Effect of Nitrogen Application Timing on Corn Production Using Subsurface Drip Irrigation

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Abstract: The use of subsurface drip irrigation (SDI) in row-crop agriculture is increasing because of potential increases in water and nutrient use efficiency. Research-based information is needed to manage N applications through SDI systems in field corn (*Zea mays* L.) production. This study was conducted to assess the effect of different in-season SDI system N application timings on corn production and residual soil NO_3-N at the University of Nebraska-Lincoln West Central Research and Extension Center in North Platte, Neb, on a Cozad silt loam (fine-silty, mixed, mesic Fluventic Haplustoll). We evaluated the effect of three N application timing methods (varying percentages of the total N rate [48% of total N] applied at the V10, VT, and R3 growth stages, in addition to uniform N applications [52% of total N] over all treatments at preplant, planting, and V14 growth stage) at two N application rates (University of Nebraska-Lincoln [UNL] recommended rate and the UNL rate minus 20%) on corn grain and biomass yield and end-of-study distribution of residual soil NO_3-N. In 2006, there were no significant differences in corn grain yields between the two N application rates. In 2007, the grain yield under the UNL recommended N rate was significantly higher (190 kg ha^{-1}) than the UNL-minus-20% N rate. The average grain yield for this study was close to the predicted yields (based on average 5-year historic yields + a 5% yield increase), indicating that corn production under SDI is satisfactory. In 2006 and 2007, grain yield and biomass production for the N application timing treatments were not significantly different ($P > 0.05$). The application of 13% of the total N at as late as R3 did not result in decreased yields. The lack of response to different N application timing treatments indicates that there is flexibility in N application timing for corn production under SDI. The distribution of NO_3-N in the 0- to 0.9-m and 0.9- to 1.8-m soil profiles was not significantly different among all the treatments.

Key words: Subsurface drip irrigation, nitrogen, corn.

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Nitrogen fertilizer applications have regularly been applied before corn (*Zea mays* L.) planting either in the fall or spring. Nitrogen fertilizer applications to corn during vegetative growth stages are now common. Advantages of vegetative N fertilizer applications include the ability to spread out field work, avoiding working on wet soils in the spring, reduction of N losses because of leaching and denitrification during wet springs (Scharf et al., 2002), and increased N use efficiency (NUE) and/or yield (Tarkalson and Payero, 2008; Fox et al., 1986; Welch et al., 1971).

In-season N applications are common using center pivot sprinkler irrigation systems, allowing for ease of N application during corn growth. Applying small amounts of N through irrigation systems during the season has the potential to adequately supply crop N requirements while minimizing the potential for nitrate-N (NO_3-N) leaching below the rooting depth (Lamm and Trooien, 2003). Several studies have compared N fertilizer application timing before or at planting with in-season N applications before the V8 growth stage of corn (Jokela and Randall, 1989; Roth et al., 1995; Bundy et al., 1992; Reeves and Touchton, 1986; Stecker et al., 1993). The advantages of N application timings (preseason, at planting, and in-season) on yield are varied. In some studies, the grain yields did not vary between application timings.

Limited research has been conducted to evaluate in-season N applications with subsurface drip irrigation (SDI) in corn production systems. Potential advantages of N fertilization through SDI systems include supply of N fertilizer directly to the center of the root zone and weed suppression caused by reduced N supply at the soil surface (Bar-Yosef, 1999). In Kansas, Lamm et al. (2001) found no difference in corn grain yield whether all the N fertilizer was applied preplant or weekly starting at 42 to 44 days to approximately 115 days after planting. The N was applied to match a corn N utilization model curve developed by the (Iowa State University (1989)) using an SDI system. However, Lamm and Manges (1991) found that in an SDI system, soil NO_3-N concentrations were greater at the end of the season when N was applied in-season compared with preplant N application. The authors suggested that increased NUE under in-season N applications could result in lower N requirements. Tarkalson and Payero (2008) found that corn yields and NUE increased when N was applied through an SDI system during the growing season compared with a one-time application of N early in the season. There is no reported research assessing the effects of different in-season N application timing methods on corn production under SDI. The objective of this study was to determine the effect of different in-season N application timings through an SDI system on corn grain yield, biomass production, and residual soil NO_3-N.

MATERIALS AND METHODS

Site Description

Field data for this study were collected in 2006 and 2007 at the University of Nebraska-Lincoln West Central Research and Extension Center in North Platte, Nebraska (41.1 °N, 100.8 °W, 861 m above sea level). The climate at North Platte is semiarid, with average annual precipitation and reference evapotranspiration of approximately 508 and 1403 mm, respectively. On average, about 80% of the annual precipitation occurs during the growing season, which extends from late April to mid-October (USDA, 1978). The soil at the experimental site is a Cozad silt loam (fine-silty, mixed, mesic Fluventic Haplustoll).

Experimental Design

The experiment was conducted using a randomized complete block factorial design with three N application timing

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TABLE 1. N fertilizer Application Timing and rates for 2006 and 2007

AT†	N rate treatment	N rates kg ha⁻¹	N application date and growth stage of corn: Preplant	Planting‡	V10	V14	VT	R3
			% of N rate (kg ha⁻¹)					
29:13:0	UNL§	233	30 (70)	5 (11)	29 (68)	23 (54)	13 (30)	0
13:29:0	UNL	233	30 (70)	5 (11)	13 (30)	23 (54)	29 (68)	0
29:0:13	UNL	233	30 (70)	5 (11)	29 (68)	23 (54)	0	13 (30)
29:13:0	UNL −20%	186	30 (56)	6 (11)	28 (52)	23 (43)	13 (24)	0
13:29:0	UNL −20%	186	30 (56)	6 (11)	13 (24)	23 (43)	28 (52)	0
29:0:13	UNL −20%	186	30 (56)	6 (11)	28 (52)	23 (43)	0	13 (24)

†Percentage of total N applied at V10, VT, and R3 growth stages (V10:VT:R3).

‡N applied 5 cm below and 5 cm to the side of the seed. Values inside parentheses represent kg N ha^{-1} applied.

§UNL N fertilizer recommendation (Shapiro et al., 2003).

AT: N application timing.

treatments, two application rate levels, and four replications. Each experimental plot was 9 m × 37 m, which accommodated 12 rows of corn. The N application timings consisted of uniform applications of 30% of the N fertilizer at preplant (34-0-0, broadcast), 5% at planting (10-34-0; 5 cm to the side and 5 cm below the seed zone), and 23% at the V14 growth stage. The remaining 42% of the total N was applied at various rates for each treatment at the V10, VT, and R3 corn growth stages (Table 1). The three N application timing treatments (29:13:0, 13:29:0, and 29:0:13) were supplied as liquid urea ammonium nitrate (32-0-0) and are designated as the percentage of total N applied at V10, VT, and R3, respectively (V10:VT:R3). Nitrogen applications were based on the University of Nebraska-Lincoln (UNL) N recommendations for corn (Shapiro et al., 2003) and the UNL recommendation minus 20%. The purpose of the UNL-minus-20% treatment was to include a rate that would be slightly N limited, which might show differences in N-timing treatments in case the UNL recommendation supplied excess N to corn.

The UNL N recommendations aim to supply N at rates that optimize yield and economic return. However, because of the variability of N release from soil organic matter and the inherent variability associated with estimating crop yields, oversupply of N can occasionally occur. Based on an average corn grain yield history at the site (13.8 Mg ha^{-1}), residual soil NO_3-N determined from a composite sample of three soil cores (38 mm diameter) collected from each plot at depths of 0 to 0.2, 0.2 to 0.6, 0.6 to 0.9, and 0.9 to 1.2 m in the spring before planting, soil organic matter levels (1.8%), and NO_3-N in the irrigation water (5 mg L^{-1}), the UNL N recommendations were 230 and 237 kg N ha^{-1} in 2006 and 2007, respectively (Table 2). We applied 233 kg N ha^{-1} in 2006 and 2007 for the UNL N application rate, or within 2% of the calculated N recommendations in 2006 and 2007 (Tables 1 and 2). The reason for the slight variation in the applied UNL N application rate was caused by an error in calculating the UNL N application rate in 2006. In 2007, because the UNL N recommendation was so close to the 233 kg N ha^{-1} rate used in 2006, the same rate was applied. The UNL-minus-20% treatment received 186 kg N ha^{-1} in 2006 and 2007 (Table 1). The treatments were located in the same plots in 2006 and 2007.

Cultural Practices

The corn hybrid Kaystar KX-8770Bt was planted in 2006 and Pannar 890Bt in 2007. Both hybrids had a relative maturity of 112 days. The crop was planted at a 0.76-m row spacing at a seeding rate of approximately 74,000 seeds ha^{-1}. Corn was planted on May 11 and 14 and reached physiological maturity on September 16, 2006, and September 10, 2007, respectively. To control weeds, a recommended rate of herbicide mixture (Lumax + Banvel + Atrazine 90 DF + crop oil) was applied when the crop was at the four-leaf stage in both years. In 2006, Counter® was applied at planting for insect control. The target insects were the corn rootworm beetle (*Diabrotica*

TABLE 2. Information needed to determine UNL recommended N rate for irrigated corn†

	Year	Grain yield Mg ha⁻¹	Crop N requirement	Residual NO_3-N credit, 0–1.2 m	Organic matter N credit, 0–0.2 m	Irrigation NO_3-N credit‡	Recommended N rate†
			kg N ha⁻¹				
Predicted§	2006	13.80	335	35	62	8	230
	2007	13.80	335	28	62	8	237
Actual‖	2006	12.41	306	32	56	8	209
	2007	12.02	297	28	54	8	208

†Shapiro et al. (2003); University of Nebraska-Lincoln (2008).

‡Irrigation water NO_3-N concentration was 5 mg L^{-1} in 2006 and 2007.

§Predicted grain yield goal before start of the study. Based on historic yields and average values from the Hybrid Maize Model (Dobermann and Shapiro, 2004).

‖Yields are the average of all N rate and N application method treatments.

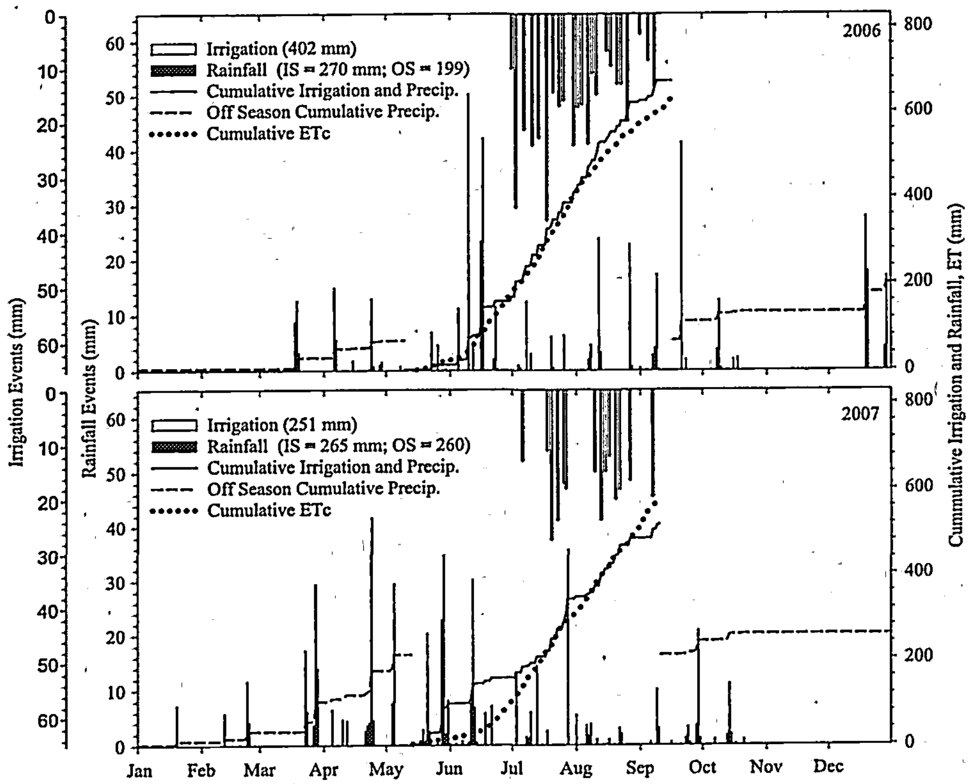

FIG. 1. Irrigation, precipitation, and evapotranspiration (ET) data from research area in 2006 and 2007. The ETc is the actual crop ET. During 2006 and 2007, ETc = ETw (ET assuming water is not limiting). The in-season (IS) period was from emergence to physiological maturity. The off-season (OS) period was the remaining time during the year.

virgifera virgifera LeConte) and the European corn borer (*Ostrinia nubilalis* [Hübner]).

Irrigation System and Irrigation Scheduling

The crop was irrigated with an SDI system that was installed just before planting in 2005. The laterals were spaced at 1.5 m (every other corn row) and were installed at a depth of 0.4 m in the middle of two crop rows. Laterals were 12.5-mil thin-wall dripper lines (Dripnet PC 1613 F, Netafim USA, Fresno, CA) with an inside diameter of 1.6 cm and pressure-compensating emitters spaced every 45.7 cm. The nominal flow of the emitters was 0.98 L h^{-1} (applying 1.5 mm h^{-1}) at a pressure of 69 kPa. Water for the system was pumped from the Ogallala aquifer and was filtered using a 152-mm-diameter screen filter with a 150-mesh screen (model 8060F-MN, Netafim USA). Irrigation to each treatment was controlled from a manifold that had eight branches. Each branch delivered water to all four replications of one treatment and had a flowmeter (25.4-mm model 36M251T) equipped with a pulse reed switch (model 36RD, Netafim USA). Each branch also had a 19-mm electric/manual control valve (model S390-3-0, Dorot Control Valves Inc, Fresno, CA), a pressure regulator (standard model, 0.22–1.26 L s^{-1}, 62.1 kPa) (Netafim USA), and an air-and-vacuum relief air vent with shrader valve ("guardian" model, Netafim USA). The study used six of the eight branches for the six total treatment combinations. The irrigation system was controlled with an automatic controller (model NMC-64, Netafim USA).

At the manifold, each branch delivering water to a treatment contained a chemigation port that allowed injection of the liquid urea ammonium nitrate into the irrigation water. The chemigation system consisted of a fertilizer storage tank, a piston chemical injection pump, a chemigation check valve, and a flowmeter.

Irrigation amounts and timing were scheduled to supplement rainfall and meet crop water requirements (ETc) aimed at producing maximum yield. If necessary, irrigation was applied a maximum of three times a week. Crop water use was determined using the procedure described in FAO-56 (Allen et al., 1998; Wright, 1982). According to this procedure, ETc can be obtained as the product of the evapotranspiration of a grass-reference crop (ETo) and a crop coefficient. The ETo was calculated using the weather data as input to the Penman-Monteith equation, and the crop coefficient was used to adjust the estimated ETo for the reference crop to that of corn at different growth stages and growing environments. Weather and climate data were collected from a High Plains Climate Center weather station located approximately 550 m from the research site.

Grain Yield and Biomass

Corn grain yield was determined by harvesting the entire length (37 m) of six rows of each 12-row plot (Rows 2, 3, and 4, and Rows 8, 9, and 10) using a plot combine with a three-row corn head. The combine was instrumented with an HM-400 Harvest Data System (Juniper Systems, Inc, Logan, UT), which measured grain yield, grain moisture, and test weight. This information was used to determine the grain yield from each plot, adjusted to a standard water content of 15.5%.

At physiological maturity, eight plants from each plot were hand-harvested from rows not used for grain yield harvest to

TABLE 3. Corn grain yield (15.5% moisture content) and ANOVA for effects of N AT and NR in 2006 and 2007

AT†	NR	2006 Mg ha^{-1}(SE‡)	2007	Mean
29:13:0	UNL§	12.35 (0.29)	12.10 (0.08)	12.22
13:29:0	UNL	12.35 (0.32)	12.24 (0.14)	12.29
29:0:13	UNL	12.27 (0.22)	12.02 (0.17)	12.15
Mean		12.32	12.12	
29:13:0	UNL −20%	12.46 (0.26)	11.94 (0.13)	12.20
13:29:0	UNL −20%	12.51 (0.43)	12.10 (0.05)	12.31
29:0:13	UNL −20%	12.51 (0.57)	11.76 (0.01)	12.13
Mean		12.49	11.93	
ANOVA (*df*)		Pr > F		
AT (2)		0.9796	0.0578	
NR (1)		0.3698	0.0461	
AT × NR (2)		0.9525	0.8033	

†Percentage of total N applied at V10, VT, and R3 growth stages (V10:VT:R3).

‡SE of treatment mean.

§UNL N fertilizer recommendation (Shapiro et al., 2003).

AT: N application timing; NR: N application rate.

determine aboveground total biomass production. Plants were cut at ground level, the ears were separated from the stover, and ear and stover samples from each plot were transported to the laboratory for further processing. In the laboratory, the stover samples from each plot were weighed, chopped using a heavy-duty plant chopper, and a subsample was collected and weighed. The subsamples were oven dried at 70 °C until they reached a constant weight (approximately 7 days), and the weight was then recorded. The ear samples were placed in a greenhouse and air dried to a moisture content of approximately 15% to 16%. The ear samples were then weighed and shelled by hand. The grain and cob samples were oven dried at 70 °C until they reached a constant weight (approximately 7 days), and the weight was then recorded.

TABLE 4. Total corn biomass yield (dry weight basis) at physiological maturity and ANOVA for effects of N AT and NR in 2006 and 2007

AT†	NR	2006 Mg ha^{-1}(SE‡)	2007	Mean
29:13:0	UNL§	19.25 (0.16)	18.60 (0.18)	18.92
13:29:0	UNL	19.02 (0.34)	18.92 (0.20)	18.97
29:0:13	UNL	18.62 (0.36)	18.32 (1.15)	18.47
Mean		18.96	18.61	
29:13:0	UNL −20%	18.45 (0.22)	18.75 (0.09)	18.60
13:29:0	UNL −20%	18.97 (0.34)	18.70 (0.09)	18.83
29:0:13	UNL −20%	18.58 (0.15)	19.26 (0.30)	18.92
Mean		18.67	18.90	
ANOVA (*df*)		Pr > F		
AT (2)		0.3941	0.9656	
NR (1)		0.2164	0.4988	
AT × NR (2)		0.3360	0.5289	

†Percentage of total N applied at V10, VT, and R3 growth stages (V10:VT:R3).

‡SE of treatment mean.

§UNL N fertilizer recommendation (Shapiro et al., 2003).

AT: N application timing; NR: N application rate.

TABLE 5. Soil NO_3-N mass at the 0- to 0.9- and 0.9- to 1.8-m depths and ANOVA for effects of N AT and NR at the end of the study

Soil depth, m	AT†	NR UNL‡	UNL −20%
		kg ha^{-1}(SE§)	
0–0.9	29:13:0	38.9 (6.0)	38.5 (6.4)
	13:29:0	45.0 (10.1)	41.3 (4.7)
	29:0:13	45.2 (4.7)	49.7 (8.8)
	Mean	43.0	43.2
	ANOVA (*df*)	P > F	
	AT (2)	0.3777	
	NR (1)	0.9795	
	AT × NR (2)	0.7937	
0.9–1.8	29:13:0	21.6 (4.7)	15.9 (2.0)
	13:29:0	18.0 (4.2)	13.5 (1.4)
	29:0:13	17.8 (3.7)	15.5 (2.6)
	Mean	19.1	15.0
	ANOVA (*df*)	P > F	
	AT (2)	0.5676	
	NR (1)	0.0920	
	AT × NR (2)	0.8264	

†Percentage of total N applied at V10, VT, and R3 growth stages (V10:VT:R3).

‡UNL N fertilizer recommendation (Shapiro et al., 2003).

§SE of treatment mean.

AT: N application timing; NR: N application rate.

Soil Nitrate-N

Nitrate-N in the soil profile was quantified at the end of the study, Replications 1 and 2 on April 2, 2008, and Replications 3 and 4 on April 15, 2008. A composite sample of three soil cores (38 mm diameter) was collected from each plot at depths of 0 to 0.2, 0.2 to 0.6, 0.6 to 0.9, 0.9 to 1.2, 1.2 to 1.5, and 1.5 to 1.8 m in the rows, approximately 10 cm adjacent to the SDI drip lines. The number of soil cores per plot was determined based on past SDI research on the same field that indicated that three cores per plot were sufficient to detect differences in soil NO_3-N between two N application methods (Tarkalson and Payero, 2008). Soil samples were air dried, ground to pass through a 2-mm sieve, and analyzed for NO_3-N concentration (Keeney and Nelson, 1982). Average bulk density values and the NO_3-N concentrations for each sampling depth were used to determine the mass of NO_3-N in the soil (bulk densities for the 0- to 0.2-, 0.2- to 0.6-, 0.6- to 0.9-, 0.9- to 1.2-, 1.2- to 1.5-, and 1.5- to 1.8-m depths were 1.37, 1.33, 1.33, 1.29, 1.31, and 1.31 g cm^{-3}, respectively).

Statistical Analysis

Data conformed to the assumptions of analysis of variance (ANOVA). The ANOVA and separation of treatment means by Tukey method was conducted using Statistix 8 (Analytical Software, 2003). Significance was determined at the 0.05 probability level.

RESULTS AND DISCUSSION

A total of 29 and 38 days of rainfall and 24 and 14 irrigation events occurred during the growing seasons in 2006 and 2007, respectively (Fig. 1). Rainfall contributed 43% and 47% and irrigation contributed 64% and 44% of the cumulative ETc during the growing seasons in 2006 and 2007, respectively (Fig. 1).

The measured (actual) grain yields (averaged over all N rates and N application methods) were 10.1% and 12.9% lower than the predicted yield goals in 2006 and 2007, respectively (Table 2). In 2006, the applied N rates of the UNL (233 kg N ha^{-1}) and UNL-minus-20% (186 kg N ha^{-1}) treatments, which were based on the predicted recommended rates, were 11.5% greater and 11% lower than the recommended N rate when using the actual grain yields to predict N requirements, respectively (Tables 1 and 2). In 2007, the applied N rates of the UNL (233 kg N ha^{-1}) and UNL-minus-20% (186 kg N ha^{-1}) treatments, which were based on the predicted recommended rates, were 12.0% greater and 10.6% lower than the recommended N rate when using the actual yield to predict N requirements, respectively (Tables 1 and 2).

Analysis of variance of the effects of N application timing and N application rate on corn grain yield and biomass was conducted separately in 2006 and 2007. The N application timing and N application rate main effects and the interaction for grain yield were not significant in 2006 (Table 3). However, in 2007, the main effect of N application rate was significant (Table 3). The corn grain yield of the UNL N application rate was 190 kg ha^{-1} greater than that of the UNL-minus-20% N application rate in 2007 (Table 3). These data indicate that corn grain yields under SDI can be optimized at N application rates less than the recommended rates in some years. Differences in N mineralization from soil organic matter and potential improved N use efficiency using SDI will likely contribute to differences in actual N requirements. The application timing and N rate application rate main effects and the interaction for biomass production were not significant in 2006 and 2007 (Table 4). These data show that there was little effect of the N application timing treatments used in this study on corn grain yield and biomass production, suggesting that corn is not sensitive to variations in N application timings during the season, and N application at as late as R3 will not result in decreased yield. However, in this study, at least 87% of the total N was applied by the end of the VT growth stage. If a greater percentage of the N requirement was applied at R3, the results might have differed. At the R3 growth stage, approximately 80% of the total N uptake by corn has been acquired (Ritchie et al., 1993). Therefore, if greater than approximately 20% of the total N was applied at or after R3, grain and biomass yield could have been negatively affected. More work is needed to further elucidate the effects of N application timing on soil N supply, corn grain yield, and biomass production.

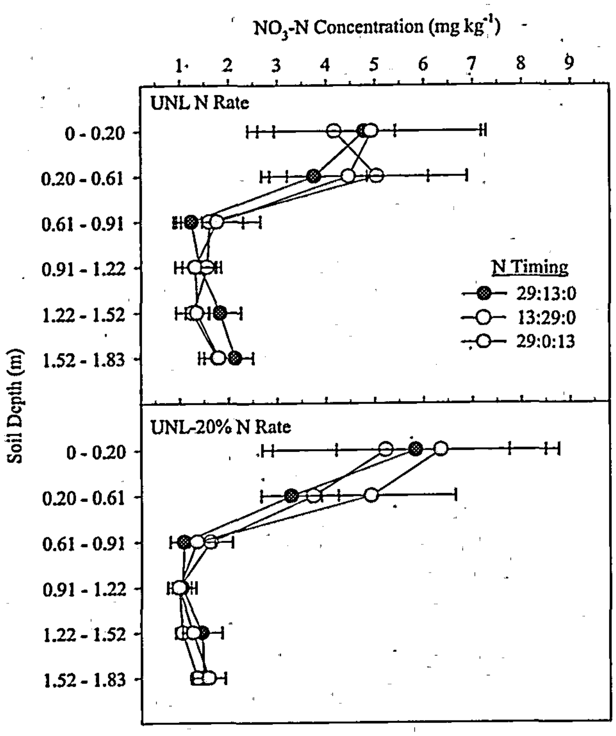

FIG. 2. Concentrations of soil NO_3-N at six depth increments in plots receiving N application rates of 186 and 233 kg ha^{-1} and three N application timings at the end of the study (Spring 2008). Nitrogen application timings are the ratios of percent N applied at V10 to percent N at VT to percent N at R3 (V10:VT:R3). Each concentration is the mean of four replications. Fifty-eight percent of the total N applied at preplant, planting, and the V14 growth stage for all treatments. Error bars are the SE of the treatment means.

The lack of yield difference among N application timings was likely a result of corn plant using sufficient amounts of N applied up to the R3 growth stage for grain and biomass production. This theory is strengthened by the fact that although grain yield was limited with the UNL-minus-20% N application rate in 2007 compared with the UNL N application rate, there was no effect of application timing under the UNL-minus-20% rate on corn grain yields. Although not quantified in this study, it is possible that root proliferation around the drip line and the direct application of N to the roots could have increased N use efficiency compared with other irrigation systems, where the roots and N application points are more disperse throughout the soil profile. This theory needs to be explored further.

The N application timing and N application rate main effects and the two-way interaction for soil NO_3-N mass were not significant at the 0- to 0.9- and 0.9- to 1.8-m depths in spring 2008 (Table 5). The average mass of NO_3-N in the 0- to 0.9- and 0.9- to 1.8-m profiles averaged across all N application rates and application timings was 43.1 and 17.1 kg ha^{-1}, respectively. Although not significant, there was a trend for increasing NO_3-N mass in the 0.9- to 1.8-m depth as N application rate increased (Table 5). At both N rates, concentrations of NO_3-N measured at depths of 0 to 0.2, 0.2 to 0.61, 0.61 to 0.91, 0.91 to 1.22, 1.22 to 1.52, and 1.52 to 1.83 m were not significantly different (ANOVA table not shown) for the three N application timing treatments (Fig. 2).

CONCLUSIONS

Results from this study indicate that different in-season N application timings through an SDI system can produce comparable corn grain and biomass yields and cause little difference in NO_3-N masses in the soil profile. Corn grain and biomass production was maintained under SDI even when 13% of the total N is applied at the R3 growth stage. The lack of yield differences between N application timing treatments indicates that there is flexibility in N application timing for corn production under SDI. In this study, under SDI, optimum N rates for corn grain production can be less than the recommended rate in some years. Corn production under SDI can produce yields close to historic yields under conventional irrigation systems.

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