RESEARCH

Effects of different irrigation methods and plant densities on silage quality parameters of PR 31Y43 hybrid corn cultivar (*Zea mays* L. var. *indentata* [Sturtev.] L.H. Bailey)

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The yield and quality of corn silage is related to genotype as well as factors such as climate, soil conditions, altitude, planting time, plant density, irrigation, and harvesting time. This study was conducted to determine the effects of different irrigation methods (drip, subsoil drip, and subsoil capillary) and different plant densities (102 040, 119 040, and 142 850 plant ha^{-1}) on silage quality parameters of PR 31Y43 hybrid corn (*Zea mays* L. var. *indentata* [Sturtev.] L.H. Bailey) in 2011 and 2012 under ecological conditions in Eskipazar-Karabuk, Turkey. Plant densities were significantly different on fresh ear ratio and plant crude protein (CP) yield in both years under study. The highest fresh ear ratio values were obtained with 102 040 and 119 040 plant ha^{-1} densities and the highest plant CP yield with 142 850 plant ha^{-1}. While the irrigation method × plant density interactions were significant for silage CP ratio in the first year, they were significant on fresh ear ratio in the second year. The highest fresh ear ratio values were obtained from subsoil capillary × 119 040 plant ha^{-1} and drip × 119 040 plant ha^{-1} interactions; the highest plant and silage CP ratio values were obtained from subsoil capillary × 142 850 plant ha^{-1} and subsoil drip × 102 040 plant ha^{-1} interactions. As a result of the research, high Flieg scores were obtained from each irrigation method and plant density. When plant CP yield is taken into consideration, the 142 850 plant ha^{-1} density is more important.

Key words: Corn, drip irrigation, subsoil drip irrigation, subsoil capillary irrigation, plant density, silage quality parameters.

INTRODUCTION

Even if hunger is not currently an issue in Turkey, we can still observe unbalanced nutrition dependent on cereals. Consumption of animal proteins should be increased to at least 50% for balanced nutrition (Tukel and Hatipoglu, 1997). The increase in the consumption of animal products can only be possible by producing these products in our own country in adequate amounts and at reasonable costs. Feed costs include 65% of animal production costs. Corn (*Zea mays* L.) is the most important silage plant which can satisfy the demand for both concentrate feed and fodder. The concentrate feed requirement decreases by 33-50% in animals fed with corn silage (Sade and Soylu, 2008). Corn is the most important plant that is grown for silage both in our country and worldwide (Turgut, 2002).

The yield and the quality of corn silage is related to genotype as well as factors such as climate, soil conditions, altitude, planting time, plant density,

irrigation, and harvesting time (Cusicanqui and Lauer, 1999). A suitable plant density must be provided to obtain a high yield in corn production. The determination of optimum plant density is a way to enable the plant to benefit from available water and nutrients in the soil; light energy is also highly important to decrease production costs (Kırtok, 1998). The corn ear, leaf, and stem ratios affect silage quality (Saruhan and Sireli, 2005). Alcicek and Ozkan (1997) stated that the most important principle to determine silo feed quality was the Flieg score obtained as a result of chemical evaluation, which is done according to the appearance recognized by sense organs and silo acids; they also said that DM and pH content of silo feed were also important. Ideally corn silage must contain 28% to 42% DM and 40% to 50% grain at moment it is ensiled. When corn is harvested at the dough stage and these conditions are provided, it will have a suitable DM content as well as sufficient DM soluble in water and a lower buffer capacity (Ergun et al., 2004).

Nowadays, using irrigation methods and systems that will not cause drainage and salinity problems in soil, which use less irrigation water with more economical applications, have become more and more important (Aras, 2006). Arranging precise irrigation programs and using more effective irrigation methods are the best ways

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to increase yield and decrease the amount of irrigation water used in agriculture. These problems have partly been solved with the subsoil drip irrigation method. However, in this method the emitters are plugged by the plant roots and the use of chemical weed controllers thus becomes necessary to prevent this problem. As a result, plant roots are damaged. The subsoil capillary irrigation system was developed to prevent all these negative effects. This new irrigation system was used as a third irrigation method in our research.

The aim of this study was to determine the effects of different irrigation methods and plant densities on silage quality parameters of PR 31Y43 hybrid corn (*Zea mays* L. var. *indentata* [Sturtev.] L.H. Bailey).

MATERIALS AND METHODS

The study was conducted in the experimental fields of Eskipazar Vocational High School in 2011 and 2012 under ecological conditions of the district of Eskipazar (40°56'17" N, 32°30'45" E; 781 m a.s.l.) in the province of Karabuk, Turkey. The hybrid corn cv. PR 31Y43 was used as material in this study. Three different irrigation methods (drip, subsoil drip, and subsoil capillary) and three different plant densities (70 × 14 cm: 102 040 plant ha^{-1}; 70 × 12 cm: 119 040 plant ha^{-1}; and 70 × 10 cm: 142 850 plant ha^{-1}) were investigated. Composite fertilizer 13.24.12.10.1.1 (13% N, 24% P_2O_5, 12% K_2O, 10% SO_3, 1% Zn, 1% Fe) was applied as the base-fertilizer and ammonium nitrate (33% N) was used as top-dressing fertilizer. Drip lines (Hydro PCND, John Deere Water, San Marcos, California, USA) with 50 cm emitter spacing, 16 mm diameter, and 2.35 L h^{-1} flow rate for each emitter were used in the drip, subsoil drip, and subsoil capillary irrigation methods. Irrigation was done by coating these drip lines with microfiber material in plots where the subsoil capillary irrigation method would be used.

The experimental design was a randomized complete block in a split-plot arrangement with three replicates. The irrigation methods (drip, subsoil drip, and subsoil capillary) for use in the main plots and plant densities (102 040, 119 040, and 142 850 plant ha^{-1}) for use in the split-plots were selected randomly. The split-plot size was 2.8 × 5 m with four rows per plot.

Manual planting was done on 25 May in the first year and on 10 May in the second year. Two seeds were sown for each plant density and manually thinned after emergence. After plants emerged and rows were cleared, the first hoeing was done when the plant was at the 4-5 leaf stage; three different irrigation methods were applied to the plots. The drip lines were placed 1.4 m apart and each drip line was centered between two corn rows spaced 70 cm for the three irrigation methods. Drip lines were buried with an installation depth of 20 cm in the subsoil drip irrigation method. The drip lines were coated with dispersion material made of polypropylene microfibers

with a higher water-holding and transition capacity and outer surface covered with polyethylene film; this new irrigation system was the subsoil capillary irrigation method. These capillary drip lines were buried just as in the subsoil drip irrigation method. Potable water was used in the study and was classified as low Na and medium salinity according to the analysis.

A transition climate between the Black Sea and continental climate occurs in the Eskipazar district where the experiment was carried out. Some of the climate data recorded in the Eskipazar district during the 2011-2012 corn growing periods and the long term means of these data (1985-2006) are given in Table 1. Total rain, temperature and relative humidity means in 2011 and 2012 were similar to the long term means (Table 1).

Soil samples were taken from 0-30 cm depths and analyzed to determine physical and chemical properties. Analysis results of soil samples are given in Table 2; soils are clay-loam textured with low organic matter content (1.49%).

A time-domain reflectometer (TDR 300, Spectrum Technologies, Plainfield, Illinois, USA) was used to measure soil moisture and determine the irrigation program during the study. This method is based on measuring travelling time between two parallel points in the soil of the electromagnetic waves sent from a voltage source through metal bars buried in the soil. For the calibration of the TDR 300 device, a plastic case with dimensions of 40 × 70 × 25 cm was filled with soil taken from the experimental field and then completely saturated with water. Afterwards, undisturbed soil samples were taken periodically and gravimetric moisture estimates were made with an incubator; these estimates were transformed into volumetric values and the related TDR readings were recorded. The TDR calibration curve was constructed with the data.

Table 1. Climatic data of the research location in 2011 and 2012 and the long term mean (1985-2006) in Eskipazar, Turkey.

Months	Precipitation			Mean temperature			Relative humidity		
	2011	2012	Long term	2011	2012	Long term	2011	2012	Long term
	——— mm ———			——— °C ———			——— % ———		
May	68.4	68.2	57.1	13.4	15.4	14.3	73.9	66.7	60.2
June	54.8	21.8	54.8	16.9	20.2	17.9	72.3	58.7	60.8
July	8.2	51.4	24.8	21.6	22.6	20.9	63.1	57.7	55.4
August	17.0	48.0	22.9	19.9	19.9	21.1	62.0	59.9	53.9
September	4.4	6.0	21.6	17.1	18.7	16.3	57.4	54.7	57.5
Total/Mean	152.8	195.4	181.2	17.8	19.4	18.1	65.7	59.5	57.6

Table 2. Physical and chemical soil properties of the research location in Eskipazar, Turkey.

Properties		Properties	
Sand, %	38.0	pH	7.60
Silt, %	20.0	Salt, %	0.04
Clay, %	42.0	Lime, %	37.59
Texture class	Clay-Loam	Field capacity, %, (v v^{-1})	26.32
Total N, kg ha^{-1}	0.34	Wilting point, %, (v v^{-1})	16.25
P_2O_5, kg ha^{-1}	23.60	Bulk density, g cm^{-3}	1.23
K_2O, kg ha^{-1}	170.10	Organic matter, %	1.49

The TDR value 55 was read against field capacity (26.32% v/v), 42 against 30% consumption of readily available soil water (23.29% v/v), and 25 against permanent wilting point (16.25% v/v). The TDR readings were taken for soil depths of 20 and 40 cm. In all three irrigation systems, the accuracy of the amount of irrigation water was controlled with the TDR readings taken 24 h after irrigation. The amounts of irrigation water measured with water counters were recorded and the total amounts used at the end of the season were defined.

When plants grew to a height of approximately 40 cm, secondary hoeing was done. In all plant densities, fertilization took place by calculating the rate as follows: 3 g N plant^{-1}, 1.4 g P$_2$O$_5$ plant^{-1}, and 0.7 g K$_2$O plant^{-1}. A part of N, whole P, and K were given with the base fertilizer (0.75 g N plant^{-1}, 1.4 g P$_2$O$_5$ plant^{-1}, 0.7 g K$_2$O plant^{-1}). The rest of N (2.25 g plant^{-1}) was provided with each irrigation event in the form of ammonium nitrate (33% N).

After removing border effects, two center rows of each split plot were harvested. Harvesting at the milkline stage was between 50% and 75%. The basic plant measurements were taken on five plants randomly selected from two center rows of each split-plot. Then the plants were transformed into silage with machines and packaged. The packaging materials were 57 × 75 sized, 80 µ thick white bags produced from 20% virgin and 80% recycled low density polyethylene. The silage-based analyses were made after a fermentation period of 75 d. Silage quality category can be determined through a regression equation using the relationship between the pH value and DM content of silage (Geren, 2001).

Flieg score: [220 + 2 × (silage DM (%) - 15)] – (40 × silage pH value)

The Flieg score obtained from the above equation gives important clues about the quality of silage according to the criteria given in Table 3. The DM (%), pH, silage quality category, fresh ear ratio (%), dry leaf, ear, and stem ratios (%), dry leaf-stem ratio (%), plant CP (%), plant CP yield (t ha^{-1}), and silage CP (%) were examined in these analyses (TIVT, 2010).

All data were analyzed using ANOVA according to a randomized complete block in a split-plot experimental design. The LSD procedure was used to separate mean values when the F-test was significant (Mstat-C, 1980).

RESULTS AND DISCUSSION

Silage dry matter, pH, Flieg score, and quality category
In the first year, silage pH values obtained from plant densities were significantly different (P < 0.05). Highest silage pH value (4.02) was obtained with 102 040 plant ha^{-1} and took place in the first group (a) and the lowest silage pH value (3.93) was obtained with 142 850 plant ha^{-1} and took place in the last (b) group (Table 4). In both years, no significant difference was found between silage DM level, Flieg score, and silage quality category values (Table 4).

Fresh ear ratio, and dry leaf, dry ear, and dry stem ratios
In both years, fresh ear ratio values obtained from plant densities were significantly different (P < 0.05 and P < 0.01, respectively). In the first year, the highest fresh ear

Table 3. Flieg scores and silage quality categories that are calculated with DM and pH values.

Flieg scores	Silage quality categories
0-20	Poor
21-40	Low
41-60	Medium
61-80	Good
81-100	Well

Table 4. Effects of irrigation and plant density on silage DM, silage pH, Flieg score, and silage quality category.

Irrigation (I)	Plant density (D) plant ha^{-1}	Silage DM %		Silage pH		Flieg score		Silage quality category	
		2011	2012	2011	2012	2011	2012	2011	2012
Drip	102 040	29.9	33.7	4.02	4.09	88.9	93.9	Well	Well
	119 040	29.2	33.4	3.97	4.01	89.8	96.3	Well	Well
	142 850	28.4	29.3	3.89	4.05	91.3	86.8	Well	Well
Subsoil drip	102 040	29.3	30.7	4.01	4.03	88.3	90.2	Well	Well
	119 040	29.0	30.4	3.99	3.94	88.3	93.3	Well	Well
	142 850	30.6	31.7	4.04	3.97	89.5	94.4	Well	Well
Subsoil capillary	102 040	31.1	33.1	4.02	3.97	91.3	97.7	Well	Well
	119 040	27.2	32.5	3.99	4.05	85.0	92.8	Well	Well
	142 850	30.5	30.2	3.86	4.05	96.3	88.6	Well	Well
I	Drip	29.2	32.1	3.96	4.05	90.0	92.3	Well	Well
Mean	Subsoil drip	29.6	30.9	4.01	3.98	88.8	92.6	Well	Well
	Subsoil capillary	29.6	31.9	3.96	4.02	90.9	93.0	Well	Well
LSD		ns	ns	ns	ns	ns	ns		
D	102 040	30.1	32.5	4.02a	4.03	89.6	93.9	Well	Well
Mean	119 040	28.5	32.1	3.98 ab	4.00	87.7	94.1	Well	Well
	142 850	29.8	30.4	3.93b	4.02	92.4	89.9	Well	Well
LSD		ns	ns	0.05*	ns	ns	ns		
I × D interaction	LSD	ns	ns	ns	ns	ns	ns		

ns: non significant, LSD: least significant difference.

ratio (42.5) was obtained with 102 040 plant ha⁻¹ and took place in the first group (a). In the second year, the highest fresh ear ratio values (40.4 and 40.3, respectively) were obtained with 102 040 and 119 040 plant ha⁻¹ and took place in the first group (a) (Table 5).

In the second year, fresh ear ratio values obtained from the irrigation method × plant density interactions were significant (P < 0.01). The highest fresh ear ratio values (41.7 and 41.6, respectively) were obtained from the subsoil capillary × 119 040 plant ha⁻¹ and drip × 119 040 plant ha⁻¹ interactions that took place in the first group (a) (Table 5). In both years no significant difference was found between dry leaf, ear, and stem ratio values (Table 5).

Dry leaf-stem ratio, plant and silage crude protein, and plant crude protein yield

In the first year, plant CP values obtained from irrigation method × plant density interactions were significant (P < 0.01). The highest plant CP values were obtained from subsoil capillary × 142 850 plant ha⁻¹ and subsoil drip × 102 040 plant ha⁻¹ interactions that took place in the first group (a) (Table 6). In the second year, plant CP values obtained from irrigation methods were significant (P < 0.05). The highest plant CP (8.7) was obtained from subsoil capillary irrigation and took place in the first group (a) (Table 6). In both years, plant CP yield values obtained from plant densities were significant (P < 0.05). The highest plant CP yields (1.89 and 1.82, respectively) were obtained with 142 850 plant ha⁻¹ and took place in the first group (a) (Table 6).

In the first year, silage CP values obtained from irrigation methods were significantly different (P < 0.01). The highest silage CP (7.3) was obtained from subsoil drip irrigation and took place in the first group (a) (Table

6). In the first year, silage CP values obtained from plant densities were significantly different (P < 0.01). The highest silage CP (7.2) was obtained with 119 040 plant ha⁻¹ and took place in the first group (a) (Table 6). In the first year, silage CP values obtained from irrigation method × plant density interactions were significant (P < 0.01). The highest silage CP value was obtained from subsoil drip × 102 040 plant ha⁻¹ interactions and took place in the first group (a) (Table 6). In both years no significant difference was found between dry leaf-stem ratio values (Table 6).

In both years under study plant densities were significant on fresh ear ratios and plant CP yield. The highest fresh ear ratio values were obtained with 102 040 and 119 040 plant ha⁻¹ densities and the highest plant CP yield was obtained with 142 850 plant ha⁻¹ density. In the first year, plant densities were significant on silage pH and silage CP (Tables 4, 5, and 6). In this study, plants did not encounter water stress in the growing seasons due to optimum irrigation management, which created the appropriate conditions to grow more plants per unit area (Karasahin, 2013).

Results obtained from many research studies on the effects of different irrigation methods and plant densities on silage quality parameters of corn support our findings (Cox and Cherney, 2001; Iptas and Acar, 2006; Yilmaz et al., 2007; Budakli Carpıcı et al., 2010), while some studies provide different results (Cusicanqui and Lauer, 1999; Stanton et al., 2007; Ozturk et al., 2008; Baghdadi et al., 2012). The similarities and differences in results regarding plant densities may be due to the ecological conditions and differences and similarities of the genetics of the cultivars used in these studies.

Irrigation methods were significant for silage CP in the first year and the highest value was obtained from

Table 5. Effects of irrigation and plant density on fresh ear, dry leaf, dry ear, and dry stem ratios.

Irrigation (I)	Plant density (D)	Fresh ear ratio		Dry leaf ratio		Dry ear ratio		Dry stem ratio	
		2011	2012	2011	2012	2011	2012	2011	2012
	plant ha⁻¹				%				
Drip	102 040	42.8	39.1abcd	16.3	16.8	53.5	50.5	30.3	32.6
	119 040	40.9	41.6a	15.4	16.3	51.0	55.6	33.6	28.1
	142 850	39.1	38.9abcd	14.0	18.8	45.4	48.1	40.6	33.0
Subsoil drip	102 040	42.6	41.5ab	15.2	16.5	52.2	48.3	32.6	35.2
	119 040	40.5	37.6cd	15.6	19.9	54.5	43.8	29.9	36.3
	142 850	40.5	38.0bcd	17.7	17.3	48.8	48.8	33.5	33.9
Subsoil capillary	102 040	42.2	40.5abc	15.8	17.0	53.1	50.4	31.1	32.5
	119 040	43.4	41.7a	15.6	17.5	52.8	48.0	31.6	34.5
	142 850	40.2	36.1d	17.3	18.4	50.9	50.2	31.7	31.4
I	Drip	40.9	39.9	15.2	17.3	50.0	51.4	34.8	31.2
Mean	Subsoil drip	41.2	39.0	16.2	17.9	51.8	47.0	32.0	35.1
	Subsoil capillary	41.9	39.4	16.2	17.6	52.3	49.5	31.5	32.8
LSD		ns	ns	ns	ns	ns	ns	ns	ns
D	102 040	42.5a	40.4a	15.8	16.8	52.9	49.7	31.3	33.4
Mean	119 040	41.6ab	40.3a	15.5	17.9	52.8	49.1	31.7	32.0
	142 850	39.9 b	37.7b	16.3	18.2	48.4	49.0	35.3	32.8
LSD		1.75*	2.05**	ns	ns	ns	ns	ns	ns
I × D interaction	LSD	ns	3.55**	ns	ns	ns	ns	ns	ns

*, **Significant at 0.05 and 0.01 probability level, ns: non significant, LSD: least significant difference.

Table 6. Effects of irrigation and plant density on dry leaf-stem ratio, plant and silage crude protein, and plant crude protein yield.

Irrigation (I)	Plant density (D)	Dry leaf-stem ratio 2011	Dry leaf-stem ratio 2012	Plant crude protein 2011	Plant crude protein 2012	Plant crude protein yield 2011	Plant crude protein yield 2012	Silage crude protein 2011	Silage crude protein 2012
	plant ha^{-1}			%		t ha^{-1}		%	
Drip	102 040	54.2	51.8	7.4b	7.5	1.32	1.61	7.1ab	6.9
	119 040	49.1	58.6	7.3b	7.4	1.86	1.63	7.2ab	7.1
	142 850	43.3	57.3	7.3b	7.9	1.84	1.61	6.5cd	7.3
Subsoil drip	102 040	47.1	47.4	8.0a	7.2	1.71	1.41	7.7a	6.5
	119 040	52.9	55.3	7.5b	7.7	1.62	1.40	7.3ab	6.0
	142 850	53.0	51.4	7.4b	8.4	1.71	1.96	7.0bc	7.2
Subsoil capillary	102 040	51.0	52.5	7.2b	8.5	1.56	1.69	6.2d	7.1
	119 040	49.5	51.7	7.3b	9.4	1.74	1.73	7.1ab	7.9
	142 850	54.8	58.7	8.0a	8.1	2.11	1.88	6.9bc	7.6
I	Drip	48.9	55.9	7.3	7.6b	1.67	1.62	6.9b	7.1
Mean	Subsoil drip	51.0	51.4	7.6	7.8b	1.68	1.59	7.3a	6.6
	Subsoil capillary	51.8	54.3	7.5	8.7a	1.80	1.77	6.7b	7.5
LSD		ns	ns	ns	0.61*	ns	ns	0.34**	ns
D	102 040	50.8	50.6	7.5	7.7	1.53b	1.57b	7.0ab	6.8
Mean	119 040	50.5	55.2	7.4	8.2	1.74ab	1.59b	7.2a	7.0
	142 850	50.4	55.8	7.6	8.1	1.89a	1.82a	6.8b	7.4
LSD		ns	ns	ns	ns	0.21*	0.18*	0.34**	ns
I × D interaction	LSD	ns	ns	0.48**	ns	ns	ns	0.59**	ns

*, **Significant at 0.05 and 0.01 probability level, ns: non significant, LSD: least significant difference.

subsoil drip irrigation. Irrigation methods have also been statistically significant for plant CP in the second year and the highest values were obtained from subsoil capillary irrigation.

Irrigation method × plant density interactions were significant for plant and silage CP in the first year and significant on fresh ear ratios in the second year. The highest fresh ear ratio values were obtained from subsoil capillary × 119 040 plant ha^{-1} and drip × 119 040 plant ha^{-1} interactions and the highest plant and silage CP values were obtained from subsoil capillary × 142 850 plant ha^{-1} and subsoil drip × 102 040 plant ha^{-1} interactions (Tables 5 and 6).

The findings of our research provided similar results with most of the previous research studies done to determine the effect of different irrigation methods on silage quality parameters of corn cultivars (Camp et al., 1989; Howell et al., 1997; Montemayor et al., 2006; Hassanli et al., 2009; Karasahin and Sade, 2011); however, they also provided different results with others (Schneider et al., 2001; Humphreys et al., 2005; Kheira, 2009). The differences and similarities between results of these research studies regarding the effect of irrigation methods on corn yield and silage quality parameters may be due to the differences and similarities of the ecological conditions of the locations where the studies were carried out as well as the cultural conditions such as fertilization, soil texture, and genetics of the cultivars.

CONCLUSIONS

As a result of the research study, high Flieg scores are obtained with each irrigation method and plant density. When plant CP yield is taken into consideration, the 142 850 plant ha^{-1} density becomes more important.

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