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Original Research Article

Effects of Different Irrigation Levels on Yield and Yield Components of Drip Irrigated Popcorn

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ABSTRACT

In areas of water scarcity, plant responses to soil water levels should be investigated to improve crop water productivity. This study was carried out to determine the effects of different irrigation levels on yield and some yield components using the drip irrigation method of popcorn (*Zea mays* L. *everta* R427) in sub-humid climate conditions in western Turkey. A field experiment was conducted in a randomized complete block design with three replicates. Four different irrigation treatments were studied: 100% (S1, pan-crop coefficient k_{pc}=1.00), 75% (S2, k_{pc}=0.75), 50% (S3, k_{pc}=0.50), and 25% (S4, k_{pc}=0.25) of the evaporation measured in the Class-A pan. The amount of irrigation water applied varied between 126-516 mm, and crop evapotranspiration was between 245-590 mm. While the highest grain yield (486.2 kg da^{-1}) was obtained from the S1 irrigation treatment, followed by S2. The yield decreased owing to the decrease in irrigation level. Thousand-grain weight, ear diameter, ear length, single-ear weight, number of rows per ear, and plant height values in the S1 and S2 irrigation treatments were higher than the S3 and S4. It was concluded that the Class-A pan could be used to schedule popcorn irrigation, and 75% of evaporation from Class-A pan would be enough for irrigation. In this condition, around 25% savings in irrigation water and a 20% decrease in crop evapotranspiration could be achieved. In comparison, a decrease of 6% in grain yield and an enhancement in water productivity could be attained.

Keywords: Class-A pan, Drip irrigation, Water productivity

INTRODUCTION

Corn is one of the most important crops globally (Panda et al. 2004). According to the United Nations Food and Agriculture Organization (FAO) data, world corn production and consumption has been around 1.1 billion tons in the last five market years. The total area of corn cultivation in the world is around 190 million hectares. Corn has the third-largest cultivation area of Turkey after wheat and barley as well as corn production is around 6 million tons throughout the country. The Mediterranean region has the largest corn cultivation area in Turkey with 34%, followed by the Southeastern Anatolia and Aegean Regions. Although yields far above the world are attained in corn, the production in the country cannot meet the consumption (FAO 2020). In Bursa, an essential province for Turkey's agriculture, corn is vital in making and marketing. Corn ranks third in Bursa with 160 thousand tons of production, and the average grain yield is around 1120 kg da^{-1} (Anonymous 2010; Kuşçu 2010).

With the increase in irrigable areas, significant increases have been observed in corn-planted areas recently. Higher yields can be achieved in fertile, well-drained loamy soils. Though water is a vital resource for agricultural production, the water supply in many parts of the world is limited financially and technically. For that reason, the agricultural sector has to advance strategies pointed at saving water and maximizing productivity under water scarcity. Especially in arid regions, there is a need to use innovative and sustainable methods for more effective water applications (Dhanapala 1992; Hook 1992; Fereres and Soriano 2007). Insufficient and irregular irrigation for plant growth in climatic regions where precipitation is inadequate creates a significant risk in cultivating corn plants and turns irrigation into the most vital yield parameter. Furrow irrigation has played an essential role in the irrigation of corn for many years. However, the use of the drip irrigation method has become extensive in recent years attributable to the amplified importance of water on account of droughts and global warming and the cost increases caused by over-irrigation (Kuşçu 2010).

In the Marmara region of Turkey, water supply is the principal natural factor enabling the expansion and development of agriculture. Provided that new and solving studies on irrigation are not carried out, water scarcity is anticipated in the region. Bursa province is also located in the Marmara region, and there may be water problems soon on its borders. According to the data of long years, the average rainfall is around 100 mm between the sowing and harvesting months of corn in Bursa (Kuşçu et al. 2013). It is observed that the corn

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plant, whose seasonal water consumption varies around 500-800 mm, decreases significantly in yield if sufficient water is not given (Doorenbos and Kassam 1979). Hence, irrigation is an essential input since only seasonal precipitation will not meet the water requirement of the corn plant in Bursa conditions.

Hitherto, many studies have been carried out both around the world and in our country regarding the irrigation of corn (Yıldırım et al. 1996; Eşiyok et al. 2004; Sampathkumar et al. 2012; Karrou et al. 2012; Kuşçu et al. 2013; Marques et al. 2015; Hamza and Radian 2019). However, despite the fact there are very few studies on the response of popcorn to different irrigation levels in Turkey, no scientific study has been found on the reaction of popcorn to irrigation in the province of Bursa in the literature reviews. For this reason, in this study, the response of the popcorn plant grown in Bursa climate conditions in the Marmara region with a sub-humid climate to different irrigation levels applied with the drip irrigation system was investigated. The grain yield and some yield components of popcorn were determined in the experiment. Thus, the optimum irrigation program was established by revealing the water-yield relations, and suggestions were made for the conditions where the irrigation water was insufficient.

MATERIALS AND METHODS

This study was carried out in the experimental area of Bursa Uludağ University Agriculture Faculty during the corn growing period in 2019. The average altitude of the research area is 100 m above sea level and is located at 40° 11' north latitude and 29° 04' east longitude. According to the annual total rainfall amount, the experimental site has sub-humid climatological properties. According to the long-term data, the annual average temperature, precipitation, relative humidity, and wind speed are 14.6 ºC, 708 mm, 67%, and 2.1 m s^{-1}, respectively. The soils of the research area belong to the clay class. In the first 120 cm of the soil, the bulk density was between 1.34-1.38 cm^{-3}, the wilting point varies between 23.18-27.07%, and the field capacity differs between 38.17-43.01%. The soil water holding capacity up to 90 cm is 163.3 mm.

R427 popcorn seed variety with high yield potential was used in the study. Seeds were sown on 25 June 2019. Field experiments were carried out in a randomized block design with three replications. Each plot had four plant rows. The plant inter-row spacing and intra-row spacings were 0.7 and 0.20 m., respectively, and the plot area was calculated as 14.56 m^2. A space of 2 m was left between blocks and plots. In this study, four different irrigation levels were determined as the effects of irrigation on the plant were investigated. Irrigation treatments were applied as given in Table 1.

The irrigation water was supplied from a hydrant. A drip irrigation system was installed to control irrigation water to the plant's root zone. Polyethylene pipes, hydro-cyclone filter, disc filter, manometers, water meters, and valves were used to apply water systematically. The diameter of the drip irrigation pipes (polyethylene, PE) was Ø16 for each plant row, and the flow rates of the inline emitters were 2 L h^{-1} at an operating pressure of 1 atm. Due to soil characteristics, the emitter spacing was 0.40 m (Papazafiriou 1980). The diameter of PE manifolds and PE main pipe were Ø32 and Ø50, respectively.

Table 1. Irrigation treatments.

Treatments	Definition
S1	Irrigation up to 100% (pan-crop coefficient kpc=1.00) of the water evaporating from Class-A pan every four days
S2	Irrigation up to 75% (kpc=0.75) of the water evaporated from Class-A pan every four days
S3	Irrigation up to %50 (kpc=0.50) of the water evaporated from Class-A pan every four days
S4	Irrigation up to 25% (kpc=0.25) of the water evaporated from Class-A pan every four days

After the sowing process, the amount of water required to reach the current soil moisture in the 0-90 cm effective root depth to the field capacity was given via the drip irrigation system (Çamoğlu et al. 2011). The following equation was used to determine the amount of irrigation water applied (Çetin et al. 2002).

$$I = A \times E_p \times k_{pc} \times P \qquad (1)$$

In the equation, I is the irrigation amount (L), A is the experimental plot area (m^2), Ep is the cumulative evaporation amount from Class-A pan for considering irrigation interval (mm), k_{pc} is the pan-crop coefficient, and P is the rate of wetted area. The pan-crop coefficients for treatments of S1, S2, S3, and S4 were 1.00, 0.75, 0.50, and 0.25, respectively. The wetted area was determined as 0.90 using the method described by Keller and Bliesner (1990). Irrigation intervals have been determined as four days as they are commonly preferred in the irrigation of corn plants in the region.

Actual crop evapotranspiration was calculated with the water balance equation defined by James (1988). Soil moisture was determined gravimetrically for each plot in the second block, including replications considering 30 cm layers in the depth of 0-120 cm of the soil (Çetin et al. 2002). The amount of irrigation water applied was measured by a flow meter. Rainfall was obtained from the records of the climatological station in Bursa Uludağ University. Runoff and the capillary additive were ignored (Çetin et al. 2002).

Water productivity indicators were used to interpret the various irrigation practices' efficiencies. Water productivity (WP, kg m^{-3}) and irrigation water productivity (IWP, kg m^{-3}) were calculated with the following equations (Bos 1980).

$$WP = YLD / ETa \qquad (2)$$

$$IWP = YLD / IRGA \qquad (3)$$

In the equations, YLD is fruit yield (t ha^{-1}), ETa is actual seasonal evapotranspiration (mm), and IRGA is seasonal irrigation water amount (mm).

Popcorns that reached sufficient maturity were harvested on 15 October 2019. Post-harvest popcorn; grain yield, thousand kernel weight, ear weight, ear length and diameter, kernel number, and plant height values were measured (Sweeney and Marr 2005).

The effects of treatments on yield and yield components were subjected to one-way analysis of variance (ANOVA) according to randomized blocks with three replications. Duncan's multiple test was used to compare different irrigation treatments. IBM SPSS package program (Statistics for Windows, Version 22) was used for statistical analysis. In addition, simple regression analysis was performed to determine the relationships between the amount of irrigation water applied and the actual evapotranspiration versus grain yield.

RESULTS AND DISCUSSION

Irrigation water amount and actual evapotranspiration

Popcorn irrigations started on 05 July 2019, and the amount of precipitation falling from sowing to harvest was recorded as 76 mm. Irrigation could not be done for three irrigation days owing to rain. Total irrigation water varied between 129 mm and 516 mm for irrigation treatments. Seasonal evapotranspiration values of popcorn determined for each experimental treatment are given in Table 2. The highest evapotranspiration was 590 mm from treatment S1 (irrigation rate of 100% of the evaporation measured in the Class-A pan). The lowest was 245 mm from the S4 treatment with the slightest irrigation. The amount of irrigation water applied to the corn plant during the growing period and the evapotranspiration values obtained accordingly; Oktem et al. (2002) found 610-876 mm in the first year of the experiment, 612-889 mm in the second year in semi-arid climatic conditions, Kırnak et al. (2003) found 1215 mm and 1320 mm in the first year, and 1295 mm and 1435 mm in the second year in Harran Plain conditions, and Çamoğlu et al. (2011) reported 50-373 mm and 271.6-483.2 mm in the first year, and 53-389 mm and 201.4- 423.0 mm in the second year in Çanakkale ecological conditions, respectively.

Table 2. Seasonal irrigation water applied and evapotranspiration.

Treatments	Irrigation water applied (mm)	Rainfall (mm)	Soil moisture change (mm)	Evapotranspiration (mm)
S1 (k_{pc}=1.00)	516	76	-2	590
S2 (k_{pc}=0.75)	387	76	+8	471
S3 (k_{pc}=0.50)	258	76	+32	366
S4 (k_{pc}=0.25)	129	76	+40	245

Grain yield

Irrigation levels on grain yield were statistically significant (P<0.01). Grain yield values are shown in Figure 1. The highest grain yield was found from treatment S1 as 486.25 kg da^{-1}, followed by S2 treatment, while the lowest was obtained as 294.63 kg da^{-1} from treatment S4 with the lowest irrigation level. The S1 irrigation level is taken as a reference; the yield reduction rates in S2, S3, and S4 treatments were 6%, %25, and %39, respectively. For this reason, the treatment of S1 can be suggested. The coefficient k_{cp}=1.00 is applied to the water evaporating from the Class-A pan where sufficient irrigation water. In the state of affairs where water is scarce, the first recommended irrigation level is S2 (k_{cp}=0.75). Considering that, compared to the S1, 25% savings are achieved in the irrigation level, while the reduction rate in grain yield is only 6%. In more water stress applications, yield losses increase significantly (25-40%). Similar results were obtained in some studies conducted in Turkey on the irrigation of corn. When the corn grain yields are examined for different climatic conditions, in the study conducted on seven different popcorns with distinct characteristics, the grain yield was 198-435 kg da^{-1} (Sade et al. 1996). The grain yield values on thirteen diverse corn genotypes in Kahramanmaraş conditions were 396-498 kg da^{-1} (İdikut et al. 2015), the grain yield in the in Aydın was 108.641 kg da^{-1} (Vural and Dağdelen 2008). The peak profit of 395.6 kg da^{-1} with 6-day irrigation interval and the lowest grain yield of 255.7 kg da^{-1} with 18-day irrigation interval were found for the variety grown in Amik plain conditions (Akçalı and Gözübenli 2020).

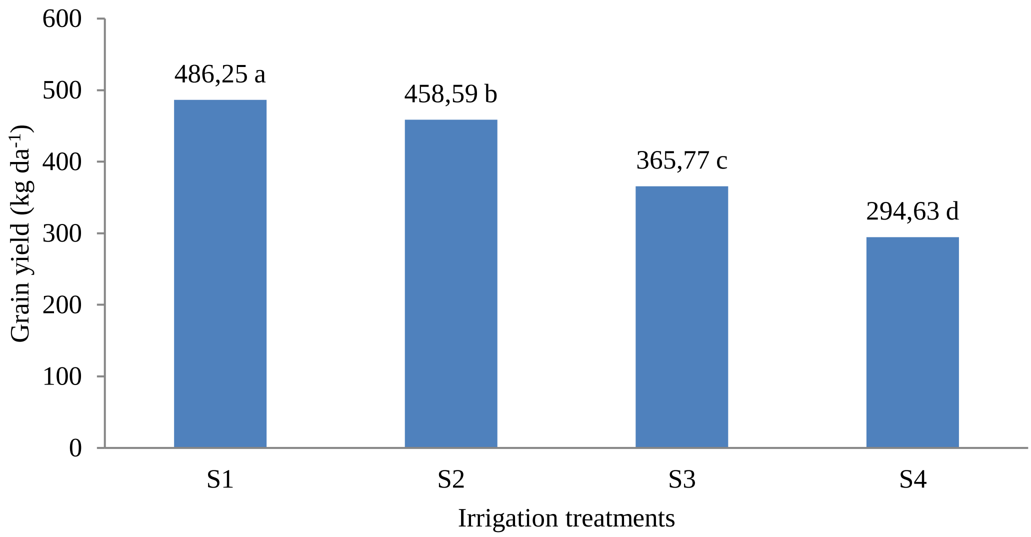

Figure 1. Grain yield values for different irrigation levels.
Note: According to Duncan's test, values indicated with different letters show statistically significant differences.

Yield components

The effect of irrigation levels on thousand-grain weight, single cob weight, cob length, cob diameter, number of grains per cob, and plant height was statistically significant (P<0.01). The results of yield components are shown in Table 3. As seen in Table 3, the highest values of thousand-grain weight, cob length, cob diameter, and the number of grains per cob were obtained from treatments of S1 and S2, while the lowest values were achieved from treatment S4 with the lowest irrigation level. For these parameters, S1 and S2 treatments were statistically in the same group according to the Duncan test, and S3 and S4 treatments followed them, respectively.

In line with the results of this study, in the experiment conducted in Iran conditions, it was observed that the thousand-grain weight decreased with decreasing irrigation water (Sepaskhah and Khajehabdollahi 2005). In Lebanese conditions, an 18% decrease was observed in thousand-grain weight with water stress (Karam et al. 2003). Another research conducted in Bursa conditions reported that water stress made according to different plant development periods significantly affected single ear weight. The highest ear weights were obtained from the full irrigation, while the lower ear weights were obtained from the little water applied treatment (Kuşçu et al. 2013). In similar studies, as the quantity of water decreased, a decrease in the single ear weight was also observed (Kara and Akman 2002; Eşiyok et al. 2004; Okay 2006). According to the results of the similar study; in the research carried out concerning not the same irrigation intervals in Amik plain environments, 29.7 mm ear diameter was found from the treatment irrigated every six days and 28.7 mm from the treatment irrigated every eighteen days (Akçalı and Gözübenli 2020). In another study on the corn plant, it was found that plant height was directly proportional to irrigation, and it was reported that plant height reduced as irrigation was decreased (Kang et al. 2000).

Table 3. Yield components for different irrigation levels.

Treatments	Thousand-grain weight (g)	Single cob weight (g)	Cob length (cm)	Cob diameter (mm)	Number of grains per cob	Plant height (m)
S1 (k_{pc}=1.00)	164 a	152 a	22.4 a	35.0 a	456 a	1.80 a
S2 (k_{pc}=0.75)	163 a	126 b	21.1 a	33.9 a	449 a	1.70 b
S3 (k_{pc}=0.50)	159 b	81 c	18.6 b	31.5 b	340 b	1.68 b
S4 (k_{pc}=0.25)	157 c	46 d	15.8 c	29.9 c	287 c	1.55 c
Significant	**	**	**	**	**	**

** Significant at the 0.01probability level.
Note: Means different according to Duncan test are shown using different letters.

Water-yield relationships

Water-yield functions describing the effects of irrigation water amounts and evapotranspiration values applied to the research treatments on average grain yield were created and given in Figure 2 and Figure 3. A quadratic equation [$Y = -0.0007 I^2 + 0.9389 I + 180.04$] was acquired between the amount of seasonally applied irrigation water (I) and grain yield (Y). A linear relationship [$Y = 0.5836 ETa + 157.36$] was found between seasonal plant water consumption (ETa) and grain yield (Y). The coefficients of determination of the mentioned functions were 0.98 and 0.96, respectively, showing that the experimental data fit the equations obtained at a high level. Gençoğlan and Yazar (1999) expressed the relationship between irrigation water and corn grain yield with the quadratic equation in the field experiment conducted in Çukurova conditions. Kuşçu (2010) reported that relationships between grain yield, irrigation water, and evapotranspiration were linear.

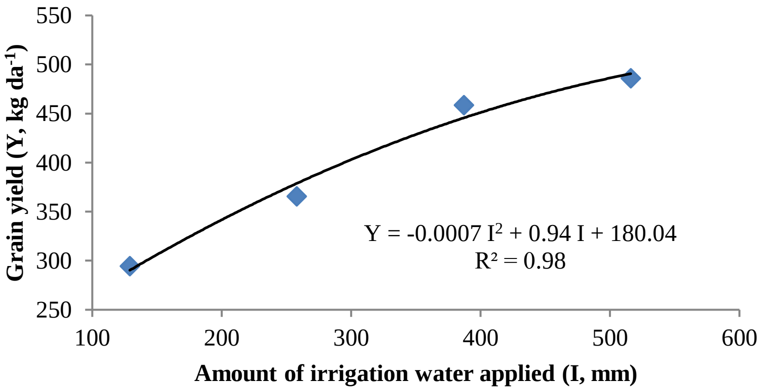

Figure 2. The relationship between applied irrigation water and grain yield.

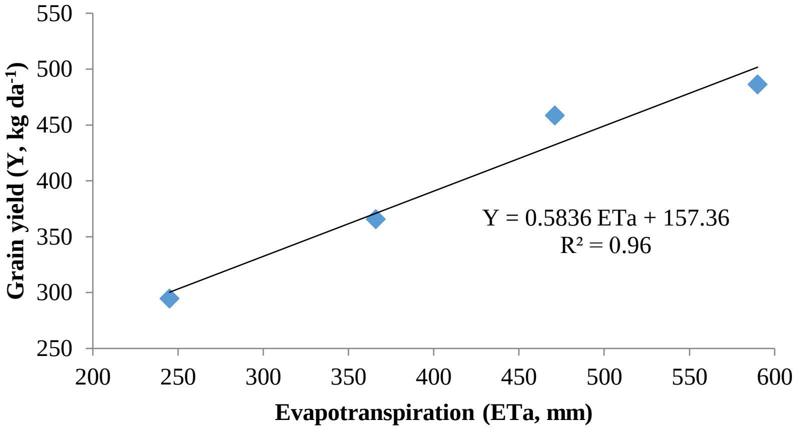

Figure 3. Relationship between plant water consumption and grain yield.

Water productivity

Irrigation water productivity (IWP) and water productivity (WP) values associated with research treatments are given in Table 4. As shown in Table 4, the IWP values varied between 0.94 and 2.28 kg m^{-3}, and the WP values were between 0.82-1.20 kg m^{-3}. The highest IWP and WP values were obtained from the S4 treatment; the lowest was the S1. As the amount of applied irrigation water and evapotranspiration values increased, IWP and WP values declined. This result indicates that the productivity of popcorn was good even at low water supply levels. Even though WP and IWP data showed a wide distribution in researches conducted in various climatic regions, it was observed that WP and IWP values improved as water stress amplified in other field experiments guided together with the data obtained in this study (Kuşçu et al. 2013; Oktem 2008; Köksal and Kanber 1998).

Table 4. Irrigation water productivity (IWP) and water productivity (WP).

Irrigation treatments	IWP ($kg\ m^{-3}$)	WP ($kg\ m^{-3}$)
S1 (k_{pc}=1.00)	0.94	0.82
S2 (k_{pc}=0.75)	1.18	0.97
S3 (k_{pc}=0.50)	1.41	0.99
S4 (k_{pc}=0.25)	2.28	1.20

CONCLUSIONS

There were significant variances for the grain yield of popcorns according to different irrigation levels. The highest grain yields were achieved from the treatment S1 with a pan-crop coefficient (k_{pc}) at 1.00. The results concluded that popcorns grown under Bursa conditions should be irrigated as the quantity of irrigation water determined by employing k_{pc} at 1.00 using cumulative evaporation occurring from a Class-A pan every four days. Consequently, this irrigation program's irrigation water requirement and evapotranspiration were 516 and 590 mm, respectively. Compared to the S1 treatments, a 6% reduction in yield was determined in the S2 treatment (k_{pc}=0.75), where 25% less irrigation water was applied. This application can be recommended in environments where irrigation water is inadequate. In this condition, the yield components and water productivity were also at a very satisfactory level. Lower water levels (k_{pc}= 0.50 or 0.25) are not recommended as they cause a significant reduction in grain yield.

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