NARDI FUNDULEA, ROMANIA
www.incda-fundulea.ro

ROMANIAN AGRICULTURAL RESEARCH, NO. 34, 2017
Print ISSN 1222-4227; Online ISSN 2067-5720

EFFECT OF DRIP IRRIGATION LEVELS ON DRY MATTER YIELD AND SILAGE QUALITY OF MAIZE (*ZEA MAYS* L.)

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ABSTRACT

The goal of this research was to determine the effects of different irrigation levels applied via drip irrigation on the dry matter yield (DMY) and silage quality of maize grown on clay loam soil in the sub-humid environmental conditions of Turkey. Six irrigation treatments were studied: full irrigation (FI) in which irrigation water was applied at 100% crop evapotranspiration (ETc) at 7-day intervals during the entire growing season; deficit irrigation (DI) in which 0%, 25%, 50% and 75% of FI irrigation water was applied; and excessive irrigation (EI) in which 125% of FI irrigation water was applied. The DMY, pH, dry matter ratio (DMR), crude protein (CP), acid detergent fibre (ADF), neutral detergent fibre (NDF) and water soluble carbohydrate (WSC) contents of maize silage were measured in 2007 and 2008. Increasing the irrigation rate increased DMY; the highest values obtained were from the EI treatment in 2007, 2008 and in the two years combined. Deficit irrigation improved irrigation water use efficiency in relation to dry matter yield. Increasing the drip irrigation levels decreased the CP and WSC content of silage but did not affect the dry matter rate, pH, ADF and NDF content of silage. With respect to dry matter yield, irrigation water productivity and the silage quality of maize, 100% ETc and 75% ETc irrigation strategies can be considered optimal.

Key words: maize; silage; deficit irrigation; dry matter; crude protein; water soluble carbohydrate.

INTRODUCTION

Maize (*Zea mays* L.) is an important forage plant because of its high dry matter yield and favourable quality characteristics for optimum animal production (Roth et al., 1995). Maize forage yield and quality are influenced by many interacting environmental, agricultural and genetic factors. It is well known that maize grain and forage yields decrease under conditions of drought and soil water deficit (Hajibabaei and Azizi, 2012). Furthermore, the availability of water in the plant root zone affects the nutritional content of the maize crop and therefore the silage made from it (Islam et al., 2012). Maize forage growers require additional information on how irrigation affects DMY and silage quality. Maize has high water requirements (Karam et al., 2003). Karam et al. (2003) reported that grain yield, DMY, and leaf area index were reduced by increasing the soil water deficit. Gheysari et al. (2009) focused on the response of silage maize to variable irrigation under the arid and semi-arid conditions of Iran. Their findings showed that the biomass of maize increased as a function of the irrigation water level. Rusere et al. (2012) noted that deficit irrigation caused a significant decline in silage maize yield. Islam et al. (2012) reported that increasing the quantity of irrigation water applied (0-480 mm) increased DMY from 9.3 to 23.8 t ha^{-1} and NDF from 524 to 555 g kg^{-1} but decreased CP from 78 to 52 g kg^{-1} and WSC from 88 to 31 g kg^{-1}. By decreasing the CP and WSC of the plant material, the value of silage can be reduced despite high yields. Yazar et al. (1999) assessed the influence of different irrigation strategies on grain yields and the resulting crop water stress index. They determined that higher grain yield, kernel numbers, dry matter and water productivity occurred under irrigation at 100% ETc or 80% ETc.

Most studies have focused on the effects of different irrigation rates on the grain yield of maize, but there is insufficient research

Received 5 Septemaber 2016; accepted 7 February 2017. First online: April, 2017. DII 2067-5720 RAR 2017-103

evaluating the influence of irrigation strategies on DMY and silage quality. This subject needs to be scientifically investigated and the findings presented for the benefit of growers.

The primary goal of this research was to determine the effects of different irrigation strategies applied via drip irrigation on the dry matter yield, irrigation water productivity and silage quality of maize.

MATERIAL AND METHODS

This study was carried out at the Uludag University Mustafakemalpasa Vocational School research station in Turkey (40°02′ N, 28°23′ E) during the 2007 and 2008 growing seasons. The rainfall distribution and quantity were markedly different between the growing seasons (Table 1). Total rainfall during the growing season in 2007 was 77.1 mm, which is lower than the long-term average, as a result of low precipitation in May, August and September of that year. The total rainfall during the growing season in 2008 was 122.8 mm, which is similar to the long-term average (Table 1). The temperatures during the experimental years and over the long term were very similar. The average relative humidity was 55.4%, 65.78% and 63.02% in 2007, 2008 and over the long term (1975-2007), respectively (Table 1). The soil was a clay loam with a bulk density of 1.41 g cm^{-3}, a pH of 7.8, and was non-saline and low in organic matter and lime. The field capacity and wilting point for 0-90 cm soil depth averaged 36% and 21% by weight, respectively.

Table 1. Average temperature, relative humidity, and total rainfall for 2007, 2008 and over the long term (1975-2007) in the experimental area, Bursa

Months	Mean of temperature (°C)			Mean of relative humidity (%)			Total rainfall (mm)		
	2007	2008	Long years	2007	2008	Long years	2007	2008	Long years
May	19.9	18.1	17.2	61	66.7	66.3	12.1	24.8	42.9
June	24.6	23.1	21.6	55	63.2	61.2	47.2	10.8	23.4
July	26.2	24.3	23.6	51	60.9	61.1	13.4	0	13.9
August	26.4	24.1	23.3	53	62.0	61.7	1.0	0	14.9
September	21.4	20.2	19.6	57	76.1	64.8	3.4	87.2	31.2
Mean/Total	23.7	21.96	21.06	55.4	65.78	63.02	77.1	122.8	126.3

The ADA-523 variety of maize was used for the field experiments. Six treatments were created in a complete randomized block design with three replications. The following irrigation treatments were applied via a drip irrigation system: (1) full irrigation (reference; FI) in which irrigation water was applied at 100% of crop evapotranspiration (ETc) in 7-day intervals during the entire growing season; (2) deficit irrigations (DI-0, DI-25, DI-50, DI-75) in which 0%, 25%, 50% and 75% of FI irrigation water was applied; and (3) excessive irrigation (EI) in which 125% of FI irrigation water was applied. The soil moisture was measured gravimetrically prior to each irrigation. The quantity of irrigation water for the FI treatment was defined as the volume needed to fill the soil to field capacity at a depth of 0-90 cm (Doorenbos and Kassam, 1979).

A drip irrigation system was installed to distribute water to the trial plots. Water was supplied from a borehole to the drip system. Drip laterals, with emitters located at intervals of 30 cm and an emitter flow of 1.60 l h^{-1}, were positioned at each plant row. All plants were fully irrigated (to field capacity) on the evening prior to the start of the experiment via this drip irrigation system.

The total quantity of irrigation water applied to the experimental plots during the growing period ranged between 76 and 1042 mm in the first year and 91-985 mm in the second year of the experiment (Table 2).

Table 2. The quantity of irrigation water applied to each treatment during 2007 and 2008

Years	Irrigation water applied (mm)					
	DI-0	DI-25	DI-50	DI-75	FI	EI
2007	76	274	466	658	850	1042
2008	91	269	448	627	806	985

The maize was sown by hand at a depth of 5-6 cm on 10 and 17 May of 2007 and 2008, respectively. The row spacing and crop spacing within rows were 65 cm and 10 cm, respectively, and four rows were sown per plot giving a plant density of 15.4 plants m^{-2}. Prior to planting, 180 kg of nitrogen and 120 kg of phosphorus fertilizer were applied per hectare. The area of each plot was 13 m^2 (5.00 m length × 2.60 m width). Weeds were controlled by mechanical hoeing as needed.

The two central crop rows were hand-harvested from each plot, and crop samples were dried at 70°C for 48 h to determine DMY. Silage quality characteristics were evaluated from 2 plants. The samples were sliced into 2.0 cm pieces and ensiled in 1.5 l special anaerobic jars (Le Parfait, France) equipped with a lid that enabled gas release only. They were then incubated for two months to allow fermentation, and the silages were removed from the jars. The DMR of the silage material was determined from the dried samples. The pH of the silage juice was measured using a pH metre (Sartorius PB-20, Germany). To analyse the ADF and NDF, the sequential detergent analysis method was used (Goering and Van Soest, 1970). The Kjeldahl method was used to determine total nitrogen, and the CP content was estimated by multiplying the total nitrogen by a constant of 6.25. The phenol sulfuric acid method was used to determine the WSC content (Dubois et al., 1956).

Dry matter irrigation water use efficiency (DMIWUE, kg m^{-3}) was estimated as the ratio between total dry biomass (DW, kg ha^{-1}) and seasonal irrigation water applied (SIWA, m^3 ha^{-1}).

The data on DMY and silage quality were analysed using an analysis of variance at the 1% and 5% significance levels with a complete randomized block experimental design. Where necessary, an LSD test was used to test for differences between groups at the 5% significance level. All calculations were conducted using the MINITAB and MSTAT-C programs.

RESULTS AND DISCUSSION

Irrigation regimes significantly affected the DMY in 2007, 2008 and in both years combined (Table 3). Increasing the irrigation rate increased DMY. The relation of DMY to seasonal irrigation water applied (SIWA) is shown in Figure 1. The relation was linear, indicating that DMY increased directly with an increased application of irrigation water. Furthermore, this linear relation implies that a DMY of approximately 17 t ha^{-1} can be achieved even without the application of irrigation water (Figure 1). Of course, this outcome is only probable if there is sufficient residual water in the soil to support such a yield (Igbadun et al., 2008). In addition, this situation is closely tied to annual variability in the quantity and temporal distribution of precipitation during the plant growing season (Kuscu et al., 2014). The results obtained from this study are consistent with the findings by Islam et al. (2012), who showed that that total DMY increased linearly from 9.3 to 23.8 t ha^{-1} with an increase in the irrigation rate. In this study, the highest DMYs (49.28, 41.66 and 45.47 t ha^{-1}) were observed at the excessive irrigation level (EI) for 2007, 2008 and for the two-year average, respectively. In contrast, the lowest yields (21.20, 17.57 and 19.38 t ha^{-1}) were observed in the DI-0 treatment for 2007, 2008 and the two-year averages, respectively (Table 3). The reason for this low yield is that the soil was dry for an extended period, resulting in a decrease in dry matter accumulation. In general, deficit irrigation decreased DMY. In both years, the DI-75 treatment produced higher values of DMY than other deficit irrigation applications. Consistent with our results, Simsek et al. (2011) noted that a maximum DMY of 23.6 t ha^{-1} was obtained with the application of full irrigation and that DMY also decreased under deficit irrigation. Rusere et al. (2012) stated that the total fresh yield changed significantly with an increase in deficit irrigation. However, the DMY range obtained in this study was greater than that obtained by the studies cited above. The reason for this difference may be related to the irrigation methods or the potential crop productivity.

Table 3. Effects of irrigation levels on dry matter yield of maize

Irrigation levels (IL)	Dry matter yield (DMY, t ha^{-1})		
	2007	2008	Combined years
DI-0	21.20 e[x]	17.57 d	19.38 e
DI-25	26.17 d	22.21 cd	24.19 d
DI-50	36.70 c	30.08 bc	33.39 c
DI-75	40.25 bc	36.12 ab	38.18 b
FI	41.77 b	37.56 ab	39.67 b
EI	49.28 a	41.66 a	45.47 a
Mean	35.90 A	30.87 B	
F values			
Year (Y)	-	-	**
Blocks (B)	*	ns	ns
IL	**	**	**
YxIL	-	-	ns

[x]Means followed by the same small letter and by the same capital letter for each components in the same column do not differ significantly at p<0.05 using LSD.
*,**, ns – *F*-test significant at p>0.05, and p>0.01, respectively; ns – not significant.

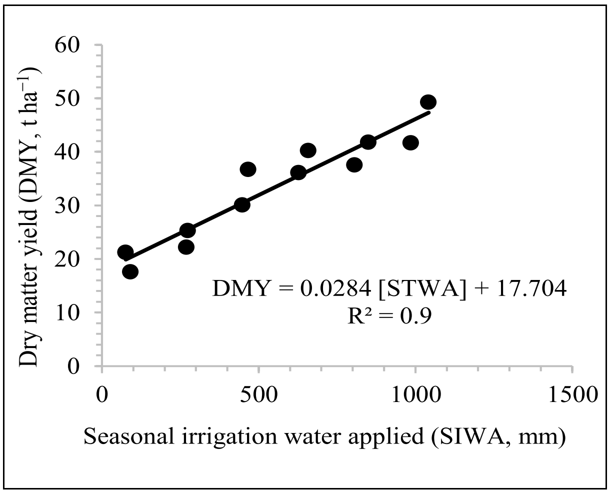

Figure 1. Dry matter yield versus seasonal irrigation water applied for combined years (2007 and 2008).
R^2 – determination coefficient;
**significant at the 1% level (p<0.01)

Irrigation treatments also significantly affected the DMIWUE (Figure 2). DI effectively enhanced the DMIWUE. Of the DI strategies, DI-0 produced significantly higher values of DMIWUE in both seasons. Excessive irrigation resulted in a substantial decrease in DMIWUE values. In 2007, no significant differences were observed among the DMIWUE values for DI75, FI and EI treatments, which varied from 4.73 to 6.12. It is evident from Figure 2 that, on average, the highest DMIWUE value was obtained when irrigation was applied only at the planting stage, indicating that the maize plants used water more efficiently when the available soil water was limited.

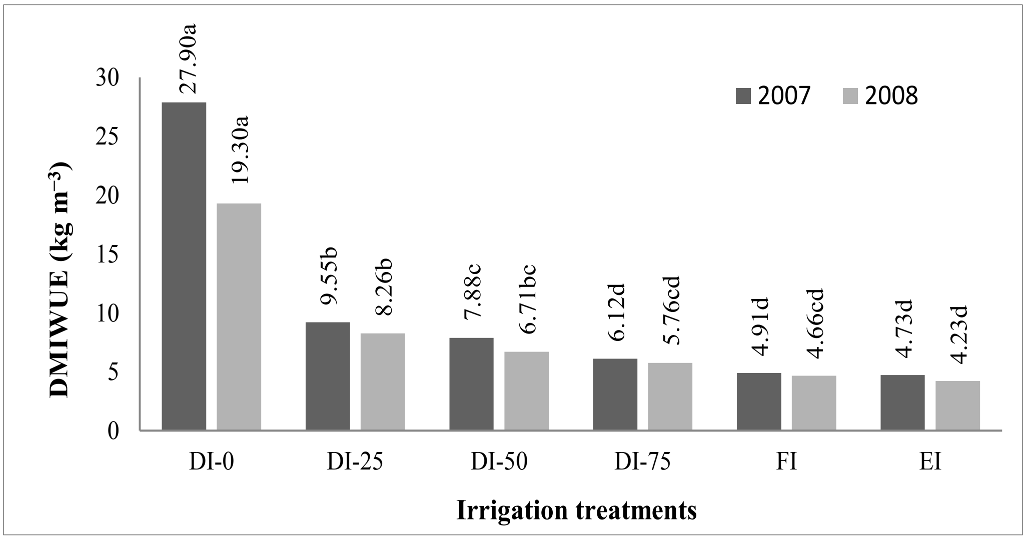

Figure 2. Dry matter irrigation water use efficiency (DMIWUE) in relation to irrigation water regime for the two years of the experiment

Irrigation level did not affect the DMR, pH, ADF or NDF of silages in 2007, 2008 or in both years combined. The two-year average values for DMR, pH, ADF and NDF of silages ranged from 32.39 to 34.40%, 3.80 to 3.85, 24.48 to 26.76% and 52.80 to 56.40%, respectively (Tables 4 and 5). Islam et al. (2012) reported that ADF was not affected by increasing the quantity of irrigation water, which is similar to our results. However, in contrast to our results, they found that NDF increased with an increasing quantity of irrigation water. The CP and WSC ratios of silage, however, were observed to be significantly different at the 1% level in both years (individually and combined). There were negative relations between the irrigation level and both CP and WSC values. Therefore, the highest values of these parameters were obtained under the severe soil water deficit (DI-0) treatment and increased as the application of seasonal irrigation water decreased in 2007, 2008 and in both years combined (Table 3). The results of some studies indicate that soil moisture stress affects the elongation of the leaf and stem (Pelleschi et al., 1997; Song et al., 2010), which restricts shoot development. This event causes stomatal closing, decreases CO_2 uptake and photosynthetic rate, and ultimately increases the level of proline and glycine. In contrast, other studies found that water stress increased the quantity of sucrose, glucose, fructose, sugar alcohols, hexose, and soluble carbohydrates in leaves (Yancey et al., 1982; Daie, 1988; Foyer, 1988; Rodriguez et al., 1993; Girousse et al., 1996). All of these findings are generally consistent with our results. Islam et al. (2012) reported that the CP and WSC values decreased with increasing levels of irrigation, which is similar to our results. However, some researchers reported that CP and WSC increased with an increase in water content in sorghum forages (Yosef et al., 2009), which is contrary to our findings. However, Montgomery (2009) observed that deficit irrigation positively affected both ADF and NDF ratios of silage maize, but irrigation level did not affect CP. Simsek et al. (2011) reported that silage quality increased with an increasing irrigation level, and the highest values of DM, ADF, NDF and pH were obtained under the full irrigation regime (I_{100}).

Table 4. Effect of irrigation levels on dry matter ratio, pH and crude protein ratio of maize silage

Irrigation level (IL)	Dry matter ratio (%)			pH			Crude protein (%)		
	2007	2008	Combined years	2007	2008	Combined years	2007	2008	Combined years
DI-0	35.86	32.95	34.40	3.78	3.92	3.85	7.39 a	6.94 a	7.16 a
DI-25	32.83	31.94	32.39	3.78	3.89	3.84	6.84 b	6.92 a	6.88 ab
DI-50	33.51	34.70	34.11	3.75	3.92	3.84	6.51 bc	6.87 a	6.69 b
DI-75	33.16	32.54	32.85	3.76	3.86	3.81	6.45 c	5.50 b	5.97 c
FI	34.01	32.60	33.31	3.77	3.83	3.80	6.30 c	5.37 b	5.84 c
EI	35.94	31.94	33.94	3.79	3.86	3.83	5.93 d	4.97 b	5.45 d
Mean	34.22A	32.78B		3.77B	3.88A		6.57A	6.10B	
F values									
Year (Y)	-	-	ns	-	-	**	-	-	**
Blocks(B)	ns	ns	ns	ns	ns	ns	*	ns	ns
IL	ns	ns	ns	ns	ns	ns	**	**	**
YxIL	-	-	ns	-	-	ns	-	-	**

[x] Means followed by the same small letter and by the same capital letter for each components in the same column do not differ significantly at p<0.05 using LSD.
*, ** – F test significant at p>0.05, and p>0.01, respectively; ns – not significant.

Table 5. Effect of irrigation levels (IL) on acid detergent fibre (ADF), neutral detergent fibre (NDF) and water soluble carbohydrate (WSC) of maize silage

Irrigation level	Acid detergent fibre (%)			Neutral detergent fibre (%)			Water soluble carbohydrate (%)		
	2007	2008	Combined years	2007	2008	Combined years	2007	2008	Combined years
DI-0	26.01	24.64	25.33	52.16	53.45	52.80	2.15 a[x]	2.25 a	2.20 a
DI-25	25.25	23.70	24.48	53.25	56.41	54.83	1.74 b	1.69 b	1.71 b
DI-50	26.51	26.87	26.69	55.90	56.07	55.98	1.20 c	1.23 c	1.22 c
DI-75	26.60	26.93	26.76	55.03	56.58	55.80	1.06 c	0.93 d	1.00 d
FI	24.40	25.52	24.96	55.90	56.01	55.96	0.88 d	0.90 d	0.89 de
EI	25.03	26.68	25.85	55.75	57.04	56.40	0.82 d	0.80 d	0.81 e
Average	25.63	25.72		54.66	55.93		1.31	1.30	
F values									
Year (Y)	-	-	ns	-	-	ns	-	-	ns
Blocks(B)	ns	ns	ns	ns	ns	ns	ns	ns	ns
IL	ns	ns	ns	ns	ns	ns	**	**	**
YxIL	-	-	ns	-	-	ns	-	-	ns

[x]Means followed by the same small letter and by the same capital letter for each components in the same column do not differ significantly at $p<0.05$ using LSD.
*, ** – F-test significant at $p>0.05$, and $p>0.01$, respectively; ns – not significant.

CONCLUSIONS

The results of this study showed that DMY increased as irrigation level increased. However, the increase in seasonal application of irrigation water decreased the CP and WSC content of silage but did not change the DMR, pH, ADF or NDF content of silage. Deficit irrigation improved water productivity in relation to dry matter yield. With respect to the DMY, DMIWUE and silage quality of maize, full irrigation (100% ETc) and deficit irrigation (75% ETc) regimes can considered optimal.

Acknowledgments

The authors wish to thank American Journal Experts (AJE) for editing and English proofreading of the manuscript. The authors also thank Uludag University for editing and English proofreading service support.

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