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Deficit Irrigation Effects on Cabbage (*Brassicaceae Oleracea* var. capitata L. Grandslam F1) Yield in Unheated Greenhouse Condition

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A R T I C L E I N F O

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A B S T R A C T

The aim of this study was to determine the effect of deficit irrigation on yield for cabbage grown under unheated greenhouse condition. The research was carried out at the Agricultural Research Station of Yenişehir High School of Uludağ University in Bursa, Turkey, in 2008. In the study, water was applied to cabbage 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 520 mm and water consumption ranged from 90 to 548 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 72.8 t ha^{-1}. Crop yield response factor for cabbage (k_y) was found as 1.036. The highest values of water use efficiency (WUE) and irrigation water use efficiency (IWUE) for 2008 year of $K2_{cp}$ treatment was calculated to be 0.143 kg m^{-3} and 0.137 kg m^{-3}, respectively. $K2_{cp}$ application (75%) can be recommended as the most effective irrigation level for the cabbage to which drip irrigation is applied under scarce and unheated greenhouse conditions.

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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.

China, India, and Russia are the world's three biggest cabbage producers 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).

Cabbage is believed to have evolved from a wild form native to Europe, growing along the coast of the North Sea, the English Channel and northern Mediterranean. Cabbage is a popular vegetable throughout the world because of its adaptability to a wide range of climatic conditions and soil, ease of production and storage, and its food value. Cabbage is a favourite cuisine dish in our country, and it is eaten raw and also prepared by various methods as wrap, stew, salad and pickle (Vural et al., 2000).

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 supply of adequate amount of water to meet the crop needs in the root zone, and at the same time, avoiding the leaching of nutrients into deeper soil layers (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.

Irrigation scheduling with drip irrigation relies on approaches based on evapotranspiration estimations (Bar-Yosef and Sagiv, 1982; McNeeish et al., 1985; Clough et al., 1990; Hartz, 1993) and 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 cabbage (Kiziloglu et al., 2008), broccoli (Ayas et al., 2011), tomato (Ayas, 2015); green bean (Büyükcangaz et al., 2008); pepper (Demirtas and Ayas, 2009), cucumber (Ayas and Demirtas, 2009), lettuce (Yazgan et al., 2008) and potato (Ayas and Korukcu, 2010; Ayas, 2013). Several studies have been performed to investigate the influence of different irrigation levels on cabbage growth and yield.

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

Materials and Methods

Field trials were conducted under unheated greenhouse conditions in the region of Bursa-Yenisehir (40º15'09 "N latitude, 29º 38'43"E longitude and altitude of 225 m above mean sea level). For experimental purposes, high tunnel type plastic covered greenhouse with the size of 8 m × 40 m was built. The climate characteristics of the experiment area was hot and dry in summer and cold and rainy in winter. Annual average precipitation and temperature values for 2008 in the regions where greenhouse experiments were carried out was 630.7 mm and 12.9°C, respectively. The average minimum temperature for 2008 were gauged as -6.6°C in January while the average maximum temperature were gauged as 32.9°C in August (Anonymous, 2010). The soil of the experiment field was classified as sandy loam and soil pH ranged between 7.99 and 8.04. Some of the physical and chemical characteristics were presented in Table 1.

Mankozeb and Endosulfan were sprayed to the experiment fields as a chemical drug against diseases and insect pests. 170 kg ha^{-1} 21% N, 50 kg ha^{-1} 46 % P_2O_5 as bottom fertilizer was applied two weeks prior to sowing process. An additional 170 kg ha^{-1} 46% K_2O fertilizer was applied when the crops reached to height of 15 cm. 10 L ha^{-1} chlorophyllous-ethyl was sprayed against insects.

Transplantation date of the cabbage seedlings to the plots were August 01 in 2008 year. In the experiments, row and plant spacing were 0.60 m and 0.60 m, respectively. Each plot has contained 44 plants. 14 plants of middle row were harvested to consider side effects. The head height (cm), diameter (cm) and weight (g) of cabbages were measured by callipers and the average of measured values was calculated. Dry matter content was determined by the separation and drying (at 65°C in drying oven) of fruits (two samples for each plot). The amount of dry matter of heads was determined by using (AOAC, 2000).

The order of the trial was set as a randomized block design with 3-replication and single factor, and 5 irrigation applications were randomly distributed to each blocks. The irrigation applications were created using five different crop evaporation coefficients ($K1_{cp}$: 1.00, $K2_{cp}$: 0.75, $K3_{cp}$: 0.50, $K4_{cp}$: 0.25, $K5_{cp}$: 0.00-for control purposes). The amount of irrigation water was determined using below stated equation (Doorenbos and Pruitt, 1977; Kanber, 1984):

$$IW = E_p \times K_{cp} \times P$$

Where, E_p is cumulative evaporation (mm) for 2-day irrigation frequency, K_{cp} is pan evaporation coefficient, and P is the percentage of wetted area. Evaporations that occurred in the 2 day irrigation frequency was measured using Class A Evaporation Pan that was held in the middle of greenhouse applications and drip irrigation method was used. The amount of irrigation water was measured with flowmeter devices at the gate of each plot. The needed irrigation water was provided from a deep well (3 L s^{-1}) that was drilled in the field. Quality properties of the irrigation water were presented in Table 2.

Irrigation water quality was low sodium risk and classified in C_2S_1 with medium level EC value. Crop evapotranspiration (Cumulative evapotranspiration - ET_c) was calculated for 2 day irrigation interval using the below stated water balance equation;

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

Where $(SWC_{t0} - SWC_{t1})$ is the change in volumetric soil water content (mm); IW (mm) and D (mm) are, irrigation water depth (mm) and drainage (mm) for the related period, respectively. Prior to irrigation water applications, water content in 0.60 mm soil depth was determined with gravimetric method (Lorenz and Maynard, 1980). Water content of the soil was monitored till 0.90 depth with increments of 30 cm depth following irrigation applications for each irrigation application. In subplots, the percolations below 0.60 m soil depth were omitted. In our study, the relationships between yield and ET were determined by the Stewart model (Doorenbos and Kassam, 1979):

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

Where, Y_a and ET_a are actual crop yield productivity ($t.ha^{-1}$) and cumulative evaporation (mm), respectively, under insufficient irrigation conditions; Y_m and ET_m are maximum crop yield productivity ($t.ha^{-1}$) and cumulative evaporation (mm) under sufficient water conditions. Yield productivity response factor of the deficit irrigated cabbage was presented with k_y. Water use efficiency (WUE) value was calculated to evaluate the irrigation efficiency in the applications. The two terms that are used to encourage the effective use of irrigation water in crop production phases are water use efficiency (WUE) and irrigation water use efficiency (IWUE). Water use efficiency (WUE) is calculated as the efficiency ratio of YLD to ET_a and depicted as WUE = YLD / ET_a (kg m^{-3}). Irrigation water use efficiency (IWUE) was estimated with the below stated equation (Howell et al., 1990):

$$\mathrm{IWUE}\left(\mathrm{kg\ m^{-3}}\right)=\frac{\mathrm{YLD\text{-}YLD_{rainfed}}}{\mathrm{IRGA}}$$

Where, YLD is yield value of each treatment plot (kg ha^{-1}), $YLD_{rainfed}$ is yield value from control (full irrigated) treatment plot (kg ha^{-1}), IRGA is seasonal irrigation water amount (mm). Cabbage seedlings completely grew and fruit had the yield productivity, head height, diameter and weight, colour and taste characteristics to its species, 90 days (DOY = 90) after plantation, i.e. in harvest season. Yield productivity and quality parameters, i.e. head height, diameter and weight and dry matter ratio, were evaluated for each harvest season.

Variance analysis was conducted with yield productivity and productivity components by using MSTAT-C (version 2.1-Michigan State University 1991) and MINITAB (Texas University, Austin) software. The significance of irrigation applications was calculated at 0.05 and 0.01 probability levels with F-test (Steel and Torrie, 1980).

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

Soil Depth (cm)	0-30	30-60
Unit weight of soil, g cm^{-3}	1.34	1.37
Soil Texture	Sandy loam	Sandy loam
Field capacity, %	19.66	17.26
Wilting point, %	11.94	9.98
pH	7.99	8.04
Total salt, %	0.058	0.051
$CaCO_3$, %	5.67	8.49
Organic matter, %	2.94	1.39
Available Phosphorus, kg da-1	1.53	1.24
Available Potassium, kg da-1	38.35	19.52

Table 2 Chemical composition of irrigation water used in the experiment

Parameter	Value
EC, dS m^{-1}	0.715
pH	7.12
Cations, me L^{-1}	
Ca^+	9.25
Na^+	2.3
Mg^+	5.7
K^+	2.56
SAR	0.85
Class	C_2S_1

Results

Water Applied and Water Used

All treatments received 70 mm irrigation water to refill available soil water content of 0-60 cm soil depth up to field capacity level following planting date. Class A pan measurements of evaporation were just started after first irrigation water application. The maximum and minimum amounts of irrigation water applied were 520-70 mm for $K1_{cp}$ treatment and $K5_{cp}$ treatment, respectively. The amount of water applied to other treatments varied from 390 to 130 mm. An increase in seasonal evapotranspiration (ET_a) was observed with an increase at applied irrigation water. The actual evapotranspiration ranged between 548-90 mm for $K1_{cp}$ and $K5_{cp}$ treatments, respectively (Table 3).

Linear relationships between crop evapotranspiration (ET_c) with yield productivity (Y_a), and irrigation water (IW) with yield (Y_a) were observed for 2008 year. The relationship equation is as follows; $Y_a = 0.1542\times ET_c - 9.0472$ with $R^2 = 0.99$ and $Y_a = 0.1406\times IW$ with $R^2 = 0.99$ (Figure 1).

The highest yield was obtained from $K1_{cp}$ application with 72.8 t ha^{-1} for 2008 year. It was followed by $K2_{cp}$, $K3_{cp}$ and $K4_{cp}$ applications with yield productivity values of 57.4 – 35.6 – 17.0 t ha^{-1}, respectively. As expected, the minimum yield (4.0 t ha^{-1}) was found from control $K5_{cp}$ application in which irrigation was not applied. The yield productivity of non-irrigated $K5_{cp}$ application was lower at a rate of 1720 % in a comparison with $K1_{cp}$ application. Moreover, lower yield productivity levels at a rate of 26.8 %, 104.5 %, 328.2 % from $K2_{cp}$, $K3_{cp}$ and $K4_{cp}$ applications were observed in a comparison with $K1_{cp}$ application (see Table 4). Crop yields and quality are reduced due to water deficits applied particularly three or four weeks before harvest.

The related equations for 2008 year were as follows; head height = 0.0165IW + 19.474 with $R^2 = 0.97$ (Fig. 2a.), head diameter = 0.0168IW + 22.186 with $R^2 = 0.96$ (Fig. 2b), head weight = 0.0097IW – 0.8507.58 with $R^2 = 0.95$ (Fig. 2c.) and dry matter = -0.0108IW + 12.019 with $R^2 = 0.99$ (Fig. 2d.).

Crop Yield Response Factor (K_y)

Linear relationship between proportional decrease in water consumption and proportional decrease in yield productivity is depicted with crop yield productivity response factor (k_y) that represents yield productivity response to be lowered in water consumption. In other words, it explains the decrease in yield productivity in relation with the decrease in water consumption per unit (Doorenbos and Kassam, 1979; Stewart et al., 1975). For irrigation application, seasonal yield productivity response factor (k_y) was calculated as 1.036 for 2008 year (see Fig. 3). k_y values increased with parallel to increase in water amount, except $K5_{cp}$ application.

Water Use Efficiencies

Values of WUE and IWUE was lowered when the amount of irrigation water was reduced. The highest WUE and IWUE values for 2008 year were calculated from $K2_{cp}$ application as 0.143 kg m^{-3} and 0.137 kg m^{-3}, respectively. WUE and IWUE values of $K2_{cp}$ application were found higher than other applications as $K1_{cp}$, $K3_{cp}$, $K4_{cp}$ and $K5_{cp}$, in order (See Table 5).

Table 3 Relationship between the decrease in relative water use and decrease in relative yield and yield response factor for drip-irrigated cabbage

IT	Y	AW	ET_a (mm)	ET_a/ET_m	Y_a/Y_m	$1-(ET_a/ET_m)$	$1-(Y_a/Y_m)$	ky
$K1_{cp}$	72.8	520	548	1.000	1.000	0.000	0.000	0.000
$K2_{cp}$	57.4	390	402	0.734	0.788	0.266	0.212	0.797
$K3_{cp}$	35.6	260	295	0.538	0.558	0.462	0.511	1.106
$K4_{cp}$	17.0	130	170	0.310	0.234	0.690	0.766	1.110
$K5_{cp}$	4.0	70	90	0.164	0.055	0.836	0.945	1.130

IT: Irrigation treatment; Y: Yield (t ha^{-1}); AW: Applied Water (mm)

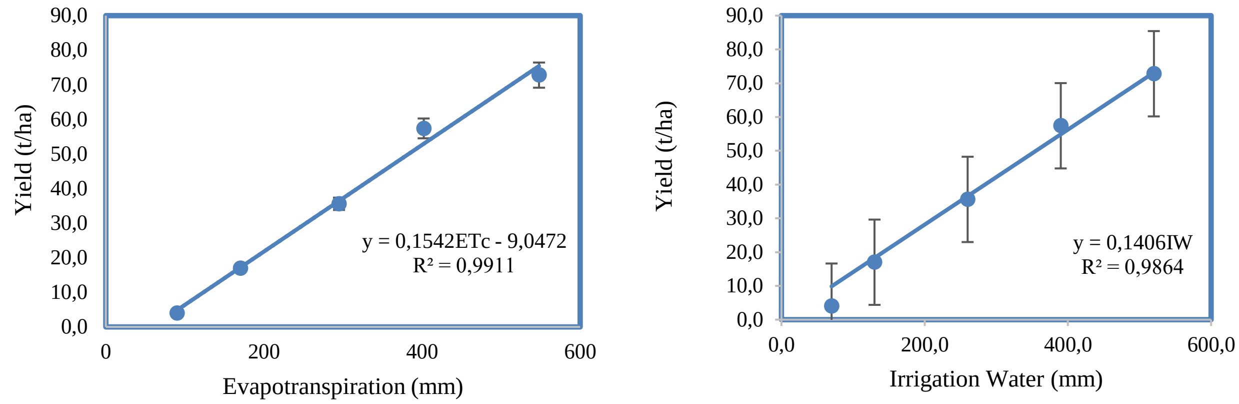

Figure 1 The relationship between crop evapotranspiration with yield and water irrigation with yield (The errors bars are SE of 14 plants)

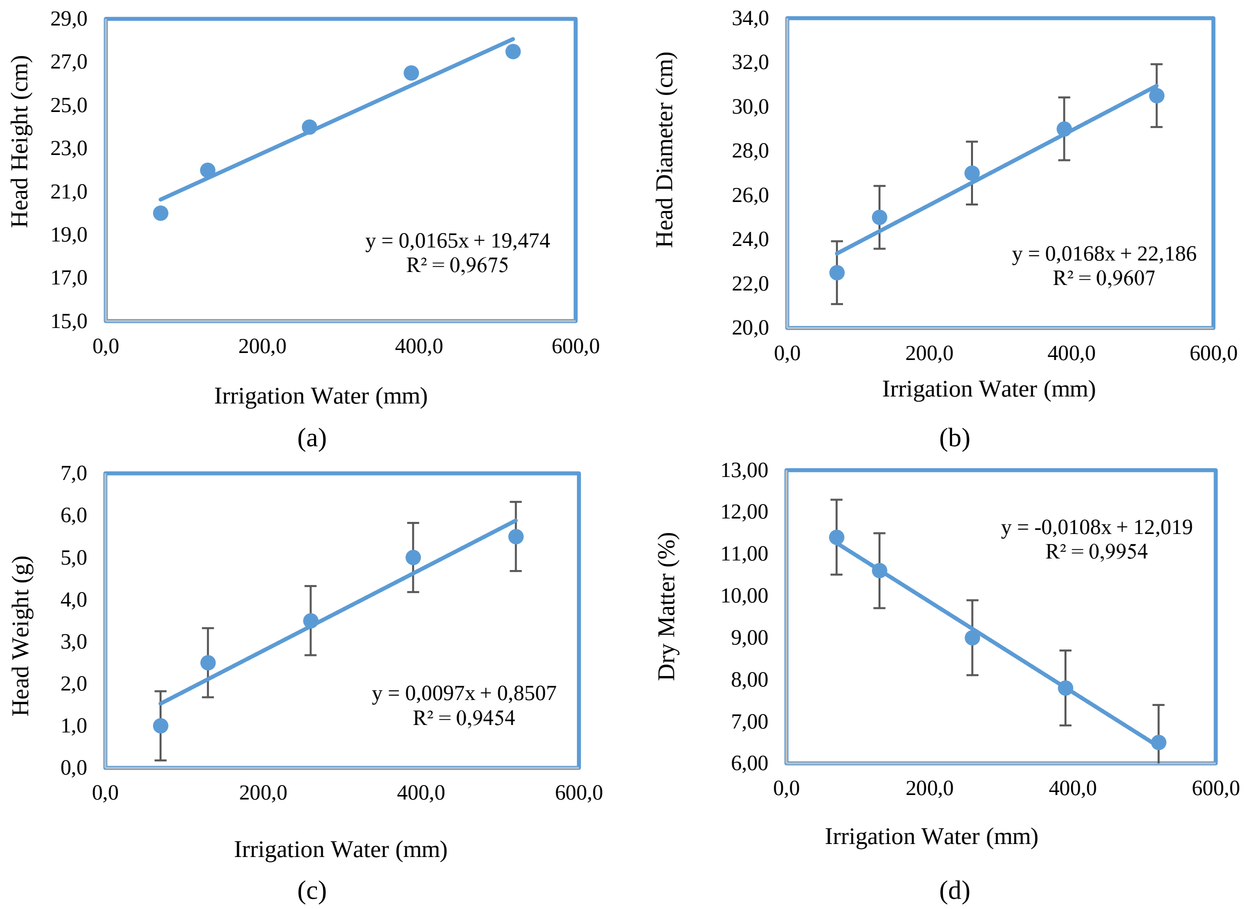

Figure 2 Relationship between applied irrigation water and head length (2a), diameter (2b), weight (2c), and dry matter (2d) (The errors bars are SE of 14 plants)

Table 4 Effects of irrigation treatments on cabbage marketable parameters

IT	Head Height (cm)	Head Diameter (cm)	Head Weight (kg)	Dry Matter (%)	Yield (t/ha)
$K1_{cp}$	27.5^{a}	30.5^{a}	5.5^{a}	6.5^{e}	72.8^{a}
$K2_{cp}$	26.5^{a}	29.0^{ab}	5.0^{a}	7.8^{d}	57.4^{b}
$K3_{cp}$	24.0^{b}	27.0^{bc}	3.5^{b}	9.0^{c}	35.6^{c}
$K4_{cp}$	22.0^{bc}	25.0^{c}	2.5^{c}	10.6^{b}	17.0^{d}
$K5_{cp}$	20.0^{c}	22.5^{d}	1.0^{d}	11.4^{a}	4.0^{e}
Treatments	*	*	*	*	*
Blocks	ns	ns	ns	ns	ns

IT: Irrigation treatment; ** Correlation is significant at the 0.01 level, * Correlation is significant at the 0.05 level, ns non-significant

Table 5 Total water use efficiency (WUE) and irrigation water use efficiency (IWUE) values for drip irrigated cabbage at different irrigation treatments

IT	Yield (t ha^{-1})	WUE kg mm^{-1}	IWUE kg mm^{-1}
$K1_{cp}$	72.8	0.133	0.132
$K2_{cp}$	57.4	0.143	0.137
$K3_{cp}$	35.6	0.121	0.122
$K4_{cp}$	17.0	0.100	0.100
$K5_{cp}$	4.0	0.000	0.000

IT: Irrigation treatment

Discussion

In this study, irrigation treatments significantly affected yield, head height, head diameter, head weight and dry matter. Water requirements of cabbage vary from 380 to 500 mm depending on climate and length of growing season (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 an amount of 449.4 mm irrigation water and amount of 932 mm evaporation were applied to the plots in whole irrigation 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 treatments were arranged in a gradient irrigation design replicated three times, and were irrigated daily with amounts ranging from 0.42 to 1.94 mm. Abdel Rahman et al. (1994) reported that the effects of two irrigation intervals ((1 and 3 days) and three application rates (3, 6 and 9 mm day^{-1}) on growth and yield of cabbage (Brassica oleracea var. capitata L.) were studied under the relatively warm (23°C) and humid (63 percent R.H.) winter conditions of Oman in the Gulf region. Smittle et al. (1994) reported that the water applied for cabbage varied 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 seasonal evapotranspiration of 205 and 209 mm for lettuce and Chinese cabbage, respectively. Kiziloglu et al. (2008) specified that the total class A pan evapotranspiration for red cabbage in Turkey conditions was 937 mm. These results are notably in accordance with the irrigation water amounts and crop water consumption values obtained from previous studies (Bucks et al., 1973; Doorenbos and Kassam, 1979; Sammis et al. 1988; Sammis and Wu, 1989; Smittle et al., 1994; Abdel Rahman 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 2008 year ranged between 72.8-4.0 t ha $^{-1}$. Based on to the results of this study, a significant effect of deficit irrigation was observed on total yield. 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).

Yield was considerably lowered as the amount of irrigation water reduced. Quality parameters such as head height, diameter, weight and dry matter have produced a similar response to deficit irrigation as observed at yield. As expected, all irrigation treatments had higher values than the non-watered ($K5_{cp}$) treatment. 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 $K1_{cp}$ treatments have higher head weight than the other treatments, the lowest dry matters were found at $K1_{cp}$ treatments when the highest values were observed at $K5_{cp}$ treatments in the study. We may conclude that significant increases in dry matter may be experienced by the increasing level of irrigation water deficit. These results are in agreement with those of (Janes, 1950; Abdel et al., 1994; Bogoescu, 2000; Wahome et al., 2009).

The maximum WUE and IWUE values were found as 0.143 and 0.137, respectively. $K2_{cp}$ treatment has had the highest as WUE and IWUE values. When the results regarding water use efficiency are compared with the findings of different researchers, they were found to be similar (Sammis et al. 1988; Himanshu et al., 2012; Kushwah and Dwivedi, 2013; Agrawal et al., 2018). Cabbage variety choice, climate, soil structure and effective use of water also affect these values. 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) was calculated as 1.036 for cabbage. The specified value of k_y (1.036) which is bigger than 1.00 shows that cabbage is susceptible to the water. Crop yield response factor (k_y) also coincides with the values found by researchers who studied on similar issues (Doorenbos and Kassam, 1979; Sammis et al. 1988; Himanshu et al., 2012; Himanshu et al., 2012; Kushwah and Dwivedi, 2013; Agrawal et al., 2018).

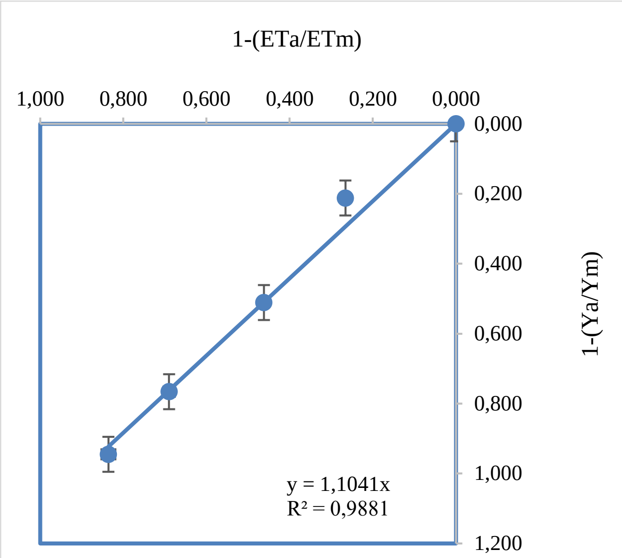

Figure 3 Relationship between relative yield decrease and relative crop evapotranspiration for cabbage throughout the total growing season

Conclusions

The ultimate goals of optimum irrigation management strategies in deficit areas are to enhance yield and quality as much as possible, increase WUE and reduce water consumption. $K2_{cp}$ treatment allowed high yield and quality (in terms of head height, diameter and weight), increased WUE and reduced water use. The variety choice of cabbage, climate and soil structure also influenced to change WUE and IWUE values. Crop yield response factor of cabbages was found as 1.036 which is bigger than 1.00 shows that cabbage is susceptible to the water. $K2_{cp}$ application (75%) can be recommended as the most effective irrigation level for the cabbages to which drip irrigation is applied under scarce water resource and unheated greenhouse conditions.

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