

THE IMPACT OF DIFFERENT IRRIGATION INTERVALS AND LEVELS ON YIELD AND QUALITY OF DRIP-IRRIGATED CORN SILAGE (*ZEAMAYS* L.) UNDER ARID CLIMATE

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Abstract. Soil moisture availability exerts significant impacts on the yield and productivity of crop plants. Moisture availability becomes more critical in arid climates, as irrigation is the single source to fulfill the moisture requirements of the plants. Therefore, the level of applied irrigation water and time interval between two irrigations significantly alter the yield and quality of produce. This two-year study determined the effects of different irrigation levels and intervals on yield, quality and water use efficiency of silage maize. The experiment was laid out according to randomized complete block design with split plot arrangements. The main plots consisted of irrigation intervals (3 and 6 days), whereas sub-plots included four irrigation levels (125%, 100%, 75% and 50% of Class-A pan evaporation) based on class A pan evaporation. Drip irrigation method was used to supply the required amount of the water according to the treatments. The annual water consumption rate (ETc) varied between 397 and 725 mm, and between 402 and 759 mm in different study years. The silage yield (FY) during the first year ranged between 36.44 and 81.69 t ha⁻¹, and between 38.31 and 78.96 t ha⁻¹ during the second year. The FY was significantly altered by different irrigation intervals ($p \leq 0.05$) and irrigation levels ($p \leq 0.01$). The dry matter ratio (DMR) (a yield component) was not altered by irrigation intervals and irrigation levels. However, the other yield components such as amount of dry matter yield (DMY) and plant height were significantly ($p \leq 0.01$) affected by irrigation levels. Crude protein (CP) content significantly differed ($p \leq 0.05$) among irrigation intervals and irrigation levels ($p \leq 0.01$). However, the remaining quality parameters, i.e., acid detergent fiber (ADF), neutral detergent fiber (NDF) and crude fiber were only affected by irrigation levels. The pH remained unaffected by irrigation levels and intervals. Leaf area index (LAI) gradually increased after sowing and reached to the highest values at 70-80 days after sowing. Water productivity (WP) and irrigation water productivity (IWP) did not differ among applied irrigation levels and irrigation intervals. It is concluded that frequent irrigations increased silage yield of corn with drip irrigation under arid climatic conditions. However, low water application during the whole growing season caused significant decreases in silage yield.

Keywords: drip irrigation, irrigation levels, water productivity, leaf area index, corn silage

Introduction

The ever increasing urban and industrial water demands along with the contamination of available water resources are decreasing the amount of water devoted to agriculture. Furthermore, water scarcity and frequent droughts because of ongoing global climate changes are seriously threatening plant production in almost all parts of the world (Katerji et al., 2008). Currently, >40% of the global human population is being adversely affected by water scarcity (Steduto et al., 2012). In Turkey, only 19% of agricultural lands can be irrigated due to the inadequate availability of water resources (DSI, 2022), and problems related to water availability will be worsened in the future. Therefore, the farmers should protect the limited water resources for their sustainable use (Cai et al., 2002; Bekele and Tilahun, 2007).

The agricultural lands in the Mediterranean basin are located in the arid and semi-arid climate zones, where summer crops cannot be grown without irrigation. The

Southeastern Anatolia region is dominated by Mediterranean climate in Turkey, and it is the most important region in terms of agricultural production in the country. Moreover, it is the hottest and driest region of the country; thus, summer crops must be irrigated for obtaining optimum yield. The crops in the region are irrigated by furrow irrigation method, which results in significant water losses. Hence, expansion and use of modern irrigation systems is the only way to effectively utilize limited available water resources in the country/region. Water savings and water efficiency can be increased by adopting modern irrigation methods, which would increase irrigation efficiency and farmers' income (Gonçalves et al., 2011; Pereira, et al., 2012). The most appropriate solution is the use of a high-efficiency irrigation system, i.e., drip irrigation (Cai et al., 2002). Drip irrigation is a highly efficient technology as it allows better timing and more precise water applications (Keller and Bliesner, 1990; Goorahoo et al., 2011).

Increasing industrialization and urbanization is decreasing agricultural areas, whereas the number of people to be fed from exiting areas is increasing rapidly. Accordingly, the demands for plant and animal products are rapidly increasing. Corn (*Zea mays* L.) is one of the most widely cultivated crops to fulfill these demands. Corn plant can provide cheap and high-quality feed (Geren et al., 2003). Corn is widely grown in all continents of the world and ranks second after wheat in terms of area production among cereal crops. Due to its high productivity, it ranks first in terms of production (FAO, 2020). The main reasons for the global preference of corn as a silage crop are production of high fresh biomass per unit area, easy harvesting, delicious and highly preferred by animals (Kaplan, 2005), suitability for silage production and high nutritional value (Miller, 1979; Kılıç, 1986; McDonald et al., 1991; Meeske et al., 1993). In addition, it requires less labor and machinery than many other forage crops (Roth et al., 1995), which is another reason for the preference of corn for silage making or ensiling.

Corn is a high-water requiring forage crop (Musick and Dusek, 1980; Stone et al., 1996; Karam et al., 2003; Payero et al., 2006; Farre and Faci, 2009). It requires ~500 to 800 mm water during the growing season (Brouwer and Heibloem, 1986). Several studies have reported adverse effects of water stress on biomass production, pollen viability and grain count in corn having tropical and temperate genetic characteristics (Herrero and Johnson, 1981; Edreira et al., 2011). Water stress decreases plant height, leaf area, DMY, FY, and quality of corn silage (NeSmith and Riechle, 1992; Cox et al., 1998).

Low and erratically distributed precipitation in arid and semi-arid climatic regions is a major hurdle in optimum plant growth of corn. Therefore, irrigation is the most important agricultural practice which would significantly alter FY in such regions (Büyüktaş, et al., 2020). Hence, producers should opt the techniques/methods with high water productivity (WP) through efficient use of limited available irrigation water (IW). Meanwhile, the opted techniques/methods should result in higher quality and quantity of silage since quality of silage is extremely important for animal production besides quantity. Several researchers around the world have investigated the effects of different irrigation practices on WP, FY, and its quality (ADF, NDF, CP, pH etc.) in different climatic regions (Islam et al., 2012; Rusere et al., 2012; Bouazzama et al., 2012; Yolcu et al., 2016; Gheysari et al., 2017; Nilahyane et al., 2020; Büyüktaş et al., 2020). However, the researchers have reported contrasting findings regarding quality and quantity of corn silage.

The extensive literature search revealed that insufficient studies have been conducted to evaluate the combined effect of different irrigation intervals and irrigation levels on

corn silage grown as a second crop under arid climate conditions. The main aim of the current study was to investigate the impact of different irrigation intervals and levels on growth, yield, quality, and the water use efficiency of drip irrigated corn silage in an arid region. It was hypothesized that growth, yield, quality, and the water use efficiency of drip irrigated corn silage will significantly differ among tested irrigation intervals and levels. The results would help to find the optimum irrigation level and irrigation interval for higher silage yield with high quality under arid climates.

Materials and methods

Experimental site climatic conditions

This current study was conducted in the Harran Plain (37°10'N, 39°59'E, and 499 m above sea level) in Şanlıurfa, Turkey, where second crop corn is intensively grown during 2017 and 2018 growing seasons.

Harran Plain is situated in the hottest region of Turkey and dominated by arid climatic. The summer months are extremely hot and dry, whereas winter months are cold and rainy. The June, July, August, and September are the hottest months, while December and January are the coldest months. The daily maximum temperature during July and August often exceeds 40 °C, while minimum temperatures drop below 0 °C during winter. According to long-term (1920-2021) climate, the annual total precipitation in Harran Plain is 340 mm, and evaporation from the open water surface is 1850 mm. The weather data of the experimental years was similar to long-term average data of the experimental site. Out of the total rainfall, only 4% is received during the vegetation period of the second crop corn.

The experimental soil was clay textured (USSL, 1954), having low salt contents and slightly alkaline. The experimental site has a deep profile and useful water holding capacity of 0-90 cm depth was 102.5 mm (*Table 1*). The electrical conductivity of the IW used in the study was 0.358 dS m⁻¹ and it belonged to C₂S₁ class according to the water quality diagram of the US Salinity Laboratory.

Table 1. Physical and chemical properties of the experimental soil

Soil layers (cm)	Texture	Field capacity (g g ⁻¹)	Wilting point (g g ⁻¹)	Bulk density (g cm ⁻³)	EC (dS m ⁻¹)	pH	Lime %
0-30	C	0.286	0.205	1.36	0.582	7.4	8.1
30-60	C	0.298	0.213	1.37	0.654	7.4	8.7
60-90	C	0.301	0.217	1.37	0.703	7.5	9.3

EC: electrical conductivity

Agronomic practices

Seedbed preparation, sowing and harvesting: The experimental site was ploughed in June immediately after wheat harvest, and prepared for corn planting with combi plough and cultivator. The corn was planted with a pneumatic seeder on 21 June and 23 June 2018 by keeping row-to-row distance of 70 cm. The 'May Hido' corn variety belonging to FAO 700 maturity group was used in the study. The experimental units were 6.00 m long and 4.20 m (6 rows) wide covering a total area of 25.60 m². However, at harvest,

0.5 m from the edges two border rows were left to avoid edge effect; thus, remaining plants in 14 m² area were manually harvested.

Plant protection and fertilization: Hoeing was done twice to control the weeds after the emergence of corn by using a manual hoeing machine. Thinning and earthing up were done with second hoeing to maintain plant-to-plant distance of 15-20 cm. A total 80 kg ha⁻¹ P₂O₅ and 240 kg ha⁻¹ N were applied. While the whole amount of P₂O₅ and 80 kg ha⁻¹ N was applied at sowing using 20-20-0 fertilizer, the remaining N was applied with fertigation in three equal splits. The insect pests were controlled by using chemical control as needed during the corn growth period.

Experimental treatments and design

Experimental treatments: The experiment was carried out according to randomized complete block design with split plot arrangements. The irrigation intervals were kept in main plots, whereas irrigation levels based on coefficients of Class a Pan were randomized in sub plots. Eight different irrigation programs were applied during the field study. The experimental treatments are summarized in *Table 2*.

Table 2. Different irrigation level and irrigation interval treatments used in the study

Main plots (different irrigation intervals)	Subplots (irrigation levels)
D ₁ (irrigation every 3 rd day) D ₂ (irrigation every 6 th day)	I ₁ = 125% (Kp ₁ = 1.25)
	I ₂ = 100% (Kp ₂ = 1.00)
	I ₃ = 75% (Kp ₃ = 0.75)
	I ₄ = 50% (Kp ₄ = 0.50)

Irrigation system and irrigation water

Drip irrigation system was used to provide the desired amount of IW according to the treatments. The IW was taken from a deep well situated in the trial area. The IW taken from the well was first filtered in the control unit. The control unit consisted of sand gravel filter, screen filter, pressure regulator, manometers, fertilizer tank and water clock. The filtered water was conveyed to the experimental site with 75 mm polyethylene pipes and then distributed to the experimental units with 50 mm polyethylene pipes. A lateral line was laid for each row; thus, lateral spacing was 0.70 m (Sl = 0.70 m). The lateral pipes were 16 mm, and the drippers were spaced 0.30 m apart (Sd = 0.30 m). The drippers had a flow rate of 4 l/h. The selection of the drippers was based on soil characteristics as described by Keller and Bliesner (1990). All experimental units were irrigated with same amount of IW by using sprinkler irrigation immediately after sowing to ensure homogeneous plant germination and development. The second hoeing and earthing up were done once the plants reached 25-30 cm height, afterwards drip irrigation system was installed in the experimental field.

Measurement of IW

The amount of IW to be applied in different treatments was determined by multiplying the evaporation amount from Class A Pan evaporation pan present in the trial area with different crop-pan coefficients (Kp). The amount of evaporation between

two irrigation intervals (3 and 6 days) was multiplied by the K_p and cover percentage (P) to determine the amount of IW. The percentage of cover used in the computations was determined by measuring the plant canopy before each irrigation. The first irrigation was given when 50% of the available water in 0-60 cm soil profile was consumed. Gravimetric method was used to determine the soil available moisture in 0-60 and 0-90 cm soil depth.

All experimental units were irrigated to field capacity during first irrigation, and then calculated amount of IW was applied according to the treatment. The applied amount of IW amounts was controlled by water clocks in each experimental unit. The precipitation amount was taken from the meteorology station located next to the experimental area. The following equation was used to calculate the amount of IW amount (Ünlü et al., 2011):

$$IW = A \times E_{pan} \times K_p \times P_c \quad (\text{Eq.1})$$

Here, IW: is the amount of irrigation water (mm), E_{pan} is the cumulative evaporation for irrigation interval (mm), K_p is the crop-pan coefficient, and P_c is plant cover (%). Free surface water evaporation was measured with a screened Class A pan located at the meteorological station near the experimental field.

Soil moisture monitoring

Soil moisture in all experimental plots was monitored at soil depth of 0-120 cm with gravimetric method. The water budget equation was used for the calculation of ET_c (James, 1988):

$$ET_c = I + P + D_p \pm R_{off} \pm \Delta S \quad (\text{Eq.2})$$

Here, ET is evapotranspiration (mm), I is the irrigation water (mm), P is the rainfall (mm), D_p is the deep percolation (mm), R_{off} is the runoff (mm) and ΔS is the change of moisture content in the 0-90 cm root depth (mm).

Irrigation water use efficiency (IWP) and water use efficiency (WP) were determined in order to assess the effects of irrigation treatments (Howell et al., 1990). The equations are as follows:

$$WP = \frac{Y}{ET} \quad (\text{Eq.3})$$

$$IWP = \frac{Y}{IW} \quad (\text{Eq.4})$$

where Y is yield (kg ha^{-1}), ET is the seasonal evapotranspiration (mm), and IW is the amount of seasonal irrigation water (mm).

Leaf area index

Plant samples were taken to score the leaf area index (LAI) throughout the growing season at intervals of 10 days. Five plants were randomly selected for sample collection.

Leaf area was measured with leaf area meter (LI-COR 3100): Leaf area index was the computed by dividing leaf area with ground area.

Ensiling procedure and chemical analyses

For analyzing silage quality, silage material was taken from each experimental unit and placed in 1 L airtight jars. The jars were opened after 60 days of fermentation. Extracts of fermented materials were prepared by homogenizing 25 g wet material with 100 mL water in a blender. The content was then filtered through two layers of cheesecloth and pH was determined. Silage samples were ground after drying at 65 °C. Afterwards, dry matter (DM) and CP were analyzed by following the procedure of AQAC (1984). The NDF and ADF contents were determined according to the procedure of Goering and Van Soest (1970). Crude fibers were analyzed according to method described by Crampton and Maynard (1938).

Statistical analysis

The results of the study were evaluated using Minitab 18 statistics software. Firstly, analysis of variance (ANOVA) was used to evaluate the effects of different irrigation treatments on the yield and quality of corn silage. Tukey's post-hoc test was used for comparing and ranking the treatment means.

Results and discussion

The ETc amounts from different experimental units were determined by considering soil moisture content at the effective root depth, rainfall, and the amount of applied IW. The seasonal water consumption of the treatments and the amount of irrigation water applied in the experimental treatments are given in *Table 3*.

Table 3. Amount of irrigation water (IW) and evapotranspiration (ETc) in different irrigation treatments used in the current study

Treatments		2017				2018			
		Rainfall mm	ΔS mm	IW mm	ETc mm	Rainfall mm	ΔS mm	IW mm	ETc mm
D₁	I ₁	0	3.1	705.3	708.4	5.7	-3.9	737.3	739.1
	I ₂	0	13.9	585.4	599.3	5.7	15.3	609.1	630.1
	I ₃	0	36.3	465.6	501.9	5.7	22.7	480.8	509.2
	I ₄	0	51.6	345.7	397.3	5.7	43.8	352.5	402.0
D₂	I ₁	0	13.4	712.0	725.4	5.7	9.5	743.9	759.1
	I ₂	0	28.0	590.8	618.8	5.7	11.6	614.3	631.6
	I ₃	0	46.1	469.6	515.7	5.7	38.3	484.7	528.7
	I ₄	0	58.7	348.4	407.1	5.7	58.4	355.1	419.2

ΔS: The change of moisture content in the 0-90 cm root depth, IW: irrigation water, ETc: crop evapotranspiration

Harran Plain receives almost no precipitation during the growing period of corn. No precipitation was recorded during the first year of study, whereas only 5.7 mm was received during the second year. Therefore, plants obtained a significant part of required

water from IW and a small amount from the water stored in the soil from early spring precipitation. The utilization of water retained in the soil was higher in treatments receiving less IW.

Since wheat was the winter crop in the experimental area, the land prepared for corn planting immediately after wheat harvest was irrigated with sprinkler irrigation to prepare seedbed. After emergence, fixed irrigation was applied twice in every year until the initiation of irrigation treatments. In the fixed irrigations, 62- and 57-mm water was applied during first and second year, respectively. The irrigation treatments were imposed once the plants attained 30 cm height. The irrigation treatments were initiated on 27 July and terminated on 25 September during 1st year. During the 2nd year, irrigation treatments were initiated and terminated on 30 July and 27 September, respectively.

The amount of IW applied to different irrigation treatments differed depending on the crop-pan coefficient and plant canopy. The amount of IW applied in I₁ treatment (full irrigation) was 705.3- and 712.0-mm during the first year, whereas IW was slightly higher in the second year due to prevailing climatic conditions.

The treatments differed for ET_c depending on the amount of IW applied. While the ET_c of the treatments where high amount of IW was applied were close to the total IW applied, the difference between the amount of IW and ET_c increased with decreasing amount of applied IW. The ET_c values for full irrigation treatment (I₁) were 708.4- and 725.4-mm during 1st year, while the values were 739.1- and 759.1 mm during 2nd year. Since the experiment was carried out in arid conditions, it increased in the amount of ET_c. In the earlier studies ET_c has been reported to vary from 474 to 605 mm by Kanber et al. (1990), from 494 to 644 mm by Kateji (1996), from 465 to 802 mm by Howell (1998), from 641 to 668 mm by Pandey (2000), from 366 to 625 mm by Payero et al. (2006), from 947 to 1003 mm by Simşek et al. (2011) from 184 to 425 mm by Ors et al. (2015), from 568 to 580 mm by Gheysari (2017), and from 708 to 759 mm by Büyüktaş et al. (2020). It can be concluded that genotypic differences, farming techniques, climatic conditions, soil texture, irrigation systems and IW amount significantly affect ET_c (Igbadun et al., 2008).

When the corn grains reach the pulping stage (BBCH 83), plants were harvested manually, and FY and yield components were recorded and presented in *Table 4*.

The data analysis of FY revealed that D₁ recorded higher yield compared to D₂ ($p \leq 0.05$). This reveals that maintain soil moisture at a specific level through frequent irrigation exerted positive impact on FY. The FY was also significantly ($p \leq 0.01$) affected by the amount of IW in addition to irrigation intervals. The reduction in the amount of IW significantly reduced FY. The 51% reduction in IW reduced FY by 53%. Similar results were obtained for the rest of the reductions in the amount of IW. In other words, the decrease in FY was closer to reduction in IW. Statistical analysis revealed that irrigation interval by irrigation level interaction had non-significant effect on FY. The highest FY was noted for D1-I1 treatment.

Statistical analysis of FY data for the second year revealed similar findings as of first year. The individual effects of irrigation intervals ($p \leq 0.05$) and irrigation levels ($p \leq 0.01$) significantly altered FY. However, interactive effect of irrigation intervals and irrigation levels remained non-significant for FY. A 7.5% decrease in FY was recorded when irrigation interval was increased to 6 days from 3 days. Similarly, 17%, 35% and 52% reduction in IW reduced FY yield by 7%, 22% and 49%, respectively. The adverse effects of water stress became more severe with increased reduction in IW.

Örs et al. (2015) reported that frequent irrigation increased FY, while Yazar et al. (2002) reported that irrigations performed with 3- or 6-days intervals had no effect on FA. In addition, several researchers reported that ET and FY are positively correlated, and the highest FY was obtained with full irrigation (Lizaso, 2001; Yazar et al., 2002; Payero et al., 2006; Bekele and Tilahun, 2007; Lauer, 2007; Montgomery, 2009; Rusere et al., 2012; Islam et al., 2012; Örs et al., 2015; Nihalyane et al., 2020; Büyüktaş et al., 2020).

Table 4. Means and statistical groups for silage yield and yield component of corn grown under different irrigation intervals and irrigation levels (n = 3)

Treatments	FY t ha ⁻¹		DMR %		DMY t ha ⁻¹		Plant height m	
	2017	2018	2017	2018	2017	2018	2017	2018
D ₁	61.50a	64.26a	27.51	28.59	16.80	18.28a	2.59	2.69
D ₂	57.39b	59.47b	28.18	27.59	16.07	16.35b	2.57	2.60
P (Factor A)	*	*	ns	ns	ns	*	ns	ns
I ₁	78.64a	77.03a	27.06	27.89	21.27a	21.51a	2.92a	3.04a
I ₂	66.70b	71.64a	27.34	27.48	18.22b	19.70ab	2.75b	2.84b
I ₃	55.54c	59.73b	28.02	27.82	15.57c	16.65b	2.48c	2.53c
I ₄	36.89d	39.05c	28.96	29.16	10.68d	11.40c	2.16d	2.18d
P (Factor B)	**	**	ns	ns	**	**	**	**
D ₁ -I ₁	81.69	78.96	26.78	27.91	21.87	22.09	2.95	3.07
D ₁ -I ₂	70.40	75.62	26.95	28.40	18.98	21.44	2.76	2.89
D ₁ -I ₃	56.59	62.68	27.86	28.20	15.74	17.69	2.45	2.58
D ₁ -I ₄	37.34	39.79	28.45	29.84	10.63	11.88	2.18	2.22
D ₂ -I ₁	75.59	75.01	27.34	27.87	20.67	20.93	2.88	3.01
D ₂ -I ₂	63.00	67.66	27.73	26.56	17.47	17.95	2.73	2.79
D ₂ -I ₃	54.50	56.79	28.18	27.44	15.39	15.60	2.51	2.47
D ₂ -I ₄	36.44	38.31	29.47	28.47	10.74	10.92	2.14	2.14
P (A*B)	ns	ns	ns	ns	ns	ns	ns	ns

FY: The silage yield, DMR: The dry matter ratio, DMY: the dry matter yield, ^{ns} = non-significant, ^aThe treatment means followed by the same letter are statistically non-significant at 95% probability level by Tukey's test

The fresh silage samples harvested from different experimental units were dried to determine matter ratio (DMR) and the amount of DMY produced. The DMRs of different irrigation treatments increased numerically with increasing water stress and the highest DMR was noted for I₄. However, the differences among treatments were non-significant according to ANOVA. The earlier studies have reported contrasting results for DMRs. Some studies reported that DMR was not affected by IW (Baran, 2015), whereas the others reported that DMR decreased with increasing amount of IW (Makela et al., 2005; Kruse et al., 2008; Setter and Parra, 2010; Bulut, 2015). In contrast to these results, İslam et al. (2012) reported a significant increase in DMR with increasing amount of IW. These differences can be explained with varieties used in different studies, agricultural techniques opted and time of silage making stage.

In parallel with FY, the amount of DMY differed among applied irrigation treatments. Different irrigation intervals had non-significant effect on DMY. However, IW significantly affected ($p \leq 0.01$) DMY. The DMY was linearly increased with increasing amount of IW. Each irrigation level was placed in different grouped according to Tukey's post-hoc test. The ANOVA revealed significant effect of irrigation intervals ($p \leq 0.05$) and irrigation levels ($p \leq 0.01$) on DMY production during second year. The DMY in corn was increased with frequent irrigation. Similarly, DMY was also increased with increasing amount of IW and reached to 21.51 t ha⁻¹ with full irrigation. The earlier studies have also reported similar results as of current study (Lizaso et al., 2001; Schmaher et al., 2003; Greysari et al., 2009; Islam et al., 2012; Ferreria, 2015).

Plant height is an important yield-related parameter of corn silage. In the current study irrigation intervals had non-significant effect on plant height during both years, whereas irrigation levels significantly ($p \leq 0.01$) altered plant height. Each irrigation level was ranked in different group according to Tukey's test. The plants receiving full irrigation (I₁) reached 2.92 m height during first year, and plant height significantly reduced with decreasing amount of IW. The 34% reduction in IW decreased plant height by 44 cm, while 51% reduction in IW decreased plant height by 76 cm. Similar results were obtained for plant height during second year of the study. The treatments receiving lower amount of IW resulted in lower plant height, whereas increase in plant height was recorded with increasing amount of IW. Several earlier studies have reported similar results as obtained in the current study (Otegui et al., 1995; İstanbulluoğlu et al., 2002; Bozkurt et al., 2006; Soler et al., 2007; Kızıloğlu et al., 2009; Greysari et al., 2009; Bulut, 2015).

Silage samples were taken from each experimental unit and quality traits were determined to assess the impact of irrigation treatments on silage quality. The quality traits of silage maize recorded during the current study are summarized in Table 5.

Silage quality is of great importance in addition to high silage yield. The CP, ADF, NDF crude fiber ratios and pH values are used to assess silage quality. High CP contents are desired in high quality silage. The CP contents were significantly altered by irrigation interval ($p \leq 0.05$) and the irrigation levels ($p \leq 0.01$) during 2017. The treatments which were frequently irrigated had higher CP contents. The amount of IW applied also affected CP content and increasing amount of IW increased CP contents. The highest CP contents were recorded for the treatment receiving the highest amount of IW. The least water receiving two treatments did not differ statistically. Similar CP contents as of first year were noted during the second year of the study. The CP contents were significantly affected by irrigation intervals ($p \leq 0.01$) and irrigation levels ($p \leq 0.01$). However, in contrast to the first year, the CP contents were lower in frequently irrigated treatments. The treatments receiving the highest amount of water resulted in the highest CP contents during second year, whereas the lowest CP contents were noted for the treatment facing higher drought stress. The interactive effect of irrigation intervals and irrigation levels remained non-significant for CP contents during both years of the study. The earlier studies have reported contrasting correlations between IW and CP contents. For example, Pelleschi et al. (1997), Yosef et al. (2009) and Şimşek et al. (2011) reported that CP contents increased with increasing amount of IW, whereas some other studies reported non-significant effect of IW on CP contents (Oweis et al., 1999; Hargreaves et al., 2009; Islam et al., 2012; Liu et al., 2013; Seif et al., 2016). In contrast, Montgomery (2019) and Nihalyane et al. (2020) reported a negative correlation between IW and CP contents.

Table 5. Means and statistical groups for some silage quality characteristics of treatments

Treatments	CP %		ADF %		NDF %		Crude fiber %		pH	
	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
D ₁	8.01a	7.54b	30.27	30.28	43.70	41.29	16.22b	16.73	3.56	3.71
D ₂	7.85b	7.68a	29.52	29.85	44.01	41.89	16.77a	16.35	3.53	3.64
P (Factor A)	*	*	ns	ns	ns	ns	*	ns	ns	ns
I ₁	8.39a	8.00a	31.40a	31.39a	46.37a	42.82	17.66a	17.40ab	3.58	3.62
I ₂	8.03b	7.65b	31.39a	31.75a	44.99ab	42.22	17.20ab	17.74a	3.54	3.62
I ₃	7.64c	7.60b	28.77ab	29.54ab	42.34bc	41.28	16.32b	16.15bc	3.49	3.75
I ₄	7.66c	7.20c	28.00b	27.40b	41.78c	40.05	14.80c	14.88c	3.57	3.71
P (Factor B)	**	**	**	*	**	ns	**	**	ns	ns
D ₁ -I ₁	8.44	7.95	32.86	31.40	45.80	42.74	17.12	17.16	3.57	3.65
D ₁ -I ₂	8.15	7.52	31.73	32.44	44.15	40.91	17.14	18.12	3.55	3.61
D ₁ -I ₃	7.74	7.64	28.23	29.21	42.13	41.68	16.05	16.31	3.51	3.79
D ₁ -I ₄	7.70	7.04	28.26	28.07	42.73	39.85	14.58	15.33	3.59	3.77
D ₂ -I ₁	8.33	8.04	29.95	31.37	46.95	42.90	18.21	17.63	3.58	3.59
D ₂ -I ₂	7.91	7.78	31.06	31.06	45.82	43.53	17.26	17.36	3.53	3.62
D ₂ -I ₃	7.54	7.55	29.32	29.86	42.56	40.88	16.58	15.98	3.47	3.70
D ₂ -I ₄	7.62	7.36	27.75	26.73	40.84	40.25	15.03	14.44	3.54	3.64
P (A*B)	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

CP: The crude protein, ADF: the acid detergent fiber, ND: the neutral detergent fiber, ^{ns} = non-significant, ^a: The treatment means followed by same letters are statistically non-significant at 95% probability level by Tukey's test

The ADF is a good indicator of feed digestibility and energy intake of the animals (Goering and Van Soest, 1970, 1994). Assefa and Ledin (2001) reported that lower ADF contents in silage represent high quality. The ADF values ranged between 27.75 and 32.86% during first year and were not affected by irrigation intervals. However, irrigation levels had significant ($p \leq 0.01$) effect on ADF. There were no significant differences among high IW receiving treatments (I₁ and I₂). However, increasing water stress significantly reduced ADF ratio. Similar results for ADF were obtained during 2018. Irrigation with 3-day or 6-day intervals did not affect ADF content; however, ADF ratio significantly ($p \leq 0.05$) increased with increasing amount of IW. Irrigation interval had non-significant effect on ADF in the current study. Ors et al. (2015) also reported that ADF was not affected by irrigation intervals. However, some previous studies indicated that ADF ratio increased with increasing amount of IW (Şimşek et al., 2011; Kuchenmeister et al., 2013; Kaplan, 2016). In contrast to these findings, Montgomery (2019), İslam et al. (2012), Seif (2016), Nihalyane (2020) and Shahrabian and Soleymani (2011) reported that increasing IW decreased ADF ratio. Besides some other studies reported that ADF content was not affected by IW (İslam et al., 2012; Işık et al., 2012; Ors et al., 2005). It is thought that the differences in the effects of IW on ADF content in current study are related to the applied agricultural techniques, crop variety and harvest time.

The NDF content is also an important quality criterion in corn silage and should not be high (Dawyer, 1998). In the study, irrigation intervals did not affect NDF ratio

during both years. However, the increase in the amount of IW applied affected the NDF ratios ($p \leq 0.01$) in the first year, while had no effect during the second year. Previous studies have reported conflicting results on the effect of IW on NDF contents. Like the findings of current study, several studies reported NDF ratio increases with increase in the amount of IW (Islam et al., 2012; Şimşek et al., 2011; Shahrabian and Soleymani, 2011; Ferreria, 2015). Contrastingly, numerous studies also reported decrease in NDF content with increasing IW application (Montgomery, 2009; Seif et al., 2016; Nihalyane et al., 2020). Besides, Işık (2012) reported that NDF was not affected by IW.

The pH values of the silages obtained from different experimental units varied between 3.47-3.59 and 3.59-3.79 in 2017 and 2018, respectively. Although the pH value, which was 3.54 in the first year, increased to 3.67 during second year, different irrigation day intervals or irrigation levels had non-significant effect on the pH of silage. The pH values of the treatments were like optimum pH levels corn silage reported by Kolver et al. (2001). Mould et al. (1983) and Bates (2009) reported that pH values decreased with increasing amount of IW. Contrastingly, İslam et al. (2012) and Kaplan (2016) reported an increase in pH value with increasing amount of IW.

Crude fiber ratio is an important quality criterion affecting the digestibility of silage. Irrigation intervals ($p \leq 0.05$) and irrigation levels ($p \leq 0.01$) had significant effect on the crude fiber content during first year; however, their interaction was non-significant. The crude fiber content increased with increase in irrigation interval, and the treatments irrigated at 6-day interval recorded higher crude fiber contents. On the other hand, crude fiber ratios increased as the amount of IW increased. According to the results of the Tukey test, each irrigation level was in a separate group, while the first group contained I₁. Irrigation interval did not affect crude fiber content during second year; however, irrigation levels significantly ($p \leq 0.01$) affected crude fiber content first year. The highest crude fiber content was recorded for I₂, while the lowest ratio was recorded for the treatment receiving the least amount of IW. Baran (2015) also reported similar results that decrease in IW lowered crude fiber content. Corn silage should have a crude fiber content of 14-18% and this ratio should not exceed 20% for feeding to dairy cattle (Yüksel et al., 2000; Aydınoglu, 2005). The crude fiber content were between these limits in the current study; thus, meet the desired ratios for dairy cattle.

Leaf area index and water use efficiencies

Leaf development is associated with photosynthesis and evapotranspiration (ET), and leaf area is used in the evaluation of most agronomic and physiological studies as well as plant growth (Guo and Sun, 2001).

LAI varies depending on leaf size and number of leaves per plant. It is negatively affected by water stress and nutrient deficiency (Longnecker, 1994). The LAI values recorded from different treatments in the current study are presented in *Figure 1*.

A sigmoidal relationship was recorded between LAI and time in the current study during both years. The LAI started to increase from plants' emergence and reached the maximum level at 0-80 days from planting. Although LAI continuously increased in all treatments, the values differed among various irrigation treatments. Negative effects of water stress on LAI became evident 48 DAS 48 (*Fig. 1*). The LAI started declining after reaching the peak values. The decrease in LAI was more pronounced in the treatments receiving lower amount of IW (I₃ and I₄), and the treatments irrigated with higher amount of IW (I₁ and I₂) observed less decrease in LAI. The highest LAI value was

noted from fully irrigated plants D₁-I₁ and D₂-I₁, and the values were 4.83 and 4.71 and 5.12 and 5.01 during 1st and 2nd year, respectively.

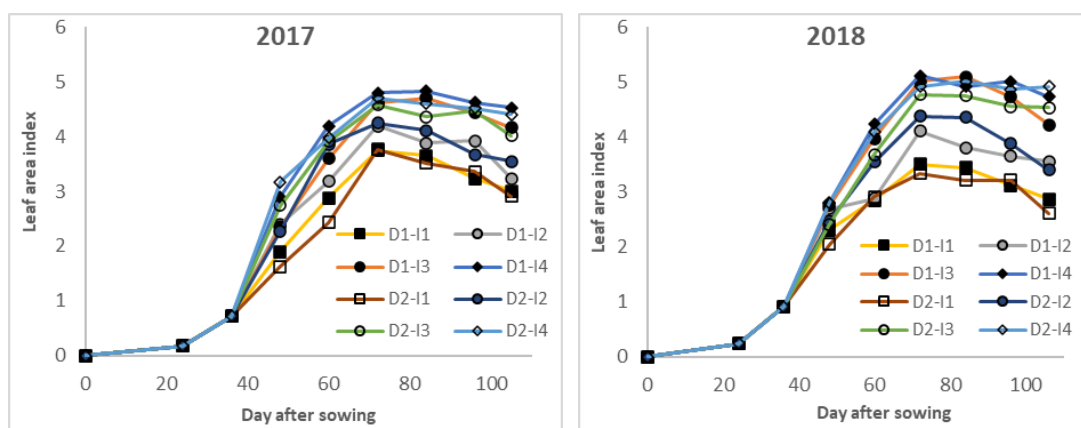


Figure 1. Temporal changes in leaf area index of corn silage grown under different irrigation treatments (DAS = days after sowing)

Although differences were noted among different irrigation treatments, the LAI values of the treatments with high IW application (full irrigation) in this study were consistent with the results of previous studies (Stone et al., 2001; Yazar et al., 2002; Karam et al., 2006; Sampathkumar et al., 2013). The highest LAI value was obtained from full irrigation treatment. However, differences were noted among treatments for time to reach the highest LAI in the current study. Agricultural practices, environment and variety exert significant effects on LAI.

Silage yield increased depending on the increase in the amount of IW and ETC. Figure 2a shows the correlation among ETC and yield. In addition, yield response factor (Ky) applied to evaluate the relation between water consumption and yield is shown in Figure 2b.

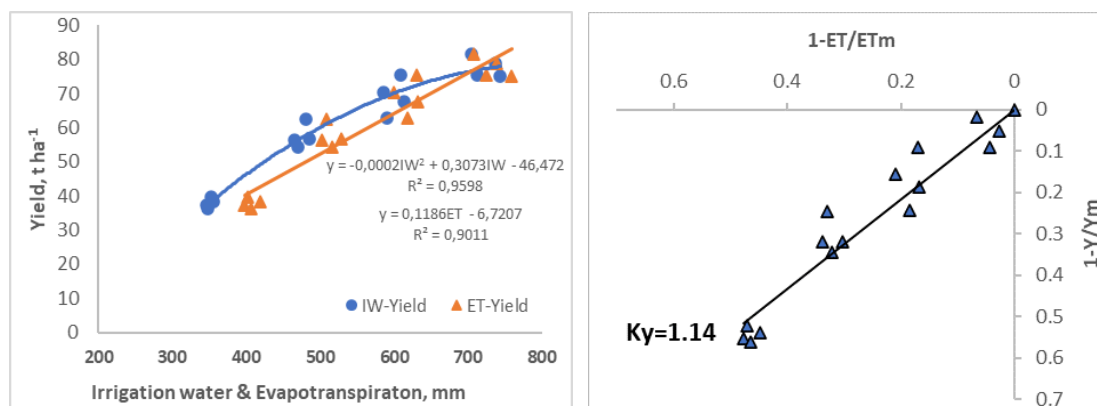


Figure 2. The relationship between fresh yield and irrigation water and evapotranspiration (a) and relationship between relative evapotranspiration deficit and relative yield reduction (b)

Silage yield witnessed an increase with increasing ETC values. A significant ($p \leq 0.01$) linear relationship was noted between ETC and yield with two years' average

data. Several researchers in earlier studies reported a linear relationship between ET and yield (Howell et al., 1998; Kızıloğlu et al., 2009; Şimşek et al., 2011; Okursoy, 2009). A second order significant sigmoidal ($p \leq 0.01$) relationship was recorded between IW and yield. Silage yield increased with increasing amount of IW. However, as the amount of seasonal IW increased, the positive effect of IW on yield decreased. While some researchers reported a sigmoidal relationship between IW and FY in previous studies on corn silage (Bozkurt et al., 2006; Ors et al., 2015), the others reported a linear relationship (Yazar et al., 2002; Okursoy, 2009).

The slopes of the relationships between relative yield reduction and relative evapotranspiration deficit termed the “yield response factor” by Doorenbos and Kassam (1979) were 1.14. The K_y value ≥ 1.0 indicate that the plant is highly sensitive to water stress. The results of this study indicated that that corn silage is highly sensitive to water stress in arid climates. The earlier studies have also reported similar results. Doorenbos and Kassam (1979), reported that seasonal K_y factor of corn grown in deep and medium textured soils was 1.25. Şimşek et al. (2011) reported the K_y factor of 1.13 for drip irrigated corn. Howell et al. (1997) reported that the k_y factor was 1.47 in Bushland, Texas.

Water use efficiency is an important criterion considered in determining the most appropriate irrigation program in limited irrigation research. The two-year average IWP and WP values calculated for the applied treatments in this study are shown in Figure 3.

There was no precipitation during corn growing season in the first year, and only a little precipitation was received in the second year. Therefore, almost all ET_c was obtained from the IW. For this reason, the WP and IWP values of the treatments where more IW was applied were close to each other. Since the treatments with low IW application benefited more from the available moisture in the soil, significant differences were noted between the WP and IWP values of these treatments. The IWP values of applied treatments ranged between 10.6 and 12.6 kg m^{-3} , with the lowest IWP values noted for D_2-I_4 and D_2-I_2 treatments irrigated at 6-day interval. The IWP values of D_1 treatment were higher than D_2 at all irrigation levels. This is because the silage yield in D_1 was higher than D_2 . These results indicate that frequent irrigation increases IW productivity of corn silage.

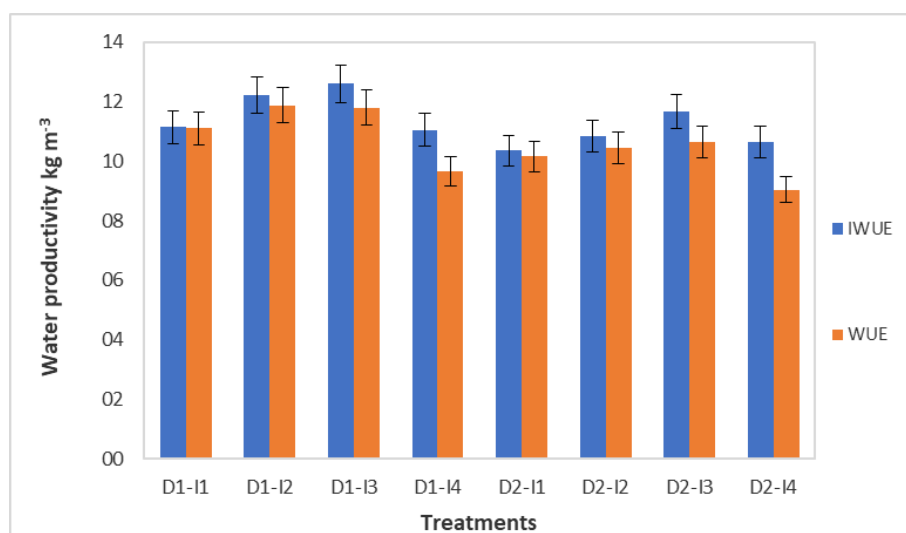


Figure 3. Water productivity and irrigation water production for various irrigation treatments used in the current study

The WP values were also like IWP values. The D₁ interval had higher WP values than D₂ with all irrigation levels. In other words, maintaining the root zone at a certain moisture level with frequent irrigation increased WP in corn. While the WP values of the treatments where more water was applied were close to each other, the WP of the least applied IW (I₄) was lower than the rest of the treatments.

No precipitation is received during the growing season of corn silage in arid regions and ET_c in such regions is higher than other climatic regions. This reduces WP and IWP values of irrigations in arid regions. Several earlier studies indicated that low water availability reduced WP (Farre and Faci, 2006; Igbadun et al., 2008; Payero et al., 2006; Kızıloğlu, 2009; Yazar, 2009; Şimşek, 2011 Bauzzama, 2012), whereas some studies reported contrasting findings that low water availability increased WP (Rusere, 2012; Mostafa, 2013). Howell (1998) reported no significant change in WP in response to water shortage. The IWP values obtained in previous studies also differed from each other. Farre (2006) reported that IWP increased with an increase in the amount of IW, while on the contrary some studies reported that IWP decreased as the amount of IW increased (Payero et al., 2006; Yenesew and Tilahun, 2009). These different results regarding the effect of IW on IWP are linked to climatic conditions and irrigation method used to grow corn silage.

Conclusion

Frequent irrigations increased silage yield of corn with drip irrigation under arid climatic conditions. However, low water application during the whole growing season caused significant decreases in silage yield. For this reason, if irrigation water needs to be reduced in corn silage cultivation, it should be applied when the plant is less sensitive to water stress. Irrigation frequency had no effect on silage quality characteristics; however, the amount of IW exerted significant impacts. Contrary to the negative effect of water shortage on yield, it improved quality of silage.

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