

NITROGEN FERTIGATION TO IMPROVE NITROGEN USE EFFICIENCY AND CRUDE PROTEIN ON SILAGE CORN

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Received: 29.05.2015

ABSTRACT

This study investigated the effect of nitrogen (N) fertigation frequency and different amounts of irrigation water on drip-irrigated silage corn. Experiments were conducted in the Southeastern Anatolia region of Turkey in 2011 and 2012. A split-plot experimental design was applied. The main plots contained four different rates of evaporation from Class A pan (Ep): I₁, 50 %, I₂, 75 %, I₃, 100 %, and I₄, 125 %. Sub-plots were designed with different frequencies of N fertigation as follows: N₁: application of two-fifths of the total N when the plant height became about 50-60 cm, and the last two-fifths of it when the plants entered the stage of tasseling, N₂: application of N applied at each 2 irrigation cycles for 10 days, and N₃: application of N applied at each irrigation cycle for 5 days. One-fifth of the total N was applied to the soil at sowing in all treatment regimes. The dry matter biomass (DM) of 30 t ha⁻¹ and total crude protein yield of 2.0 t ha⁻¹ were obtained with N application of equal amounts at each irrigation cycle (5 days) and irrigation water consisting of 100 % cumulative evaporation from Class A pan (Ep) for an optimum and appropriate treatment. Nitrogen use efficiency (NUE) and irrigation water use efficiency (IWUE) were 107.7 kg DM ha⁻¹ N and 58.0 kg ha⁻¹ mm⁻¹ (5.8 kg m⁻³), respectively. The requirement of the average value of irrigation water and the optimum wetted area ratio for drip-irrigated silage corn were 447 mm and 0.65, respectively.

Key words: dry matter, fertigation, nitrogen use efficiency, protein, silage corn

INTRODUCTION

Corn (*Zea mays* L.) is the most important silage plant in the world because of its high yield, its high energy forage, and the fact that it is produced with less labor and machinery requirements than other forage crops. Many environmental, cultural and genetic factors influence corn forage yield and quality. Concentrated feed requirements decrease by 33-50% in animals fed with silage corn (Turgut, 2002; Sade and Soylu, 2008; Carpici et al., 2010).

Silage corn is used for feeding all dairy cattle on the farm, including growing animals, dry cows, and lactating cows. It must be supplemented with protein, minerals, and sometimes energy to meet the animal's nutrient requirements (Allen et al., 1995). It contains approximately 10.5-11.5 megajoules of metabolisable energy (MJME) kg⁻¹ dry matter (DM) of energy and 7-9 % of crude protein (Kolver et al., 2001). The quality, yield, and profit of silage corn depend on the proper hybrid selection, the planting date, the plant density, the soil fertility, and pest control, irrigation and nutrition.

Corn is grown under irrigated conditions and, therefore, requires higher amounts of irrigation water compared to the other field crops (Musick et al., 1990; Cetin, 1996). In addition, it removes more N, phosphorus (P) and potassium (K) from the soil.

Arranging precise irrigation programs and using more effective irrigation methods are the best ways to increase yield while decreasing the amount of irrigation water used in agriculture (Karasahin, 2014). Thus, the correct amount of water used for silage corn is essential for producing high yields. Thus, proper irrigation management minimizes yield loss due to crop water stress, optimizes yield per unit of water applied and promotes good management practices.

The planting area and total silage production are about 17640 ha and 698956 tonnes in the region, respectively (TUIK, 2013). Recently, the growing of corn has increased in the GAP (Southeastern Anatolia Project) region of Turkey where the area featured in this study is located. This is because the climatic conditions are convenient for its growth. The water requirements of second crop corn in this region range from 800 mm through 1000 mm depending on irrigation scheduling for

the surface irrigation (Cetin, 1996). However, drip irrigation enables the saving of water compared with furrow irrigation (Yazar et al., 2002). In addition, the government in Turkey has subsidized farmers who want to use a drip or sprinkler irrigation system, which has considerably increased the number of farmers using this method for their corn. Drip irrigation saves about 30-50% more irrigation water than the irrigation in this region (Yazar et al., 2002; Cetin et al., 2013). Furthermore, many researchers reported that the saving of water and higher crop yields could be obtained if drip irrigation was used (Humphreys et al., 2005; Oktem, 2008; Payero et al., 2009; Kiziloglu et al., 2009).

On the other hand, water and nitrogen (N) are the main limiting factors affecting agricultural production in arid and semiarid regions. Therefore, improving the efficiency of these inputs is the target for improved management (Morrow and Krieg, 1990; Bronson et al., 2006). The optimum N application rate was a function of irrigation depth. Ibrici et al. (2001) reported that there were no differences among the N dosages more than the rate of 240 kg N ha⁻¹ in terms of yield for the second crop corn. Silage yield linearly increased up to rate of 240 kg N ha⁻¹ (Kara et al., 1999). A deficit irrigation level of 0.85ET (evapotranspiration) with an optimum total N of 225 kg N ha⁻¹, including initial soil N and fertilizer, resulted in the highest amount of aboveground biomass for silage (Gheysari et al., 2009).

Fertigation, a modern agricultural technique, provides an excellent opportunity to maximize yield and minimize environmental pollution (Hagin et al., 2002) by increasing fertilizer use efficiency, minimizing fertilizer application and increasing return on the fertilizer invested (Cetin and Tolay, 2009; Kafkafi and Tarchitzky, 2011). Fertigation combines two main inputs required for plant growth and

development: water and nutrients. The right combination of water and nutrients is the key to a high yield and a quality yield (Qasim et al., 2008).

Thus, silage corn producers require more information on how nitrogen fertigation and the amount of irrigation water affects forage quality and the yield of dry matter. The goal of this study was to improve N fertigation and to determine the response to different amounts of irrigation water on silage corn.

MATERIALS AND METHODS

Experimental site

This study was conducted over a two-year period at the lands of Devegeçidi Dam (Diyarbakir, Turkey) during the 2011 and 2012 growing seasons. The site is located at 37° 54'N, 40° 14'E, at an elevation of 748 m above sea level. The site shows typical terrestrial climatological properties. The average annual rainfall of 487 mm is concentrated during all months with the exception of the summer season. The average annual and daily maximum Class A pan evaporation values are 976 and 8.4 mm, respectively. During the experimental years, average temperatures, relative humidity, wind speed and rainfall are 29.2-29.5 °C, 20.9-24.9 %, 3.3-3.4 m sec⁻¹ and 3.4-9.8 mm, respectively.

The soil texture at this site is clay. The soil consisted of 16% sand, 21% silt, and 63% clay in the upper soil profile. The bulk density ranged from 1.36 to 1.40 g cm⁻³ in the soil profile (Table 1).

The infiltration rate was 9 mm h⁻¹. There were no risks associated with the water table or soil salinity. Additional physical and chemical properties of the experimental site are given in Table 1.

Table 1. Some physical and chemical properties of soil in the experimental site

Soil depth (cm)	pH	P ₂ O ₅ (ppm)	Org. mat. (%)	Lime (%)	EC (dS/m)	Soil texture				F.C. (g 100 g)	W.P. (g 100 ⁻¹ g)	Bulk density (g/cm ³)	Inf. rate (mm h ⁻¹)
						Sand (%)	Silt (%)	Clay (%)	Text. class				
0-30	7.8	18.4	2.3	11.3	1.0	16	21	63	C	34.7	23.1	1.36	
30-60	7.7	--	1.9	9.4	1.0	16	25	59	C	33.5	22.2	1.39	9
60-90	7.8	--	1.1	9.4	1.1	5	30	55	C	34.1	23.6	1.40	

Treatments and Irrigation Scheduling

The study was carried out using randomized blocks with split plots and three replications. The main plots had different irrigation levels with sub-plots in which N fertigation was applied at various frequencies. The treatments are given in Table 2.

Plot area, A: 4.20 × 8.00 m = 33.60 m²

One-fifth of the total N and P were added to the soil at sowing (Burt, 1998; Hartz and Hochmuth, 2005; Cetin and Tolay, 2009). The remaining N and P were applied by means of fertigation according to the treatment regimen. For treatment N₁, the remaining N was applied as two-fifths of the total N when the plant height became about

50-60 cm, the last two-fifths when the plants entered the stage of tasseling. For treatment N₂ and N₃, the remaining N was divided equally according to the total number of irrigation cycles depending on irrigation treatments.

The irrigation schedule was, thus, applied based on class A pan evaporation. The irrigation interval was 5 days.

The amount of irrigation water was calculated using the formula (Cetin and Bilgel, 2002)

$$I = A \cdot E_p \cdot K \cdot P$$

Where I is the amount of irrigation water applied (L), A is the area of the plot (m²), E_p is the cumulative amount

of Class A pan evaporation for every 5 days (mm), K relates to the different percentages based on the amount of irrigation water for the Class A pan, and P is the wetted area. The P was assumed and used as 0.65.

Table 2. The treatments in the experiments

Main Plots (Irrigation levels)	Sub-plots (Nitrogen fertigation frequency)
I _{1(0.50)} : 50 % of amount of cumulative evaporation from Class A pan (Ep)	N ₁ : Application of one-fifth of the total at sowing date, two-fifth of the total N when the plant height became about 50-60 cm, last two-fifth of it when the plants became the stage of tasseling
I _{2(0.75)} : 75 % of Ep	N ₂ : Application of one-fifth of the total at sowing date, the remaining N was applied at each 2 irrigation cycles for 10 days
I _{3(1.00)} : 100 % of Ep	N ₃ : Application of one-fifth of the total at sowing date, the remaining N was applied at each irrigation cycle for 5 day
I _{4(1.25)} : 125 % of Ep	

The first irrigation was applied to provide homogenous emergence by sprinkler irrigation after sowing. The amount of irrigation water applied was 60 mm for this. At the first drip irrigation, irrigation water was applied until it reached the field capacity for the soil depth of 0-60 cm for all treatments. After reaching field capacity, the irrigation program was started depending on the irrigation treatments described above. The final irrigation was applied at the dough stage, approximately a week before harvest.

The soil samples in the plots were taken to determine the gravimetric soil-water content (Smith and Warrick, 2007). Three samples were taken per plot at depths of 0-30, 30-60, and 60-90 cm. The samples were collected 1 day before irrigation.

Irrigation System and Design

The lateral lines had on-line compensating emitters; the discharge rate of the emitters was 4 L h⁻¹ at an operating pressure of 100 kPa. An emitter spacing of 0.40 m was chosen due to the soil characteristics (Yildirim, 2003). The plant row spacing and plant spacing were 0.70 and 0.15 m, respectively. Lateral lines were laid out along two corn plant rows. The drip system consisted of polyethylene (PE) laterals, 16 mm in diameter. Each plot had a PE manifold pipeline of 40 mm in diameter. The irrigation water, which was pumped from a dam reservoir, was conveyed by means of PE pipes 50 mm in diameter into the manifolds along the border of the plots. In addition, the system control unit had a vortex sand separator, sand media filters, a fertilizer tank, screen mesh filters, and pressure gauges. The water flow was measured with a mechanical water meter for each plot.

Agricultural Applications

Corn seeds (*Zea mays* cv. Dekalb, C-955) were sown on 25 June in both years. Hoeing was done twice at the beginning of the developing stage of the plants. The plots were treated with recommended insecticides against corn worms and aphids. Thus, there were no other serious health problems in terms of plants and fruits. The harvest

was carried out at the dough stage of the plants in the last week of September.

With the exception of pre-plant fertilizing, all the fertilizer was applied by fertigation. All fertilizer were applied the appropriate amount (N: 240 and P₂O₅: 100 kg ha⁻¹) recommended by Kara et al. (1999) and Ibrikci et al. (2001) for second crop silage corn.

Nitrogen Application Frequency

Before the sowing, all the plots were fertilized with N of 48 kg ha⁻¹, P₂O₅ of 20 kg ha⁻¹ as a basal fertilizer. This means that one-fifth of the total N and P were added to the soil at sowing. N fertigation was applied in blocks. Fertigation was started at the first irrigation cycle and continued through the plants' tasseling stage. The fertilizer used for fertigation was a blend that included N, P, and potassium (K) at 19-5-5.

For fertigation, a pressure differential was created by throttling the water flow in the control head and diverting a fraction of the water through a tank containing the fertilizer solution (Sne, 2006).

Dry Matter (DM)

For the original fresh yield data, all the plants in the plots were cut from above ground except 1.0 m of the beginning and end of the plot and 1 row at the side of the plots. Above-ground biomass (i.e., fresh yield), were, thus, measured based on the plot area.

For the DM, 10 plants were randomly selected to represent all the plants harvested and were then broke into pieces. The plant samples were put in an oven set 65 °C for 24 hours (Kacar, 1984). DM was calculated as the dried plant samples were divided into original fresh plants yields. This value calculated as a percentage, was used to convert the fresh silage corn yield to DM based on the unit area (Sade, 1987).

Plant Analysis

Plant samples taken from 10 plants representing the whole plot were dried in an oven at 65°C. The dried plant

samples were ground and analyzed for N content. The total N in the representing samples was determined according to the whole dried plant and was based on the method of Horneck and Miller (1998). In order to calculate the percentage of protein, the following equation was used (Tisdale et al., 1993).

$$\% \text{ Protein} = \% \text{ N} \times 6.25$$

In order to calculate total crude protein yield, the percentage protein was multiplied by the total DM yield.

Irrigation water use efficiency

Irrigation water use efficiency (IWUE, kg ha⁻¹ mm⁻¹ and/or kg m⁻³) was calculated as dry matter (DM) yield (kg) obtained per unit depth and/or volume of irrigation water applied (mm and/or m³) (Howell, 2006).

Nitrogen Use Efficiency (NUE)

The NUE for the fertigation treatments was calculated as the ratio of DM yield (kg ha⁻¹) to the amount of N (kg ha⁻¹) applied for all the nitrogen frequencies (Moll et al., 1982; Witt et al., 1999).

Statistical Analysis and Evaluation

For statistical analysis, randomized blocks in split plots with three replications were used to evaluate the effects of the treatments on DM yield and other parameters. The data were analyzed using an ANOVA.

Variance analyses were performed for each experimental year. In addition, Duncan's multiple test, an acceptable tool for the comparison of discrete data, was used to compare different treatments (Yurtsever, 2011).

RESULTS AND DISCUSSION

Total Fresh and DM Yield

The total fresh and dry matter (DM) yields of silage corn according to the experimental years are given in Table 3. It is evident that the total fresh and DM yield varied widely from 53.1 to 93.3 and 14.8 to 33.9 t ha⁻¹ depending on the treatment and experimental years, respectively. Significant (**P < 0.01) effects of different irrigation levels and N fertigation frequencies on both fresh and DM yields were found separately in both experimental years. This means that there were no interactions between the amount of irrigation water applied and different fertigation frequencies of N. Thus, the data in the main plots and subplots on the yields were derived separately from the original data in experimental plots in Table 3 to analyze the effects of the treatments. Thus, the data in Table 4 were obtained.

In general, the fresh yields in both 2011 and 2012 increased significantly depending on increasing amounts of irrigation water and N fertigation frequencies (Table 3 and 4)

Table 3. Fresh and dry matter yields according to the experimental years for main and sub-plot treatments.

Irrigation levels	Nitrogen fertigation frequency	Fresh biomass (t ha ⁻¹)			Dry matter (t ha ⁻¹)		
		2011	2012	Mean	2011	2012	Mean
I _{1(0.50)}	N ₁	53.1	54.8	54.0	14.8	16.7	15.7
	N ₂	58.1	58.8	58.5	16.4	17.3	16.8
	N ₃	56.2	60.9	58.6	16.7	19.0	17.8
I _{2(0.75)}	N ₁	62.0	66.1	64.1	19.1	21.4	20.2
	N ₂	63.2	69.1	66.2	19.4	22.9	21.2
	N ₃	72.1	71.5	71.8	21.9	24.0	22.9
I _{3(1.00)}	N ₁	68.4	70.3	69.4	22.4	23.9	23.2
	N ₂	70.1	77.6	73.9	23.1	26.4	24.8
	N ₃	85.1	90.6	87.9	28.3	31.4	30.0
I _{4(1.25)}	N ₁	73.9	78.4	76.2	25.7	28.5	27.1
	N ₂	79.6	86.0	82.8	27.6	31.3	29.4
	N ₃	86.0	93.3	89.7	30.7	33.9	32.3

Table 4. The DM yields derived separately depending on amount of irrigation water applied and nitrogen fertigation frequency

Irrigation levels	2011		2012		Nitrogen fertigation frequency	2011	2012
	IW (mm)	DM yield (t ha ⁻¹)	IW (mm)	DM yield (t ha ⁻¹)		DM yield (t ha ⁻¹)	DM yield (t ha ⁻¹)
I _{1(0.50)}	278	16,0 d ¹	292	17,6 c	N ₁	20,5 b	22,6 c
I _{2(0.75)}	357	20,1 c	376	22,7 b	N ₂	21,6 b	24,4 b
I _{3(1.00)}	435	24,6 b	459	27,2 a	N ₃	24,4 a	27,1 a
I _{4(1.25)}	514	28,0 a	543	31,2 a			

DM: Dry matter

1: The same letters are not significantly different (**P<0.01) according to a Duncan's multiple range test

DMs varied from 27.9 to 36.4% basis on fresh biomass yield depending on the experimental years and treatments. Garcia (2011) reported that high quality maize silage contains 30-35% DM. Accordingly, the results from our study were considerably appropriate for silage fodder.

In 2011, the highest DM yield varied from 16.0 to 28.0 t ha⁻¹ depending on the amount of irrigation water applied. The maximum yield (28.0 t ha⁻¹) was obtained with treatment I₄ in which 125% of Ep was applied as irrigation water and this was significantly higher compared to the other treatments. Under the irrigation treatment I₄ (125 % Ep), the amount of irrigation water applied was 514 mm.

In 2012, the highest DM yield varied from 17.6 to 31.2 t ha⁻¹ also depending on the amount of irrigation water applied. There were no significant differences between treatment I₃ and treatment I₄ in this experimental year. Under the irrigation treatment I₃ (100% Ep) and treatment I₄ (125 % Ep) the amount of irrigation water applied was 459 and 543 mm, respectively. On the other hand, there were approximately similar effects of the treatments on the DM yields in the experimental years.

The applied irrigation water in the growing periods was approximately similar (Table 4). This can be attributed to the fact that there were no considerable differences in climatic conditions such as pan evaporation, relative humidity, and wind speed during the growing period. The results obtained during the two years show that DM yield is significantly (**P< 0.01) affected by increasing water and that the highest values were obtained under treatment I₃ (100% Ep) and treatment I₄ (125 % Ep). Increasing amounts of water resulted in increased DM yield. There were, thus, significant linear relationships ($y=0.052x+1.77$, $r^2=0.99^{**}$ for 2011 and $y=0.054x+2.05$, $r^2=0.99^{**}$ for 2012) between applied irrigation water and DM yield (Fig. 1). Similar findings were put forward by Yazar et al. (2002); Oktem et al. (2003); Greenwood et al. (2008) and Bouazzama et al. (2012).

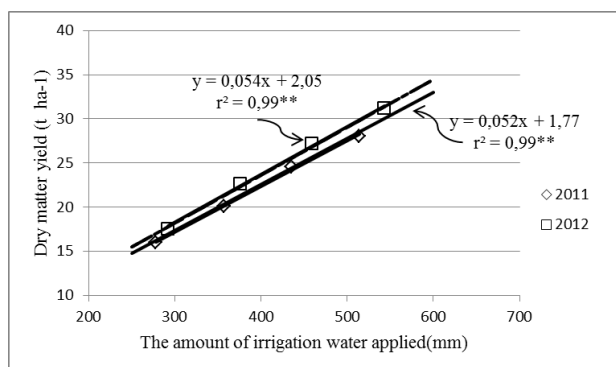


Fig. 1. Dry matter yield of corn silage versus the amount of irrigation water applied

As expected, the highest irrigation water (IW) occurred in I₄ (125 % Ep) obviously owing to an adequate and/or increased soil water supply during the growing period. Other irrigation strategies, especially I₁ (50 % Ep) and I₂ (75 % Ep) caused a certain water deficit and consequently a lower DM yield. DM accumulation was,

thus, increased by irrigation (Schmaler et al., 2003; Bouazzama et al., 2012).

Oktem et al. (2003) reported similarly that the fresh ear yield was reduced as the amount of irrigation water decreased and 100% of Ep would be optimal for sweet corn grown in semi-arid regions similar to the area where this work was conducted. They obtained also linear relationships between the amount of water applied and fresh ear yield.

On the other hand, a linear relationship has been reported between corn grain yield and evapotranspiration (Gencoglan and Yazar, 1999; Yazar et al., 2002; Cakir, 2004; Payero et al., 2006). Overman and Martin (2002) confirmed the linear relation between grain and silage yield response to irrigation for corn.

Considering the DM yields obtained in the different study areas, Emile et al. (2006) determined dry matter yield for irrigated maize as 20.1 t ha⁻¹ in France. Greenwood et al. (2008) indicated that the dry matter yield of silage corn without water stress was 22 t ha⁻¹. Bouazzama et al. (2012) reported that DM yields varied from 5.3 t ha⁻¹ under the 40 % ETc to 16.4 t ha⁻¹ under 100% ETc. Cigdem and Uzum (2006) found that dry matter yield of full irrigated silage corn was 7.2-8.5 t ha⁻¹.

Comparing our findings to the data obtained in other study areas on silage corn DM yield, it was relatively higher than those. Our study area has a hot and dry summer climate with higher amounts of sunlight. The average and maximum temperatures during the growing season in which it was from June through September were ranged from 25.0 to 31.3 °C and 32.4 to 44.7 °C, respectively. In addition sunlight duration ranged from 9.9 to 12.4 hours per day (DMI, 2014). Yields were, thus, positively associated with the accumulation of sunlight. This relationship was expected because the intensity and duration of sunlight influences the amount of photosynthesis (Duncan et al., 1977; Young and Smith, 1980; Nafziger, 2011). Warmer temperatures and increased sunshine early in the season lead to higher yields, whereas low yields are due to water stress and excessive heat during pollination and the grain-filling stages (Nafziger, 2011).

It can be assumed that, in a condition of more sunshine, with a relatively constant and/or closed capacity soil water content due to the fact that drip irrigation was used, a greater assimilation of products will be achieved. This means a higher plant height and more leaves per plant and total yield.

On the other hand, DM yields increased as long as N fertigation frequency increased (Fig. 2). This result showed that application of N as split at the right time and appropriate amount of N increased DM. This was achieved by means of an appropriate frequency (i.e. more frequency) of N fertigation. Similarly, Lui et al. (2013) reported that an increase in the fertigation splits and in the amount of N applied increased the N uptake of corn at the filling stage. Furthermore, the three fertigation splits

throughout the season produced a significantly higher yield than the single fertigation early in the season. Three fertigation splits obtained a high production while reducing the risk of N leaching. Hassan et al. (2010) stated that the maximum green fodder yield (91.3 t ha⁻¹) and DM yield (8.90 t ha⁻¹) was achieved with fertigation compared to broadcast and side dressing on silage corn.

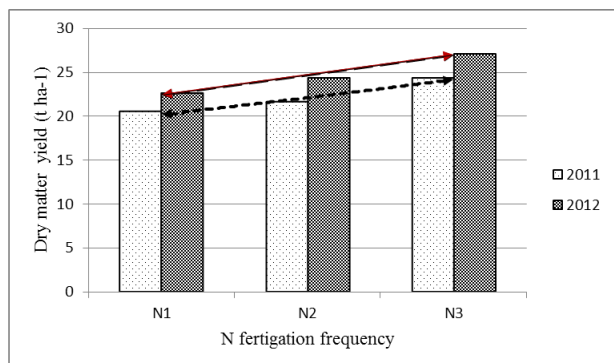


Fig. 2. Dry matter yield of corn silage versus nitrogen fertigation frequency

As a result, the corn can be seen to use nutrients when the plant grows most rapidly from about 45-50 cm high to grain fill. A split N application or applying N to the irrigation water are effective ways to minimize N loss by leading or denitrification (Garcia, 2011).

Irrigation Water Use Efficiency (IWUE)

IWUEs varied from 54.5 to 57.6 kg ha⁻¹ mm⁻¹ (or 5.45-5.76 kg m⁻³) in 2011, and from 57.5 to 60.4 kg ha⁻¹ mm⁻¹ (or 5.75-6.04 kg m⁻³) in 2012 depending on the treatments. There was no significant difference between treatments. However, decreasing amounts of irrigation water increased IWUE (Fig. 3). Similarly, Yazar et al. (2002) and Rusere et al. (2012) showed that a deficit in irrigation resulted in a significant decline in corn yield and an increase in IWUE. Additionally, Kang and Zhang (2004) reported that IWUE increased essentially by decreasing the amounts of the irrigation water. Yazar et al. (2009) reported that IWUE varied from 1.61 kg m⁻³ in full irrigation to 2.25 kg m⁻³ in some deficit irrigation

treatments. In all the cases, IWUE values related to deficit irrigations were higher than those of full irrigation.

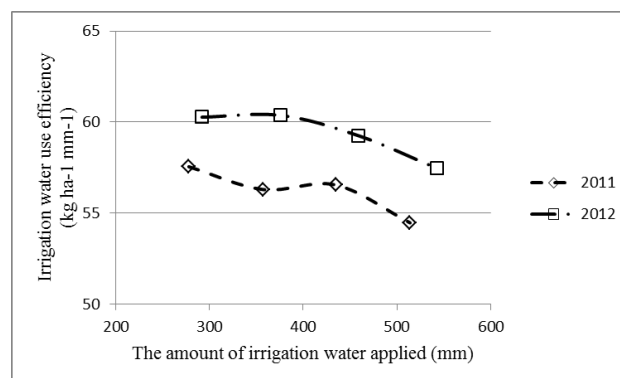


Fig. 3. Irrigation water use efficiency versus the amount of irrigation water applied

On the other hand, in the study carried out by Hammad et al. (2012) the highest IWUE achieved was 16.58 and 18.6 kg ha⁻¹ mm⁻¹ by means of an application of 225 kg N ha⁻¹ with an irrigation water depth of 525 mm during both growing seasons.

Total Protein Yield

The protein contents of silage corn ranged from 6.63 to 9.78% depending on the amount of irrigation water applied and N the fertigation frequency. The protein content decreased as long as the amount of irrigation water increased (Table 5). Similarly, Garcia (2011) reported that crude protein content was 7.2 and 5.2% for the severe deficit in irrigation and the full irrigation, respectively.

Total crude protein yield ranged widely from 1.54 to 2.19 t ha⁻¹ depending on N fertigation and the amount of irrigation water applied (Table 5). Both fertigation frequency and the amount of irrigation water significantly affected ($P < 0.05$) the crude protein content and total crude protein yield. The total protein yield increased as long as the N frequency and amount of irrigation water increased (Fig. 4).

Table 5. Protein content and total protein yield basis dry matter

Irrigation levels	2011		2012		NFF	2011		2012	
	PC (%)	TPY (t ha ⁻¹)	PC (%)	TPY (t ha ⁻¹)		PC (%)	TPY (t ha ⁻¹)	PC (%)	TPY (t ha ⁻¹)
I ₁ (0.50)	9.78	1,54 c ¹	8.57	1,52	N ₁	8.80	1,77 b	7.88	1,75
I ₂ (0.75)	8.67	1,74 b	7.87	1,78	N ₂	8.20	1,76 b	7.73	1,84
I ₃ (1.00)	8.07	1,98 a	7.50	2,03	N ₃	8.70	2,07 a	7.40	1,94
I ₄ (1.25)	7.80	2,19 a	6.63	2,06					

PC: Protein content, TPY: Total protein yield, NFF: Nitrogen fertigation frequency

1: The same letters are not significantly different according to a Duncan's multiple range test

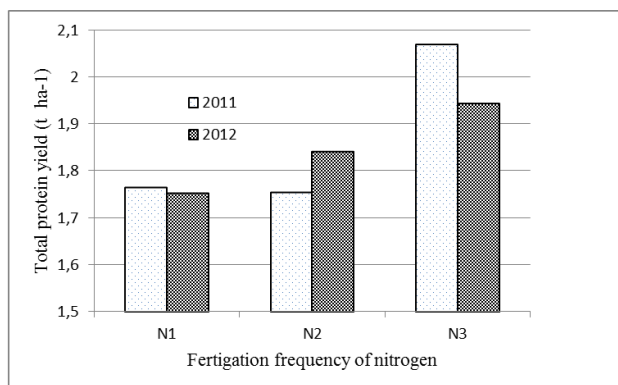


Fig. 4. Total protein yield versus nitrogen fertigation frequency
Nitrogen Use Efficiency (NUE)

The NUEs ranged from 66.5 to 130.0 kg DM kg⁻¹ N depending on the experimental years and the treatments used. The maximum NUE was obtained for N fertigation every irrigation cycles (5 days) and for applications of 125 % Ep in both experimental years (Table 6).

Table 6. Nitrogen use efficiency according to the different irrigation and fertigation frequency basis on dry matter yield (kg DM kg⁻¹ N ha⁻¹)

Irri. Levels	2011	2012	NFF	2011	2012
I ₁ (0.50)	66,5	73,6	N ₁	85,4	94,3
I ₂ (0.75)	83,9	94,9	N ₂	90,1	101,9
I ₃ (1.00)	102,5	113,5	N ₃	101,7	112,8
I ₄ (1.25)	116,7	130,0			

In the previous studies, Hammad et al. (2012) stated that NUE was optimum at 75 kg ha⁻¹. Garcia (2011) reported that severely deficit irrigation resulted in 103 kg DM kg⁻¹ N and full irrigation resulted in 161 kg DM kg⁻¹ N. Compared to the previous studies, our findings in regard to NUE were appropriate for an optimum of corn silage growth. Thus, higher accumulations of N and P in grain improves yield and consequently leads to greater efficiency of these nutrients (Fageria et al., 2006). Better distribution of dry matter in crop plants is generally associated with higher yields, and consequently, a higher level of nutrient use efficiency (Fageria et al., 2008).

CONCLUSIONS

It can be concluded that, the optimum level of irrigation was I₃ (100% Class A pan evaporation). This can be derived from a consideration of the associated effects of the amount of irrigation water applied to the DM yield for both years. When calculating the amount of irrigation water for the drip-irrigated silage corn production, an optimum wetted area must be considered. In this study, an appropriate value was 0.65. Thus, the requirement of irrigation water was 447 mm in average value. Similarly, the optimum nitrogen frequency was application of one-fifth of the total amount of N fertilizer at the sowing date, with the remaining N applied at each irrigation cycle for 5 days based on 240 kg ha⁻¹ N. Using this irrigation schedule and N fertigation frequency, a DM yield of 30.0 t ha⁻¹ and total crude protein of 2.0 t ha⁻¹ was

obtained. NUE and IWUE were 107.7 kg DM ha⁻¹ N and 58 kg ha⁻¹ mm⁻¹ or 5.8 kg m⁻³, respectively. Compared to previous studies and yields regarding silage corn, our DM yields were remarkably higher. This is an important finding for the feeding of animals, as well as sustainability of water and nitrogen use. Consequently, the lower amounts of irrigation water results in a significant decline in silage corn yield.

As a result, different fertigation techniques offer the possibility of maximizing NUE for corn silage. Thus, with an appropriate N frequency, N application should not exceed plant need and should be performed when the soil water is not leaching of the root zone. The results from this study could be very useful in the management of irrigation and nitrogen fertigation for silage corn.

ACKNOWLEDGEMENTS

This study includes a part of the doctorate thesis (Ramazan YOLCU) and the research project (ZF2011026) carried out from 2011 to 2012 at the farm of Devegeçidi Dam (Diyarbakir, Turkey). In addition, this research project was supported by the Çukurova University (Adana, Turkey), Scientific Research Projects Coordination Office.

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