^2= 0.8568$
	Y	$(1-Y_a/Y_m)=1.25 (1-E_t a/E_t m)$, $R^2= 0.8601$
	R	$(1-Y_a/Y_m)=1.26 (1-E_t a/E_t m)$, $R^2= 0.7800$
	Seasonal	$(1-Y_a/Y_m)=0.97 (1-E_t a/E_t m)$, $R^2= 0.9814$

Table 8. Effects of irrigation treatments on cabbage parameters in 2007

2007					
Irrigation Treatment	Yield (t ha ⁻¹)	Head Weight (kg)	Head Diameter (cm)	Head Height (cm)	Dry Matter (%)
E100V100Y100R100	74.2 a	5.8 a	30.2 a	28.8 a	7.2 j
E75VYR	73.8 a	5.7 ab	30.0 a	28.4 ab	7.2 j
E50VYR	72.3 b	5.6 ab	28.2 ab	27.5 bc	7.5 ij
E25VYR	70.7 c	5.5 abc	27.5 b	26.4 c	7.8 hi
EV75YR	68.4 d	5.3 abcd	27.3 b	26.2 c	7.7 hij
EV50YR	66.2 e	5.1 bcde	24.5 c	24.7 de	8.0 ghi
EV25YR	67.7 e	4.9 cde	22.4 cd	23.7 efg	8.7 def
EVY75R	63.5 f	4.9 cde	24.0 c	25.4 d	8.2 fgh
EVY50R	62.8 f	4.5 de	21.8 de	22.5 fg	8.8 de
EVY25R	59.6 g	4.0 ef	18.0 f	20.1 hi	9.6 bc
EVYR75	54.8 h	4.8 ef	22.8 cd	24.5 def	8.5 efg
EVYR50	52.4 i	4.5 f	20.1 ef	21.3 gh	9.2 cd
EVYR25	50.6 j	3.9 f	15.2 g	18.7 i	10.1 b
E0V0Y0R0	2.0 k	0.5 g	6.0 h	6.7 j	13.5 a
Treatments	*	*	*	*	*
Blocks	is	is	is	is	is

** means correlation is significant at the 0.005 level. ns shows non-significant correlation.

Table 9. Effects of irrigation treatments on cabbage parameters in 2008

2008					
Irrigation Treatment	Yield (t ha ⁻¹)	Head Weight (kg)	Head Diameter (cm)	Head Height (cm)	Dry Matter (%)
E100V100Y100R100	72.4 a	5.6 a	30.3 a	28.8 a	7.0 g
E75VYR	72.0 a	5.6 a	30.2 a	28.4 ab	7.1 g
E50VYR	71.4 a	5.5 a	28.4 ab	27.5 b	7.4 fg
E25VYR	70.7 a	5.4 a	27.2 bc	26.4 c	7.7 efg
EV75YR	67.9 b	5.4 a	27.4 bc	26.2 cd	7.6 efg
EV50YR	67.6 b	5.2 ab	25.9 cd	24.7 e	8.0 efg
EV25YR	59.5 de	4.9 abc	24.2 de	23.7 f	8.5 cde
EVY75R	63.9 c	5.0 abc	25.0 d	25.4 de	7.9 efg
EVY50R	60.7 d	4.5 bcd	22.6 ef	22.5 g	8.6 cde
EVY25R	57.9 e	4.0 d	20.2 g	20.0 i	9.4 bc
EVYR75	57.6 e	5.0 abc	24.6 de	24.5 ef	8.2 def
EVYR50	52.1 f	4.4 cd	21.4 fg	21.3 h	9.1 cd
EVYR25	50.4 f	3.8 d	17.7 h	18.7 j	10.3 b
EoVoYoRo	4.0 g	0.4 e	6.5 i	6.7 k	13.7 a
Treatments	*	*	*	*	*
Blocks	is	is	is	is	is

** means correlation is significant at the 0.005 level. ns shows non-significant correlation.

Table 10. Total water use efficiency (WUE) and irrigation water use efficiency (IWUE) values for the cabbage irrigated by a drip system at different irrigation treatments.

2007				2008			
Irrigation Treatment	Yield (t ha ⁻¹)	WUE (kg/m ³)	IWUE (kg/m ³)	Irrigation Treatment	Yield (t ha ⁻¹)	WUE (kg/m ³)	IWUE (kg/m ³)
E100V100Y100R100	74,2	0,09	0,14	E100V100Y100R100	72,4	0,09	0,14
E75VYR	73,8	0,09	0,14	E75VYR	72,0	0,09	0,14
E50VYR	72,3	0,10	0,14	E50VYR	71,4	0,09	0,14
E25VYR	70,7	0,10	0,14	E25VYR	70,7	0,10	0,15
EV75YR	68,4	0,09	0,14	EV75YR	67,9	0,09	0,14
EV50YR	67,2	0,10	0,15	EV50YR	67,6	0,09	0,15
EV25YR	66,7	0,10	0,16	EV25YR	59,5	0,09	0,14
EVY75R	63,5	0,09	0,13	EVY75R	63,9	0,09	0,13
EVY50R	62,8	0,09	0,14	EVY50R	60,7	0,09	0,13
EVY25R	59,6	0,10	0,15	EVY25R	57,9	0,09	0,14
EVYR75	54,8	0,08	0,11	EVYR75	57,6	0,09	0,12
EVYR50	52,4	0,09	0,12	EVYR50	52,1	0,09	0,12
EVYR25	50,6	0,10	0,13	EVYR25	50,4	0,08	0,12
EoVoYoRo	2,00	0,01	0,00	EoVoYoRo	4,0	0,02	0,00

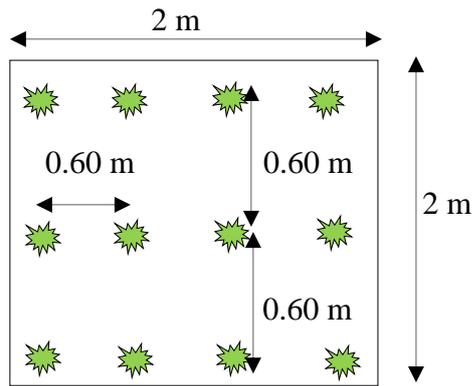


Figure 1. The detail of a plot

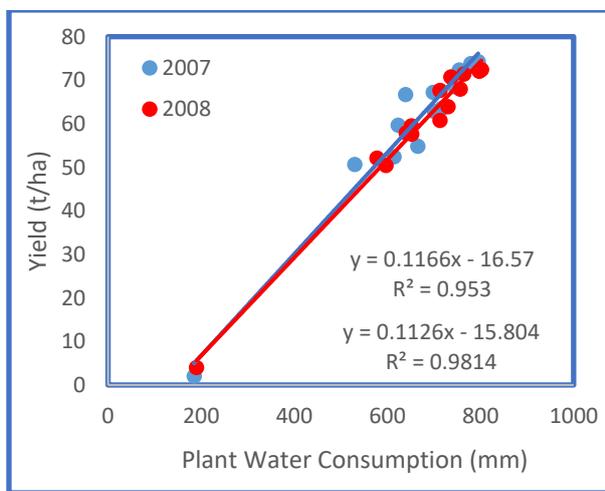


Figure 2. The relationship between Crop Water Consumption and Yield

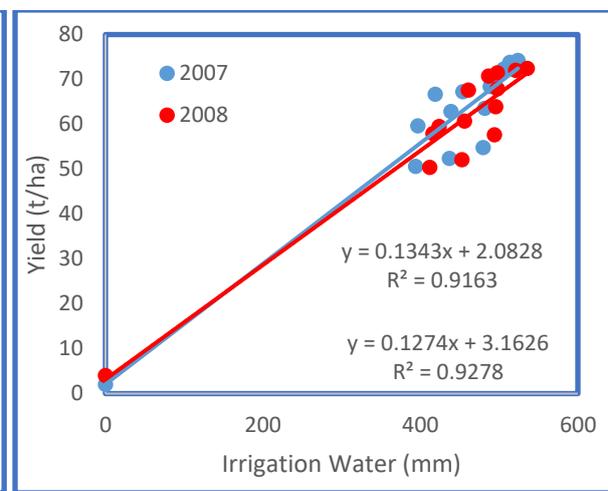
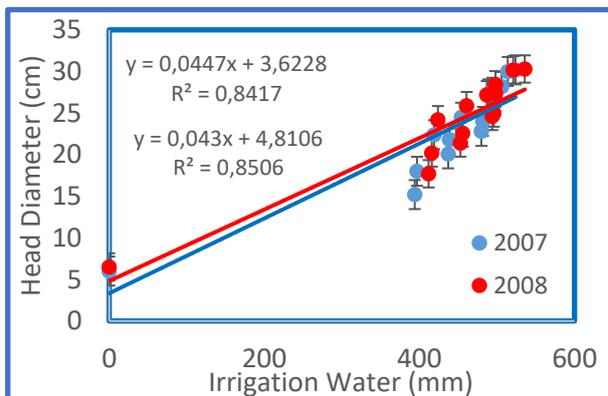
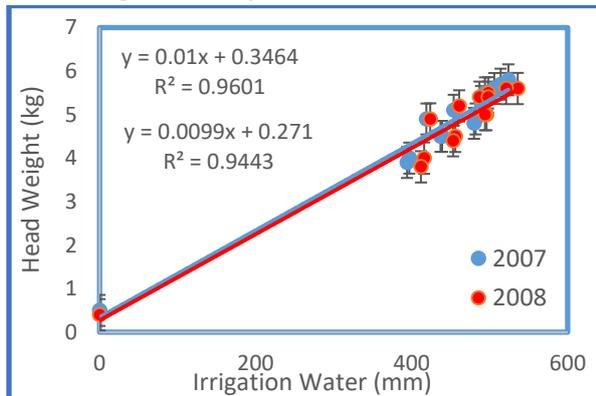


Figure 3. The relationship between Irrigation Water and Yield

Figure 4. Relationship between applied of irrigation water and head weight, head diameter, head height and dry matter ratio.



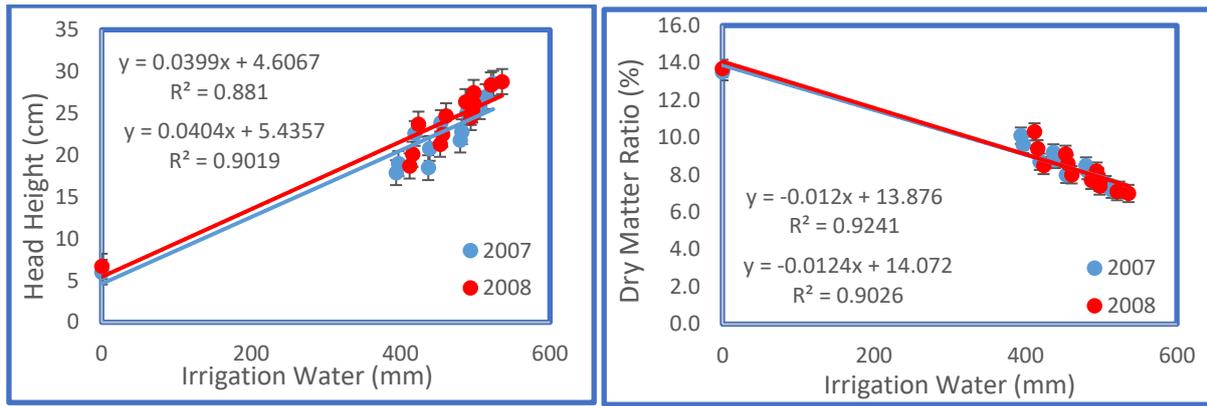


Figure 5. The relationship between relative yield decrease and relative evapotranspiration deficit for the experimental years (2007 and 2008)

