NITROGEN FERTILIZATION FOR SUBSURFACE DRIP–IRRIGATED CORN

F. R. Lamm, T. P. Trooien, H. L. Manges, H. D. Sunderman

ABSTRACT. *Microirrigation can potentially "spoon feed" nutrients to a crop. Accurately supplying the crop's nitrogen (N) needs throughout the season can enhance crop yields and reduce the potential for groundwater contamination from nitrates. A 2–year study (1990–1991) was conducted on a Keith silt loam soil (Aridic Argiustoll) to examine combinations of both preplant surface application (30 cm band in center of furrow) and in–season fertigation of N fertilizer for field corn (*Zea mays *L.) at three different levels of water application (75%, 100%, and 125% of seasonal evapotranspiration) using a subsurface drip irrigation (SDI) system. The method of N application did not significantly affect corn yields, apparent plant nitrogen uptake, or water use efficiency, but all three factors were generally influenced by the combined total N amount. The N application method did have an effect on the amount and distribution of total soil N and nitrate–N in the soil profile following harvest. In both years, nearly all of the residual nitrate–N after corn harvest was within the upper 0.3 m of the soil profile for the treatments receiving only preplant–applied N, regardless of irrigation regime. In contrast, the nitrate–N concentrations increased with increasing rates of N injected by the SDI system and migrated deeper into the soil profile with increased irrigation. The results suggest that N applied with an SDI system at a depth of 40–45 cm redistributes differently in the soil profile than surface–applied preplant N banded in the furrow.*

Keywords. *Nutrient management, Water management, Nutrient efficiency, Water use efficiency.*

One of the more significant advantages of microirrigation is its ability to "spoon feed" crop nutrients on an as–needed basis. Such an approach should reduce the amount of nutrients in the soil at any given time, thereby decreasing the potential for environmental contamination. It also may enhance crop yields by more closely matching crop needs at a particular time (Bucks and Davis, 1986).

Nakayama and Bucks (1986) point out that injection of fertilizer through a microirrigation system can increase fertilizer efficiency by placing the material where the roots are concentrated. Bar–Yosef (1999) reported a number of potential agronomic advantages for fertigation with subsurface drip irrigation (SDI) over surface drip irrigation. These include nutrients being supplied to the center of the root system, drier soil surfaces that help reduce weed germination, deeper root growth that buffers the plant against water and nutrient stresses, prevention or reduction of soil crusting in sodic soils or when saline water is used, and utilization of secondary municipal effluents for edible crops. Phene et al. (1979) found that the injection of fertilizer through a microirrigation system increased the fertilizer use efficiency of potatoes by more than 200% over that from conventional application methods. Miller et al. (1976) reported that N injected through a microirrigation system was used more efficiently by tomatoes than banded N. Mohtar et al. (1989) concluded that N application for cherries with a microirrigation system was a viable alternative to ground application, even at half the ground–applied N amount.

Point source application methods have been shown to produce different distribution patterns of soil N under sprinkler and surface irrigation and rainfall (Onken et al., 1979). Different patterns could be expected when N is applied with SDI systems, but the water carrier and application point should exert additional and different effects (Mitchell, 1981; Mitchell and Sparks, 1982; Onken et al., 1979; Bar–Yosef, 1999).

These studies emphasize that significant improvements in fertilizer application can be made with microirrigation for high–value fruits and vegetables. However, very little research has been done on the use of SDI to apply N to corn, a high N user. A 2–year study was initiated at the KSU Northwest Research Extension Center in 1990 to examine N

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fertilization methods and N requirements for subsurface drip–irrigated corn on the silt loam soils in northwest Kansas. One objective was to determine the relationships among grain yields, water use efficiency, and N uptake as affected by N application methods and amounts, and irrigation regime. A second objective was to determine the effect of irrigation regime and application method on the distribution of soil N after harvest.

Determining the optimum combination of fertilization method, fertilizer amount, and irrigation regime was not an objective in the study. In response to the many unknowns in this region about N fertilization for corn grown using SDI, combinations were selected to ensure that water and N availabilities ranged from limiting to nonlimiting. A larger number of treatments with smaller increments in fertilizer amounts would have been necessary to determine the optimum combination.

PROCEDURES

The project was conducted at the KSU Northwest Research–Extension Center at Colby, Kansas, on a deep, well–drained, loessial Keith silt loam (Aridic Argiustoll; fine silty, mixed, mesic). This medium–textured soil, typical of many High Plains soils, is described in more detail by Bidwell et al. (1980). The 2.4 m soil profile will hold approximately 445 mm of plant–available water at field capacity. The corresponding volumetric soil water content is approximately 0.37 and the profile bulk density is approximately 1.3 g/cm^3.

The continental climate is semi–arid with an average annual precipitation of 474 mm and approximate annual lake evaporation of 1400 mm (Bark and Sunderman, 1990). Irrigation was scheduled on the basis of data collected from an NOAA weather station located approximately 450 m northeast of the study site. The reference evapotranspiration (ET_r) was calculated using a modified Penman combination equation similar to the procedures outlined by Kincaid and Heermann (1974). The specifics of the ET_r calculations used in this study are described fully by Lamm et al. (1987). Basal crop coefficients (K_{cb}) were generated with equations developed by Kincaid and Heermann (1974) based on work by Jensen (1969) and Jensen et al. (1970, 1971). The basal crop coefficients were calculated for the area by assuming 70 days from emergence to full canopy for corn with physiological maturity at 130 days. This method of calculating crop evapotranspiration (ET_c) as the product of K_{cb} and ET_r was acceptable in past studies at Colby (Lamm and Rogers, 1983, 1985). In constructing the irrigation schedules (water budget), no attempt was made to modify ET_c with respect to soil evaporation losses or soil water availability as outlined by Kincaid and Heermann (1974). Irrigation was scheduled when the calculated profile soil water depletion in the water budget was between 20 and 45 mm with the irrigation amount returning the calculated depletion to near zero.

The study used an SDI system constructed in the spring of 1990. The system was constructed with dual–chamber dripline with emitters spaced 30 cm apart installed at a depth of approximately 40–45 cm with a 1.5 m spacing between dripline laterals (Lamm et al., 1990). The corn rows (76 cm apart) were planted on a 1.52–m raised bed so that each dripline lateral was centered between two rows. Irrigation water was metered separately onto each plot with commercial municipal–grade flow accumulators with an accuracy of ±1.5%.

The 1.2 ha study area was approximately 200 m wide and 60 m long with a land slope of approximately 0.5% in an east–west row direction. Approximately 20 m of buffer area was planted to irrigated corn on the north and south edges of the study. Experimental design was a split–plot, randomized complete block with three replications (table 1). The whole–plot treatment (6 m wide by 60 m long) was a factorial combination of irrigation regime by seasonal N fertigation amounts. This corresponds to eight 76–cm rows with driplines spaced every 1.5 m between corn rows. Three irrigation regimes of 75%, 100%, and 125% of ET_c were created by modifying the daily ET_r value by the respective percentage. The seasonal injected N amounts were 100% and 150% of the projected seasonal plant uptake amount. Control plots received no N through fertigation. The 60 m length of the whole plots was equally divided into three 20 m split–plots. The split–plot treatment was the surface–applied preplant N: control (0) or application of 125 or 245 kg N/ha. The UAN 32–0–0 was applied in both years in a 30 cm spray band in the center of the furrowed interrow between the 1.52 m spaced beds. Precipitation occurred within a few days of the preplant application to help redistribute the fertilizer. Early season volatilization losses from UAN 32–0–0 are usually considered to be low in this region.

Seasonal N injection treatments were intended to provide 280 kg/ha for the 100% rate and 420 kg/ha for the 150% rate and these rates were achieved in 1990 using a 32% N solution. However, in 1991, an error by the fertilizer distributor resulted in a 28% N solution being supplied for the study. This error was not caught until a sample of the fertilizer was analyzed after the season. As a result, the injection treatments for 1991 only provided 210 kg/ha and 316 kg/ha of N. Nitrogen in the form of urea–ammonium–nitrate (UAN) was injected for the appropriate treatments in the center of each 1.5 m bed at a depth of 40–45 cm with the SDI system. Weekly injections (fig. 1) were used beginning with the first required irrigation (42 and 44 days after corn emergence in 1990 and 1991, respectively). The weekly applied N fractions were estimated from an N use curve developed by Iowa State University (1989). Injections were made at the plot level with a commercial industrial–grade injector during an approximately 20–minute period for each plot as part of a multihour irrigation event. The injection period never occurred before the first 2 hours of the irrigation event or within the last 4 hours of the event. Using the irrigation system as properly designed requires approximately 21 hours for each 25 mm of irrigation applied. Injections of fertilizer were made only once a week, even if the irrigation schedule required more frequent irrigation.

A modified, ridge–till system was used for corn production with two rows, 76 cm apart, grown on a 1.5 m bed. The soil had been fertilized with 45 kg/ha of P_2O_5 (superphosphate, 0–46–0) prior to fall bedding (1989) with an Orthman Tri–Level bedder. The corn (Pioneer brand 3162) was planted on April 23, 1990, and on May 6, 1991, at seeding rates of 70,900 and 72,600 seeds/ha, respectively. The corn emerged on May 15 each year. Tractor traffic was confined to the furrowed interrows. Following the 1990 corn harvest, the stalks were chopped and the ground was

Table 1. Summary of experimental treatments with actual applied nitrogen and irrigation amounts, 1990–1991. KSU Northwest Research–Extension Center, Colby, Kansas.

Whole Plot Trt.	Split Plot Trt.										
Irrigation	Nominal N Rates		Actual Injected N			Actual Preplant N[a]			Irrigation		
	Injected	Preplant	1990	1991	Mean	1990	1991	Mean	1990	1991	Mean
	(kg/ha)		(kg/ha)			(kg/ha)			(mm)		
1.25 ET_c	0	0	0	0	0	20	19	20	582	566	574
		125				143	142	143			
		245				267	266	267			
	280	0	280	210	245	20	19	20			
		125				143	142	143			
		245				267	266	267			
	420	0	420	316	368	20	19	20			
		125				143	142	143			
		245				267	266	267			
1.00 ET_c	0	0	0	0	0	20	19	20	457	427	442
		125				143	142	143			
		245				267	266	267			
	280	0	280	210	245	20	19	20			
		125				143	142	143			
		245				267	266	267			
	420	0	420	316	368	20	19	20			
		125				143	142	143			
		245				267	266	267			
0.75 ET_c	0	0	0	0	0	20	19	20	325	304	315
		125				143	142	143			
		245				267	266	267			
	280	0	280	210	245	20	19	20			
		125				143	142	143			
		245				267	266	267			
	420	0	420	316	368	20	19	20			
		125				143	142	143			
		245				267	266	267			

[a] Total applied N from the three sources: preplant applied as related to treatment, starter fertilizer in 1991, and the small amount naturally occurring in the irrigation water.

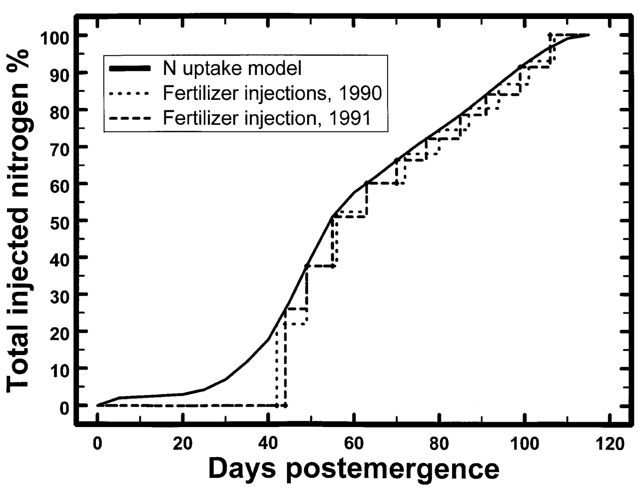

Figure 1. Total injected N, % as a function of days postemergence.

fertilized with 45 kg/ha of P_2O_5 (ammonium superphosphate, 10–34–0) broadcast–applied as a solution. The small amount of N in the ammonium superphoshate was accounted for in the total applied N amounts in 1991. The beds were reshaped with a border disk that removed the corn root clumps and heaped the residue with soil at the center of the bed. This allowed for some overwinter decay of the residue and incorporation of the fertilizer.

Soil water amounts were measured for each whole plot in 30 cm increments to a depth of 2.4 m on an approximately weekly basis each season with a neutron probe. Only one access tube was used in each whole plot and it was installed in the medium preplant–applied N subplot (125 kg/ha). The access tube was located in the corn row, resulting in soil–water measurements approximately 38 cm from the nearest dripline. No attempt was made to alter irrigation schedules based on measured soil water. Rather, the soil–water measurements were used to evaluate how well each irrigation treatment performed and to determine total water use. It was assumed that the soil water measurements from the medium preplant–applied N subplots were applicable to the other subplots.

Water use was calculated as the sum of seasonal changes in soil water between the first and last sampling dates, irrigation, and rainfall. This method of computing water use would inadvertently include any runoff and deep percolation. Although runoff was not measured, it would be expected to be negligible in the plots because of low land slope, furrow dams in 1990, and high residue amounts in 1991. Water use efficiency was calculated as the yield in Mg/ha divided by the equivalent depth of water use in mm.

The amount of N in the soil profile was measured at three times during the study (May 1990, October 1990, and October 1991). Soil samples were taken near the center of the subplot in the corn row that was both 38 cm laterally from the injection point of the dripline and 38 cm from the center of the furrow where the preplant N band was applied. Labor and analyses cost considerations did not allow a more thorough lateral sampling (perpendicular to corn rows and N application sources) of the profile. Samples were taken in 15 cm increments for the top 0.6 m and in 30 cm increments from 0.6 to 2.4 m. Samples were air–dried at 50° C and finely ground at the Center before shipping to the Soils and Plant Testing Laboratory at Kansas State University for determination of the total acetate–extractable ammonium–N and water–extractable nitrate–N.

Irrigation water samples also were analyzed for the amount of nitrate–N near the end of each pumping season to determine the contribution of the irrigation water to the N budget of the crop. Nitrate–N amounts in the water were near typical background concentrations: 3.45 mg/L and 3.29 mg/L for 1990 and 1991, respectively. This contributed less than 20 kg/ha annually, but was accounted for in the experimental results. Total applied N was calculated as the sum of preplant–applied, seasonal–injected, and the naturally occurring amount in the irrigation water.

Five whole plants (above–ground parts) were selected randomly from near the center of each subplot at grain harvest for plant tissue analysis. All five plants were chopped at the field and weighed, then air–dried at 50° C and weighed again for dry matter determination. Field biomass was calculated from the above–ground dry weights of the five random plants and the harvest plant populations for each of the subplots. The samples were ground finely again after drying and subsamples were sent to the Soils and Plant Testing Laboratory at Kansas State University for determination of total N concentration using a Kjeldahl method. The apparent nitrogen uptake (ANU) was calculated from the field biomass amounts and the whole plant N content for each subplot.

An approximately 6 m length of one corn row from near the center of each subplot was hand harvested in the fall (September 21, 1990, and September 23, 1991) for yield determination. Yields were standardized to a 15.5% wet basis.

Results and Conclusions

Weather Conditions

Overwinter precipitation (October through April) was low in both 1990 and 1991 (122 and 113 mm, respectively). However, soil water was near field capacity for the 2.4 m soil profile in all treatments in 1990 due to extensive preseason irrigation during the initial development of the SDI system. This was not the case in 1991 with no preseason irrigation where soil profiles were at 58%, 72%, and 79% of field capacity at planting for the 0.75 ET_c, 1.00 ET_c, and 1.25 ET_c treatments, respectively.

Seasonal precipitation (May–September) was near normal in 1990 and 1991 (309 and 332 mm, respectively). However, in both years, May precipitation was significantly greater than the 99–year mean. The corn emerged on May 15 in each year, so crop water use from the available May precipitation was low. In each year, one or more of the principal growth months, (June, July, or August) had less than normal precipitation.

The cumulative calculated ET_c was near the 20–year mean (587 mm) for both years of the study, 594 and 600 mm in 1990 and 1991, respectively. However, in 1990, the progression of cumulative ET_c was significantly higher than normal from mid–June to mid–July, a period characterized by windy conditions and several days with temperatures exceeding 40° C.

The normal net irrigation requirement at the study site (Thomas County, Kansas) is 391 mm based on an 80% chance precipitation (Soil Conservation Service, 1977). Overall irrigation requirements were highest in 1990, with the standard 1.00 ET_c treatment exceeding the normal net requirement by 66 mm (table 1). The crop year 1991 was characterized by slightly above–normal precipitation in June and July but appreciably below normal precipitation in August and September. The net irrigation requirement in 1991 was approximately 36 mm above normal (table 1).

Corn Yields

Corn yields were very high whenever irrigation and fertilization were sufficient, with a 2–year mean yield exceeding 15 Mg/ha for several treatments (table 2). Yields were affected significantly by all three treatment factors (irrigation regime, injected–N rate, and preplant–applied N rate) in 1991 and for the two–year mean (tables 2 and 3) as indicated by the significant 3–way interaction. The interaction between injected N and preplant–applied N had statistically significant effects on yields in both years. In general, yields tended to plateau for all irrigation treatments when the total applied N from all sources reached approximately 260 kg/ha (table 2 and fig. 2). In 1990, irrigation tended to have a stronger effect on increasing yields when no injected N was used. This may be indicating that the additional irrigation allowed the plants to explore a larger root zone to acquire nutrients. In 1991, corn yields were lower and more erratic for the 75% of ET_c irrigation regime, sometimes decreasing at the higher rates of combined fertilization. This may be indicating too much fertilizer for this reduced amount of irrigation. An alternative explanation is that lower soil water at planting in 1991 for the 75% of ET_c irrigation regime may have resulted in lower and more erratic corn yields.

Obtaining similar yields with injected N fertilizer or preplant–applied N may be instructive. The injected–N treatments began on June 25, 1990, and June 27, 1991. Delaying N application until this date without affecting yields could save or delay operating costs as well as reduce N leaching during a period when precipitation exceeds crop water use. Additionally, if crop potential is lowered by weather, disease, or crop pests, further application of fertilizer could be reduced or eliminated by using this weekly injection technique. These data suggest that a large portion of the applied N could be delayed until weekly injections begin with the first irrigation, provided there is sufficient residual soil N available for early growth.

Table 2. Summary of corn yield, nitrogen nutrient, and water use data from a subsurface drip–irrigated corn study, 1990–1991. KSU Northwest Research–Extension Center, Colby, Kansas.

Irrigation Treatment	Nominal N Rates		Total Applied N[a]			Corn Grain Yield			Water Use[b]			Water Use Efficiency			ANU[c]			Profile Nitrogen[d]		
	Injected	Preplant	1990	1991	Mean	1990	1991	Mean	1990	1991	Mean	1990	1991	Mean	1990	1991	Mean	S–90	F–90	F–91
	(kg/ha)		(kg/ha)			(Mg/ha)			(mm/2.4 m)			(Mg/ha–mm)			(kg/ha)			(kg/ha–2.4 m)		
1.25 ET_c	0	0	20	19	20	12.2	4.7	8.5				0.016	0.006	0.011	151	71	111	289	76	73
		125	143	142	143	13.4	11.0	12.2	781	796	788	0.017	0.014	0.016	202	143	173	289	102	63
		245	267	266	266	14.7	15.9	15.3				0.019	0.020	0.019	256	217	236	289	173	68
	280	0	300	254	277	14.9	15.7	15.3				0.019	0.019	0.019	288	295	291	215	378	520
		125	424	378	401	14.3	15.3	14.8	784	829	806	0.018	0.018	0.018	280	258	269	215	485	409
		245	547	501	524	14.6	15.4	15.0				0.019	0.019	0.019	248	240	244	215	490	451
	420	0	440	373	407	15.3	15.8	15.5				0.020	0.019	0.020	259	281	270	225	499	565
		125	564	497	530	14.8	15.5	15.1	781	810	795	0.019	0.019	0.019	281	290	286	225	591	510
		245	687	620	653	15.4	14.8	15.1				0.020	0.018	0.019	276	309	293	225	922	955
1.00 ET_c	0	0	16	15	15	9.3	3.9	6.6				0.014	0.006	0.010	112	55	84	257	73	56
		125	139	138	138	12.0	10.1	11.0	672	678	675	0.018	0.015	0.016	171	165	168	257	108	63
		245	262	261	262	13.5	14.0	13.8				0.020	0.021	0.020	204	244	224	257	113	126
	280	0	296	250	273	13.7	15.3	14.5				0.020	0.022	0.021	300	252	276	316	232	471
		125	419	373	396	15.1	15.2	15.1	679	705	692	0.022	0.022	0.022	309	273	291	316	425	234
		245	542	497	520	14.5	14.2	14.4				0.021	0.020	0.021	282	277	280	316	486	388
	420	0	436	369	402	14.5	15.4	14.9				0.021	0.022	0.021	272	241	257	212	583	596
		125	559	492	526	14.3	15.1	14.7	683	708	695	0.021	0.021	0.021	271	256	263	212	438	562
		245	683	615	649	14.5	13.8	14.1				0.021	0.019	0.020	284	260	272	212	930	777
0.75 ET_c	0	0	11	10	11	9.2	4.4	6.8				0.015	0.008	0.012	130	46	88	299	96	78
		125	135	133	134	12.7	9.7	11.2	597	558	578	0.021	0.017	0.019	211	137	174	299	86	84
		245	258	257	257	13.6	14.4	14.0				0.023	0.026	0.024	257	243	250	299	76	75
	280	0	291	245	268	13.5	15.1	14.3				0.022	0.027	0.024	276	233	254	276	288	302
		125	415	369	392	13.7	12.1	12.9	613	569	591	0.022	0.021	0.022	275	272	273	276	233	453
		245	538	492	515	14.4	13.9	14.2				0.023	0.024	0.024	279	252	266	276	382	251
	420	0	432	364	398	14.0	11.6	12.8				0.023	0.019	0.021	307	285	296	219	729	375
		125	555	488	521	14.2	13.7	13.9	615	600	608	0.023	0.023	0.023	278	295	286	219	563	775
		245	678	611	644	14.1	12.8	13.4				0.023	0.021	0.022	268	288	278	219	670	758

[a] Total applied N from the three sources: preplant applied, injected, and the amount naturally occurring in the irrigation water.
[b] Total of seasonal change of soil water storage in the 2.4–in profile plus irrigation and precipitation.
[c] Nitrogen fertilizer accounted for by the above–ground dry matter at harvest.
[d] Total ammonium and nitrate nitrogen in the 2.4–m soil profile for Spring 1990, Fall 1990, and Fall 1991.

Table 3. Least significant differences (LSD) at the P = 0.05 level for corn yield, nitrogen nutrient, and water use data for a subsurface drip irrigated corn study, 1990–1991. KSU Northwest Research–Extension Center, Colby, Kansas.

Treatment or Interaction	Yield (Mg/Ha)			Water Use (Mm)			WUE (Mg/Ha–Mm)			ANU (Kg/Ha)			Profile N (Kg/Ha)		
	1990	1991	Mean	1990	1991	Mean	1990	1991	Mean	1990	1991	Mean	S–90	F–90	F–91
Irrigation	0.8	Int	Int	19	18	15	0.0012	Int	Int	NS	NS	NS	NS	NS	NS
N–injection	Int	Int	Int	NS	18	15	Int	Int	Int	Int	Int	Int	NS	118	177
N–preplant	Int	Int	Int	–	–	–	Int	Int	Int	Int	Int	Int	–	93	NS
Irrigation × N–injection	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Irrigation × N–preplant	NS	Int	Int	–	–	–	NS	Int	Int	NS	NS	NS	–	NS	NS
N–injection× N–preplant within same N–injection level	0.8	Int	Int	–	–	–	0.0012	Int	Int	23	33	19	–	NS	NS
N–injection × N–preplant for different N–injection levels	1.0	Int	Int	–	–	–	0.0015	Int	Int	30	34	24	–	NS	NS
Irrigation × N–injection × N–preplant within same irrigation and N–injection levels	NS	1.4	0.9	–	–	–	NS	0.0020	0.0012	NS	NS	NS	–	NS	NS
Irrigation × N–injection × N–preplant for different irrigation or N–injection levels	NS	1.5	1.1	–	–	–	NS	0.0026	0.0019	NS	NS	NS	–	NS	NS

NS denotes nonsignificance. Int denotes a higher level interaction has occurred involving this factor and thus a LSD is not appropriate. A hyphen means that a LSD could not be calculated for the factor due to lack of replication for the split plot.

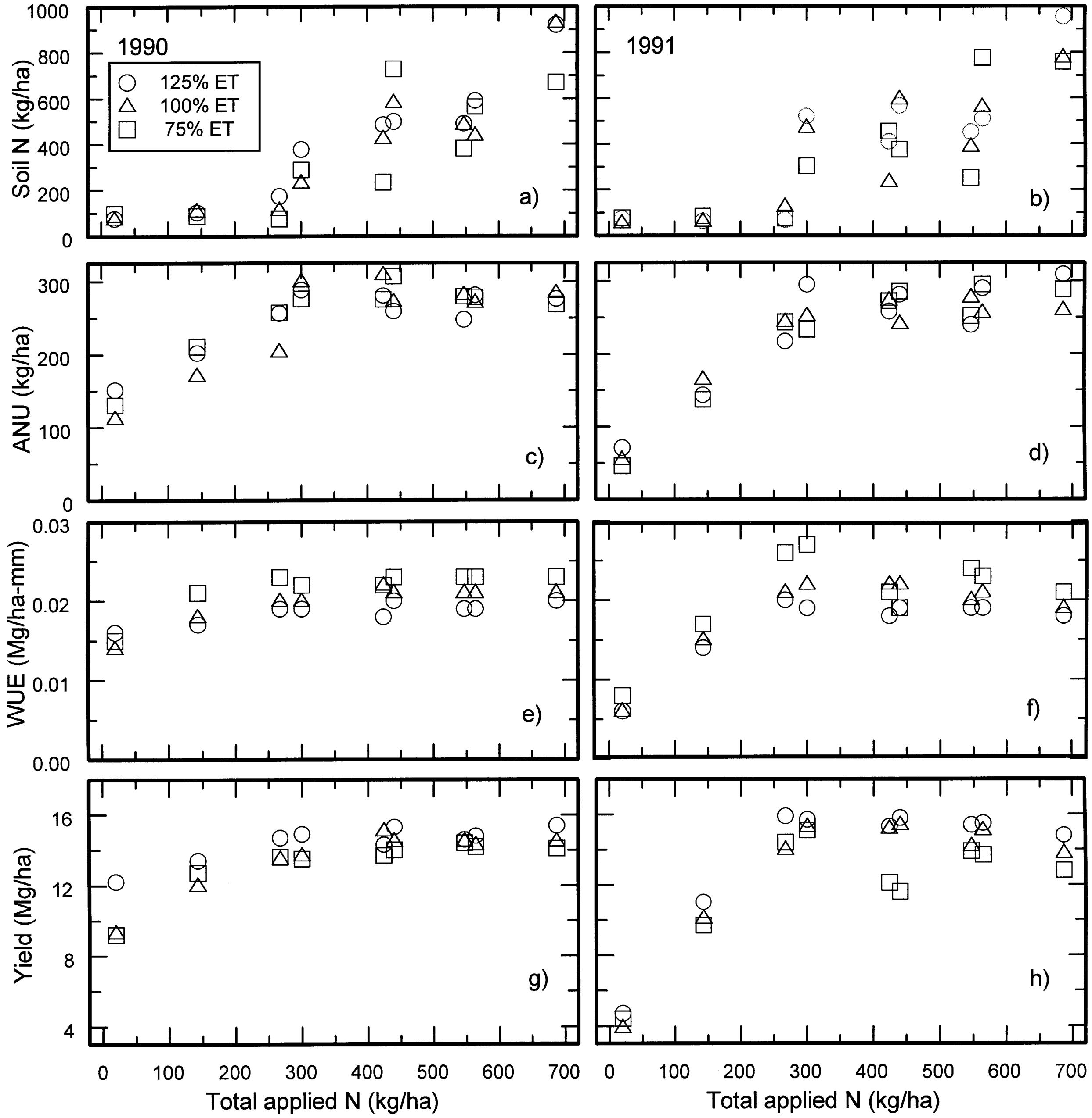

Figure 2. Corn grain yield, water use efficiency (WUE), apparent nitrogen uptake (ANU) and Soil N in the 2.4 m soil profile as affected by irrigation regime and total applied N in 1990–1991.

Water Use

Water use was increased (P = 0.05) by increased irrigation applications in both years (tables 2 and 3). This was not surprising because differences of approximately 260 mm in seasonal irrigation amounts occurred between the 75% and 125% of ET_c irrigation regimes. Deep percolation was not measured in this study, but in an nearby study conducted in the same years, Lamm et al. (1995) estimated the mean deep percolation to be 19, 47, and 117 mm for similar irrigation regimes, 0.75 ET_c, 1.00 ET_c, and 1.25 ET_c, respectively.

Water use also was increased (P = 0.05) in 1991 and for the two–year average by injection of N fertilizer with the SDI system. The additional in–season fertigation allowed for healthier and more vigorous plants that were better able to utilize soil water.

Water Use Efficiency

In both years, water use efficiency (crop yield in Mg/ha divided by unit depth of applied water in mm) was affected significantly by irrigation regime and total applied N (tables 2 and 3 and fig. 2). Higher water use efficiencies were obtained until the total applied N was approximately 260 kg/ha, indicating that to obtain high water use efficiency, adequate N must be available for crop production. Increased irrigation tended to decrease water use efficiency, especially for the high 1.25 ET_c treatment where some drainage likely occurred.

Apparent Nitrogen Uptake

Apparent nitrogen uptake (ANU), the amount of N in the above–ground crop, was not affected (P = 0.05) by irrigation regime in any year (tables 2 and 3). This suggests that the irrigation regimes of 75% to 125% of ET_c were sufficient to allow adequate N uptake by corn on this soil type in this climate.

ANU was affected significantly by both injected and preplant–applied N. It increased to approximately 260 kg N/ha, which coincided with a total applied N of approximately 260 kg N/ha (tables 2 and 3 and fig. 2). The method of N application did not appear to affect ANU. Some N uptake occurred from the residual ammonium–N and nitrate–N amounts left in the soil after harvest as well as from the release of N from the organic matter, as shown by some of the corn yields from the nonfertilized plots in 1990. However, ANU was linearly related to the total applied N up to the 260 kg N/ha approximate upper limit in both years (fig. 2). Nearly half of this uptake was in the stover portion of the whole plant for the fully irrigated and fully fertilized treatments (data not shown).

Soil Profile Nitrogen Amounts

At the beginning of the study, measured amounts of ammonium– and nitrate–N at various depths of the soil profile (0 to 2.4 m) were uniform throughout the field (table 2) as a result of uniform previous cropping of the site. In general, the initial N amounts were relatively high, ranging from 212 to 316 kg N/ha, with nearly all of the nitrate–N in the upper 0.6 m. (table 2 and fig. 3).

When the total ammonium–N and nitrate–N were measured again after the 1990 harvest, residual soil N amounts were much lower than they were at planting in the treatments receiving only preplant–applied N (table 2). Most of the residual nitrate–N was within the upper 0.3 m of the soil profile for the treatments receiving only preplant–applied N and was not significantly affected by irrigation treatment. (tables 2 and 3 and fig. 4). In contrast, when N was injected using the SDI system, considerable amounts of N remained throughout the soil profile following corn harvest, even when only 280 kg N/ha was applied (fig. 4). In general,

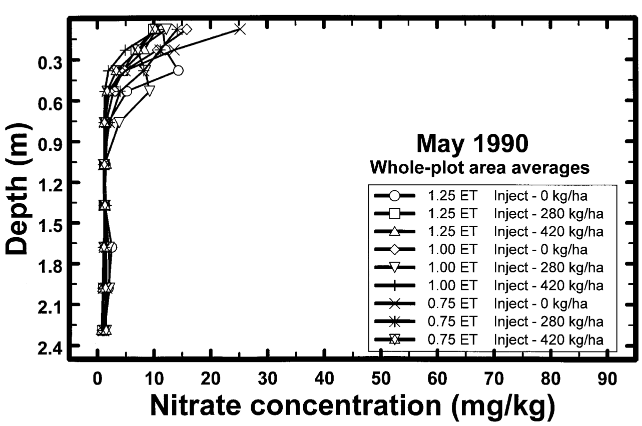

Figure 3. Profile of the soil nitrate concentrations for the whole–plot treatments at the initiation of the study, May 1990.

nitrate–N concentrations increased with increasing rates of total applied N and migrated deeper into the soil profile with increased irrigation. Similar results were obtained in 1991, but nitrate–N concentrations continued to increase and migrate deeper when N was injected with the SDI system (tables 2 and 3 and fig. 5). Elevated nitrate–N concentrations above pre–study conditions were found as deep as 1.2, 1.8, and 2.4 m for the respective 0.75 ET_c, 1.00 ET_c, and 1.25 ET_c treatments by October 1991.

No significant differences in the amounts of total ammonium–N and nitrate–N in the 2.4 m soil profile occurred among irrigation regimes at any sampling date (tables 2 and 3). Although this fact suggests nitrate–N leaching losses may have been small or negligible for all irrigation regimes during this 2–year period, the deeper migration for the heaviest 1.25 ET_c treatment suggests that nitrate–N leaching losses would occur if overirrigation was continued.

Significant differences in the amounts of total ammonium–N and nitrate–N in the 2.4 m soil profile after harvest did occur with injected N in both years and with the preplant–applied N in 1991. This would be expected. Higher rates of applied N resulted in more residual N in the soil profile after harvest, especially when applied N grossly exceeded ANU.

The lateral location of the soil N measurements with respect to the N application points might have influenced the results presented in table 2 and figures 4 and 5. Labor and economic considerations did not allow additional lateral sampling near the dripline and in the furrow. However, vertical sampling in the corn row was equidistant from the injected–N application point (dripline) and the preplant–N application point (30 cm band centered in furrow). Irrigation applied through the SDI system may have continually pushed a portion of the preplant–applied N to the edges of the wetted zone around the dripline, but this redistribution evidently did not seriously affect yield or nutrient uptake. Additionally, a portion of the preplant–applied N may have volatilized over the summer or may have been positionally unavailable to the corn roots due to the dry soil conditions in the furrow. Some volatilization losses for the preplant–applied N would be indicated by the contrasting increased residual N amounts for the injected–N treatments.

In contrast, N injected with the SDI system would move outward with the water and would be expected to migrate more in the downward direction in this nonlayered soil. Some of the injected N may have also become positionally unavailable since corn roots are most heavily concentrated in the upper soil layers. Although both fertilization methods have limitations, each method works reasonably well in this semi–arid region where the summer dominant pattern of precipitation generally allows adequate N redistribution and root growth. Further study is needed to determine if smaller amounts of injected–N could maintain high crop yields with greater N fertilizer efficiency since residual soil nitrate–N increased using this application method. The consistent year–to–year patterns of nitrate–N redistribution suggests that N applied with an SDI system at a depth of 40–45 cm was different from surface–applied preplant N banded in the furrow.

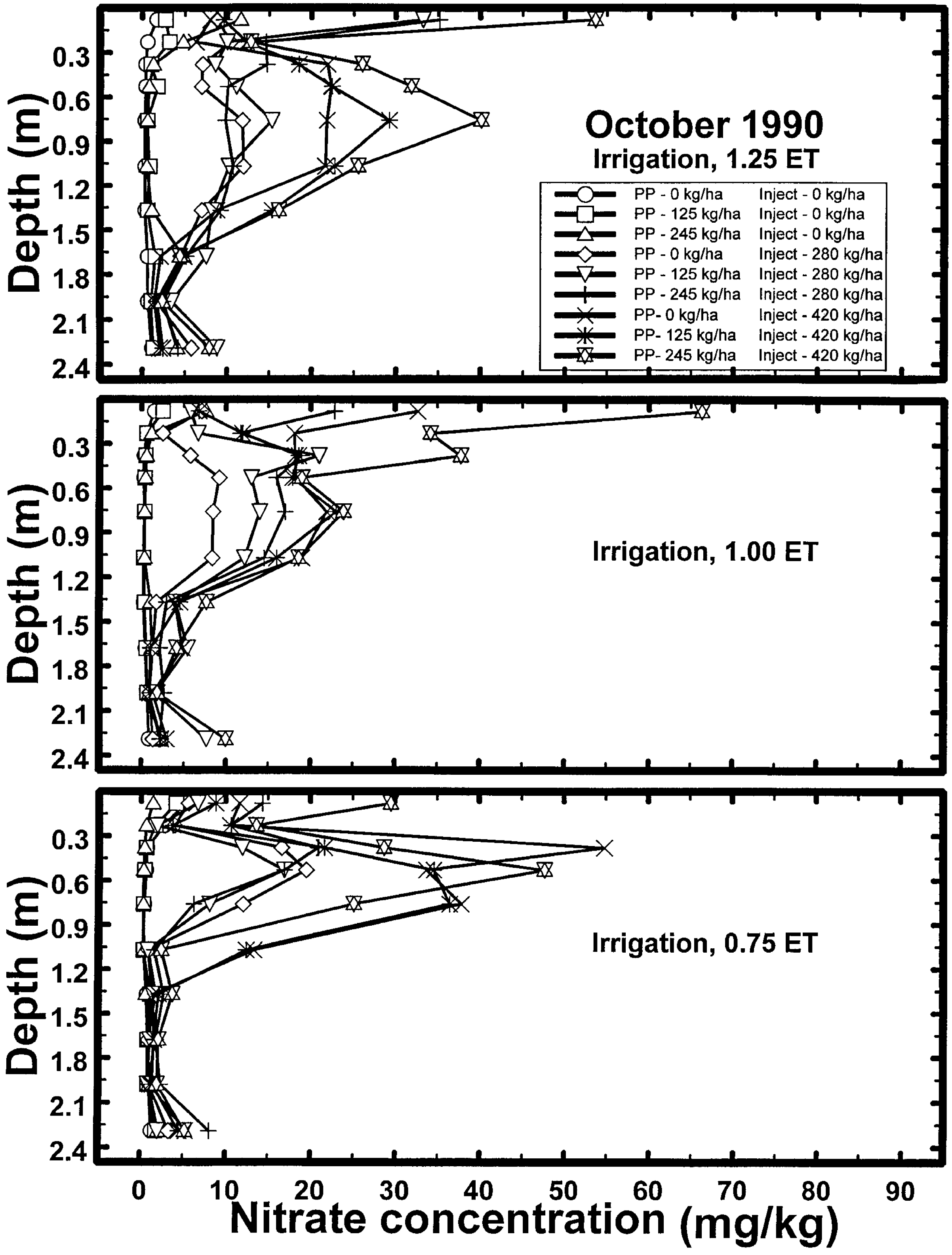

Figure 4. Profile of the soil nitrate concentrations for the three irrigation regimes and the nominal fertilizer treatments after one season, October 1990.

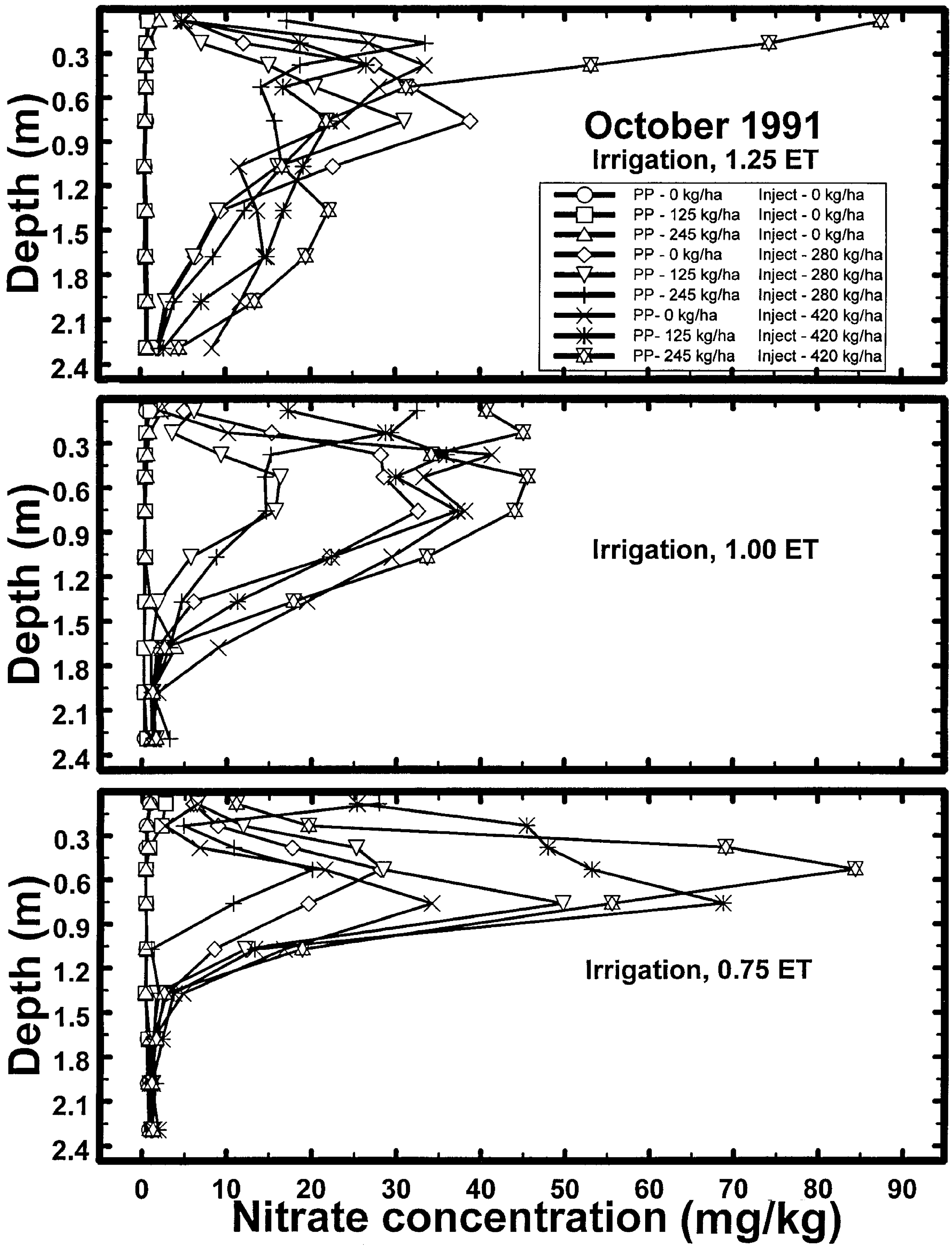

Figure 5. Profile of the soil nitrate concentrations for the three irrigation regimes and the nominal fertilizer treatments after two seasons, October 1991.

Some of the N amounts used in this study were much in excess of those required for top corn yields. However, their inclusion in this preliminary study and the results obtained help to frame the need for additional research with injected N for subsurface drip–irrigated corn. Further work should be conducted to determine the optimum injected–N amounts and procedures for subsurface drip–irrigated corn, given that residual soil N or starter N applications are sufficient to maintain a healthy crop until the first irrigation.

CONCLUSIONS

Corn yields were very high, exceeding 15 Mg/ha for selected treatments as long as irrigation and fertilization were sufficient. Yields plateaued for fully irrigated treatments when the total applied N from all sources reached 260 kg/ha. Irrigating to replace only 0.75 ET_c resulted in yield reductions, which were worsened when N fertilization was reduced to 125 kg/ha. There was no statistically significant increase in yields attributable to the fertilization method (injected–N with the SDI system or surface–applied preplant N banded in the furrow).

The ANU or the total amount of N accounted for in the whole plant (above ground) at physiological maturity plateaued at approximately 260 kg N /ha when the total applied N amount reached approximately 260 kg N/ha.

Water use efficiencies were increased by increased fertilization up to approximately 260 kg N/ha and were also increased by decreased irrigation.

In both years, nearly all of the residual nitrate–N measured after corn harvest was located in the upper 0.3 m of the soil profile for the treatments receiving only preplant–applied N, regardless of irrigation regime. In contrast, residual nitrate–N concentrations increased with increasing rates of N injected by the SDI system and migrated deeper in the soil profile with increased irrigation.

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