The effects of subsurface drip and furrow irrigation on the movement of salts and nitrate in the root zone

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ABSTRACT

Water quality issues coupled with diminishing water supplies have led to increased acreage in drip irrigation in the Arkansas River Valley (Ark Valley) of southeastern Colorado. A field experiment was conducted at the Arkansas Valley Research Center (AVRC) in 2005 to determine the effects of irrigation type and scheduling and fertilizer rate on corn yield and salt and nitrate-nitrogen (NO_3-N) concentration in the root zone. Four N fertilizer rates (0, 60, 120, and 180 lb N/acre) and four manure rates (0, 10, 20, and 30 t/acre) were tested under subsurface drip irrigation (SDI) and furrow irrigation (FrI) with full (FI) and deficit (DI) irrigation regimes. The results show no significant difference in corn yield between SDI and FrI, even though nearly twice as much water was applied with FrI than with SDI. Deficit irrigation decreased corn yield by 20 bu/acre on average. Corn yield generally increased with increasing N fertilizer rate, reaching a high of 233 bu/acre with FI and 180 lb N/acre. Corn produced the lowest yield with 30 tons of manure/acre under DI or SDI, similar to the no N fertilizer treatment. The high manure application rates increased soil salinity early in the season, which may have contributed to the lower corn population, compared to the non-manure treatments. After corn harvest, the difference in soil salinity between the manure (20 t/acre) and non-manure (120 lb N/acre) treatments was negligible. Subsurface drip irrigation had higher ECe in the furrow compared to FrI, which had higher ECe in the middle of the bed. There appeared to be salt build-up at the 4- to 6-ft depth under SDI compared to FrI, possibly due to leaching of salts with FrI. Soil NO_3-N concentration was higher under SDI than under FrI, but the difference was only significant in the top foot. There was much more NO_3-N in the top 4 ft. of soil in the spring of 2006, prior to fertilizer application, than in the fall of 2005; with no significant difference between FrI and SDI. The high manure-rate treatments had significantly more residual NO_3-N than the other treatments. More results will be available in 2006.

INTRODUCTION

Gates et al. (2006) reported moderate to high salt concentrations in the waters and soils of the Ark Valley. Average soil ECe values ranged from 3.3 to 6.5 dS/m in 1999 to 2005. Irrigation contributes approximately 14% of the total salt load in the Ark Valley (Miles, 1977). As water moves across the field or through the soil, it dissolves salts and other pollutants. Excess water flows back to the river or augments the water table, thus increasing soil salinity through re-use and evapotranspiration. Substantial reductions in salt dissolution and transport can be achieved by improving irrigation efficiency and reducing canal seepage (Gates et al., 2006).

High NO_3-N concentrations have also been reported in the Ark Valley (Yergert et al., 1997). Research indicates that corn N fertilizer rate can be reduced substantially, particularly after vegetable crops, while maintaining optimum yield (Halvorson et al., 2002 and 2005). Leaching of NO_3-N below the root zone is exacerbated by inefficient irrigation since most cropland in the Ark Valley is furrow-irrigated. Over-application of manure can also lead to NO_3-N leaching and possibly salt build-up.

Water quality issues, coupled with recent droughts and diminishing water supplies have led to renewed interest in drip irrigation, which is used mostly for high-value crops such as onions, cantaloupes, and watermelons. Research elsewhere has shown the feasibility of subsurface drip irrigation (SDI) for corn and other field crops (Lamm et al., 1995). A well designed and managed SDI system can save water by eliminating runoff and minimizing evaporation and deep percolation. It also has the potential to reduce the leaching of salts and NO_3-N, but little is known about their movement under drip irrigation in the Ark Valley.

The objective of this research was to determine the effects of irrigation type and scheduling, and N fertilizer and manure rates on corn yield, N uptake, and on salt and NO_3-N concentration in the root zone.

MATERIALS AND METHODS

A field experiment was conducted in 2005 and 2006 at AVRC near Rocky Ford, CO to accomplish the objective stated above. Only the 2005 results are included in this paper. The soil at the study site is Rocky Ford silty clay (fine-silty, mixed, calcareous, mesic Ustic Torriorthents). Prior to fertilizer (manure) application, the soil had a pH of 8.1, 1.5% O.M. and 153 lb NO_3-N/acre in the 0- to 6-ft. depth. The plot area was in soybeans in 2004 and on 27 April 2005 it was planted to corn hybrid Asgrow RX752RR/YG at 33,723 seeds/acre in 30-in. rows. The recommended N fertilizer rate was 120 lb N/acre or 10 tons of manure/acre based on a 250 bu/acre yield goal.

Irrigation treatments consisted of Furrow (FrI) and subsurface drip irrigation (SDI) applied to achieve a full (FI) or deficit (DI) irrigation regimes. Corn was irrigated 11 times in FI and eight times in DI (Fig. 1). Water was withheld from DI at approximately the 10-leaf, silk, and milk growth stages. All the plots were furrow-irrigated on 5 May and on 16 May 2005 to ensure adequate corn germination and emergence. Drip tapes of 0.875-in. diameter and 0.45 gpm/100 ft. flow rate were used in SDI. They were buried 8 in. below ground and spaced 60 in. apart. Water was pumped from the Rocky Ford Canal and filtered before it reached the drip tapes. In FrI, water from the irrigation ditch was delivered to every other furrow with siphons.

The fertilizer treatments consisted of two checks (0NP: no N or P added and 0N: 46 lb P_2O_5/acre and no N added), 60 lb N/acre (60N), 120 lb N/acre (120N), 180 lb/acre (180N), 10 t manure/acre (10T), 20 t manure/acre (20T), and 30 t manure/acre (30T). Treatments 60N, 120N, and 180N received the same amount of P_2O_5/acre as 0N. A polycoated urea with a release time of 30 days was used as the N source. Phosphorus source was 0-46-0. Nitrogen and P fertilizers were broadcast on 10 March 2005 with a hand spreader. Feedlot beef manure was applied on 18 March 2005 with a Hesston S260 manure spreader. It had 41% moisture, 1.78% total N, 1.43% Organic C, 0.35% NH_4-N, 0.001% NO_3-N, 0.4% P, a C/N ratio of 13, and a pH of 7.6. The whole plot area was disked shortly after manure application.

The experiment was designed as a randomized complete block, split-split plot with four replications. Irrigation type was assigned to the main plots, irrigation scheduling to the split plots, and fertilizer treatments to the split-split plots. Split-split plot size was 20 ft. (8 corn rows) by 60 ft. Rows 3 and 6 were used for biomass sampling (data not shown) and rows 4 and 5 for grain harvest. Corn was harvested on 18 Oct. 2005. Hot and dry conditions in July led to a somewhat severe spider mite infestation which was partially controlled with Dimethoate at 14.5 oz/acre.

Soil water status was monitored weekly with WaterMark® sensors in 120N under furrow and drip irrigation (Full and Deficit Irrigation). They were placed within 6 in. of the corn row at 1- and 3-ft soil depths. Soil samples were taken in selected treatments in March and November 2005 in FI and analyzed for NO_3-N. Other soil samples were taken in June and October 2005 in 120N and 20T of FI to assess soil salinity with the electrical conductivity (EC) method (Rhoades, 1996). An excellent correlation was found between 1:1 (soil-to-water ratio, by weight) EC and saturated-paste extract EC or ECe (data not shown). Data was analyzed using the PROC MIXED procedure (SAS 9.1 Software, 2002-2003). Grain yield was adjusted to 15.5% moisture and 56 lb/bu.

RESULTS AND DISCUSSION

Water Management:

A total of 47 in. of water was applied with FrI-FI and 33 in. with FrI-DI (Fig. 1). By comparison, only 26 in. and 19 in. were applied with SDI-FI and SDI-DI, respectively. The SDI totals include the first two furrow irrigation application amounts. Achieving adequate seed germination and plant emergence with SDI is a concern in this dry environment, unless drip tapes are placed close enough to the soil surface and to each other, which is usually the case in vegetable production systems. Another concern is salinity, thus most growers in the Ark Valley who use drip irrigation also have the option to flood or furrow-irrigate their fields to flush out the excess salts.

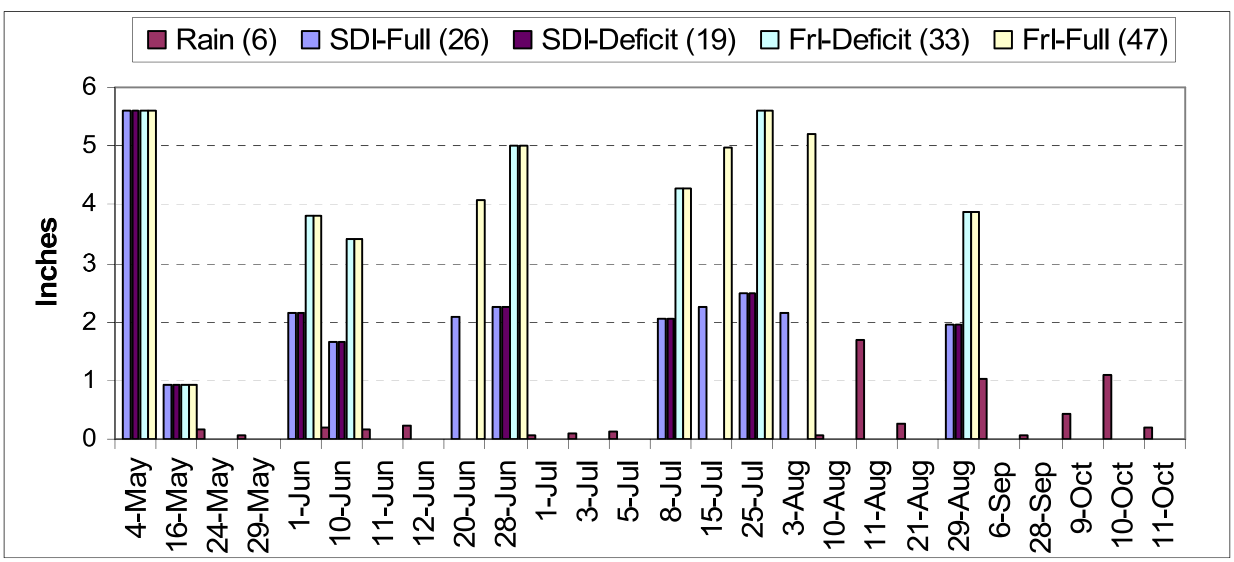

Figure 1. Rain and irrigation amounts during the 2005 corn season. Numbers in parenthesis are total gross amounts in inches.

Irrigation efficiency was estimated at less than 50% with FrI and at least 90% with SDI. There was very little rainfall except on 11 Aug. and 6 Sept. when 1.7 and 1.0 in. of rain, respectively were recorded (Fig. 1). WaterMark sensor readings indicate adequate irrigation scheduling, particularly with SDI (Fig. 2 to 5). Deficit irrigation was imposed once during the vegetative growth stage and twice during the reproductive growth stage. A more targeted deficit irrigation approach was adopted in 2006.

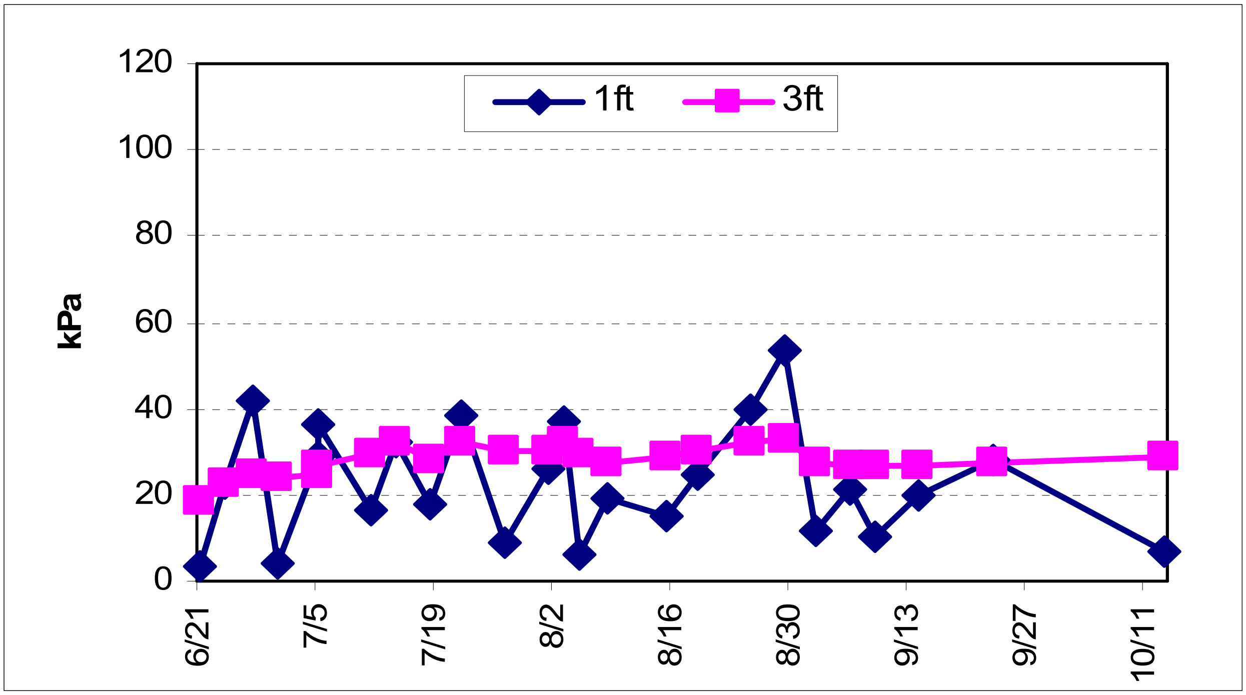

Figure 2. 2005 WaterMark sensor readings (kPa) at 1- and 3-ft depths in SDI_FI.

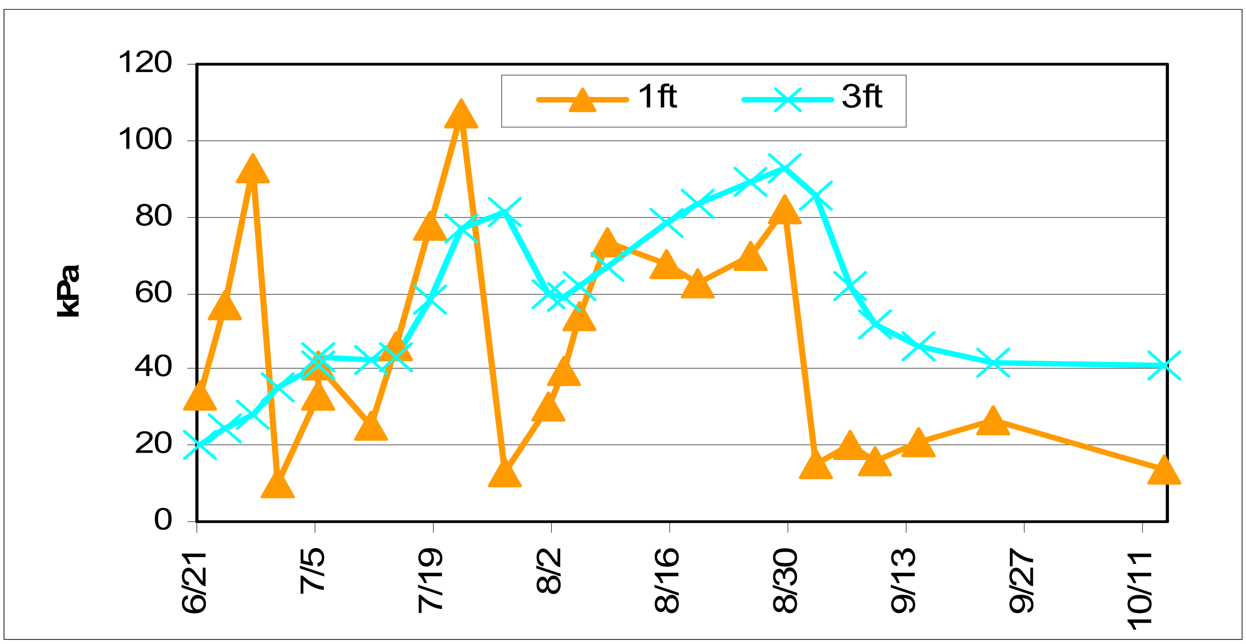

Figure 3. 2005 WaterMark sensor readings (kPa) at 1- and 3-ft depths in SDI_DI.

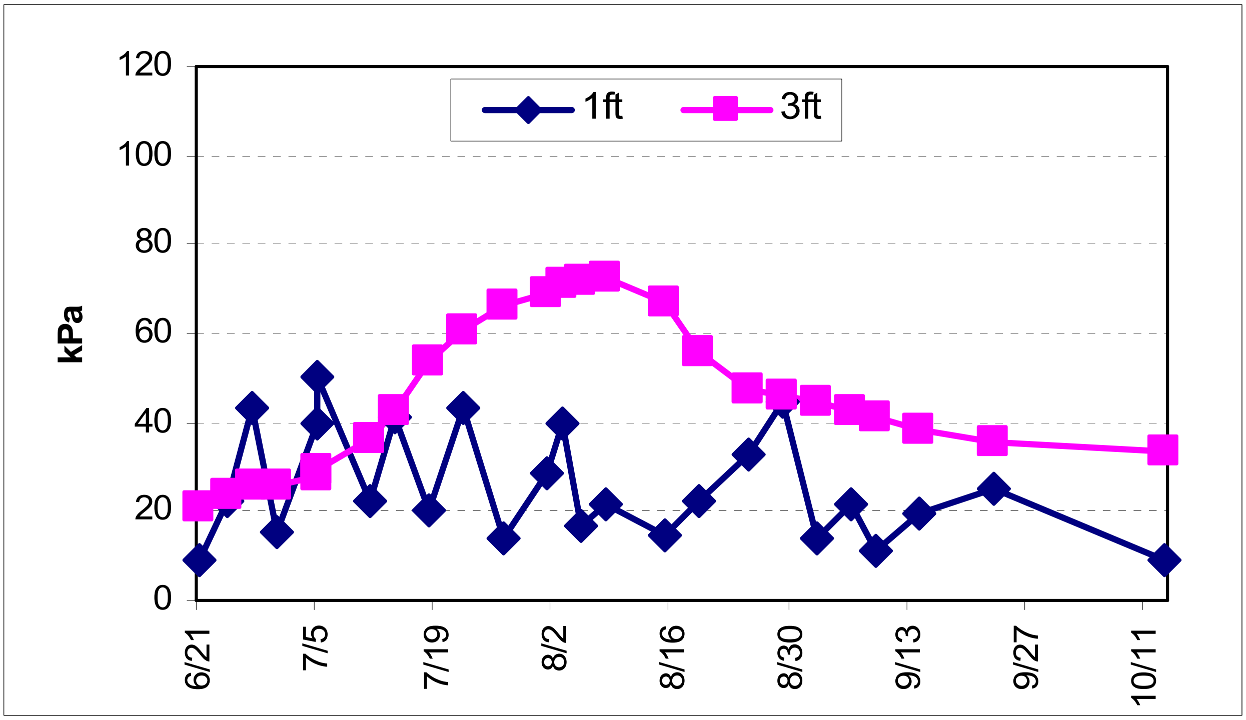

Figure 4. 2005 WaterMark sensor readings (kPa) at 1- and 3-ft depths in FrI_FI.

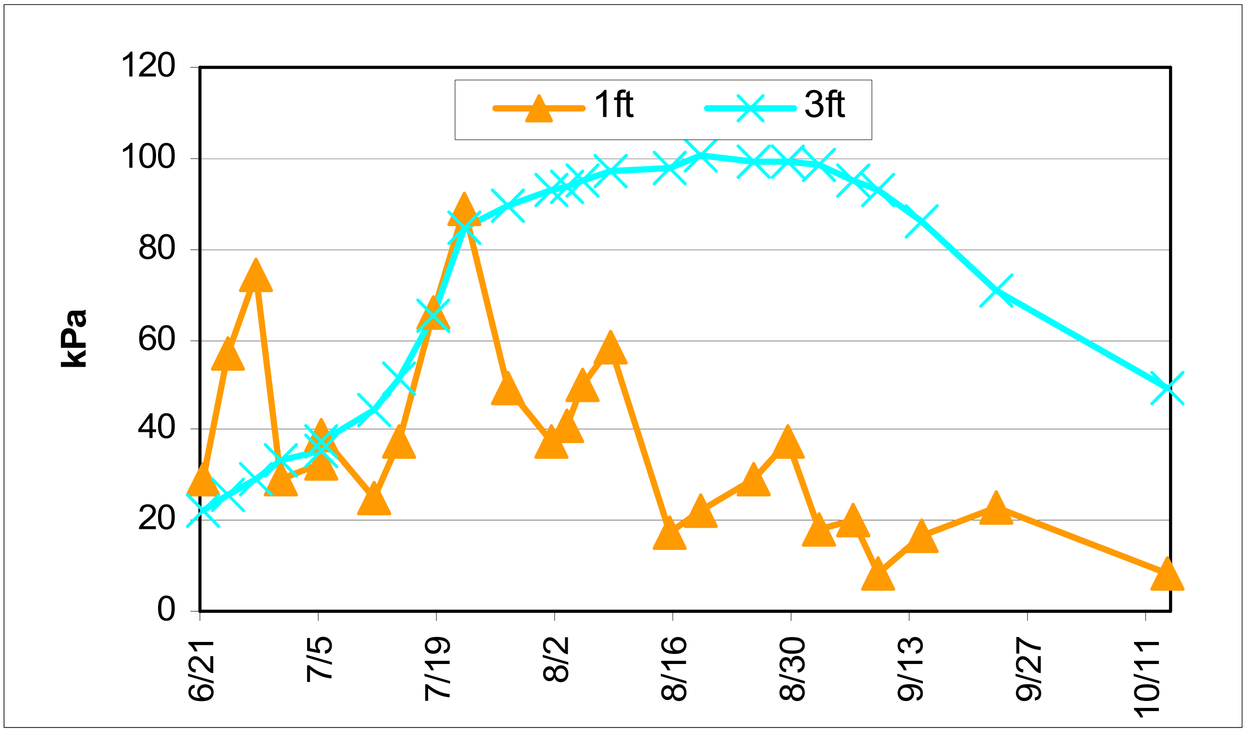

Figure 5. 2005 WaterMark sensor readings (kPa) at 1- and 3-ft depths in FrI_DI

Corn Yield:

Corn yields averaged 197 bu/acre across all treatments. Irrigation scheduling (P=0.001), fertilizer rate (P <0.0001), irrigation type by fertilizer rate (P=0.018), and irrigation scheduling by fertilizer rate (P=0.109) all had a significant effect on corn yield. There was no significant difference in corn yield between SDI and FrI, even though much more water was applied with FrI than with SDI.

Corn yield increased significantly with 60 lb N/acre with SDI and up to 120 lb N/acre with FrI (Fig. 6). Corn also responded positively to 10 tons of manure/acre (10T=20T=30T>0NP) with FrI, whereas corn yield of SDI dropped sharply at 30T (Fig. 7). It was unclear at this writing why 0N and 0NP had such relatively high yields with SDI, as opposed to FrI (Fig. 6 & 7). Halvorson et al. (2006) also found higher onion yields with SDI than with FrI with no N applied.

The highest corn yield of 233 bu/acre was obtained with FI and 180 lb N/acre. The response was linear, indicating that a higher N rate may have been required to achieve maximum yield with FI (Fig. 8). Corn yield leveled off at or below 120 lb N/acre with DI. There was no significant response to manure application with FI, whereas corn maxed out at 196 bu/acre with DI and 20T, then dropped to 175 bu/acre with 30T (Fig. 9).

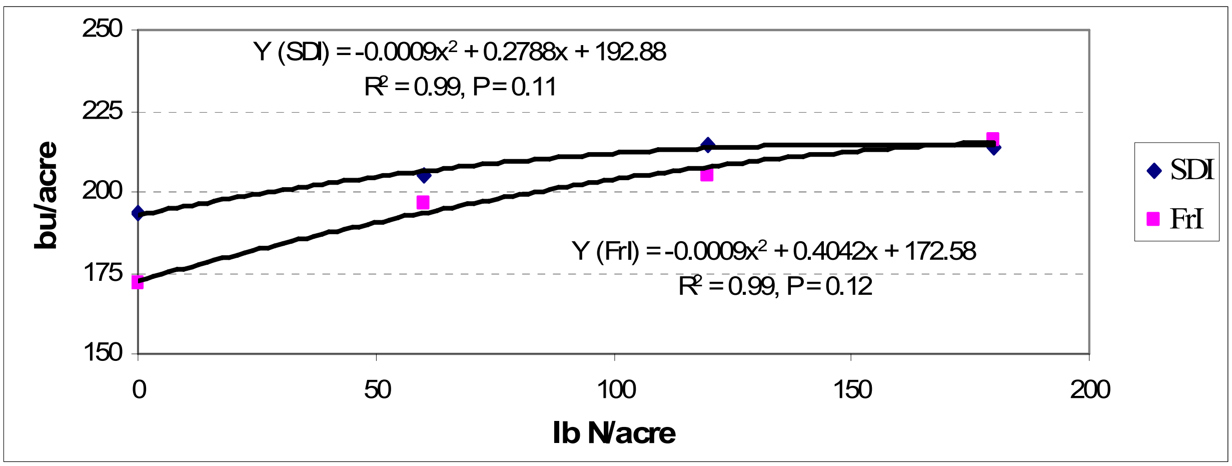

Figure 6. 2005 corn yield of SDI and FrI as a function of N fertilizer rate.

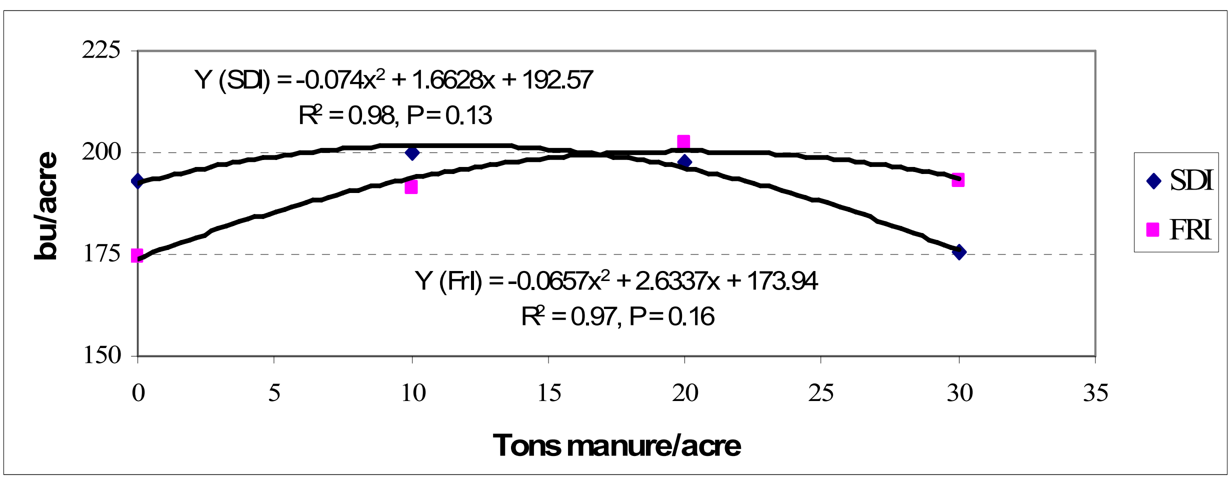

Figure 7. 2005 corn yield of SDI and FrI as a function of manure rate.

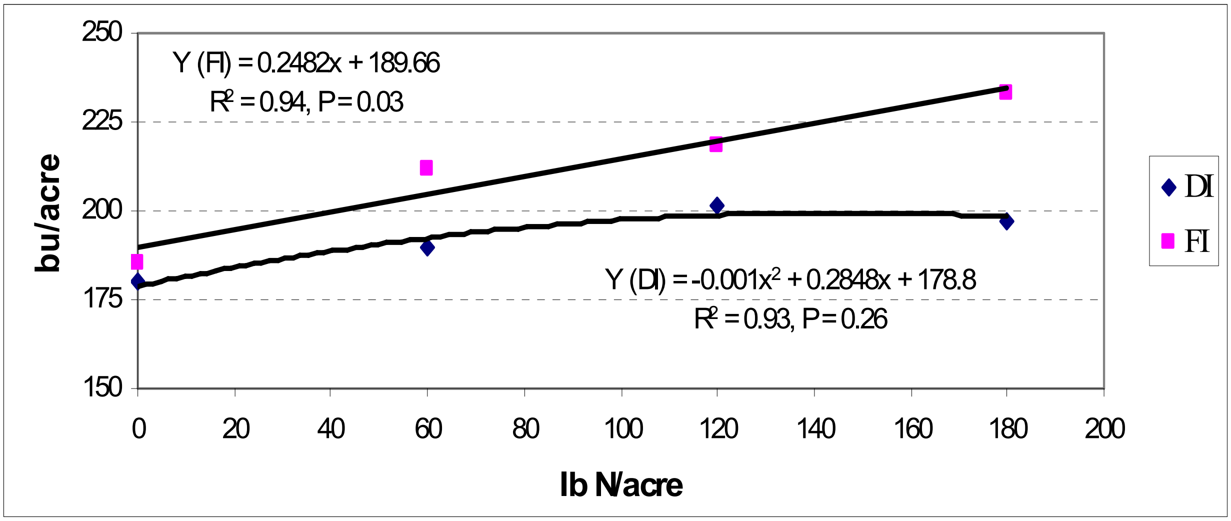

Figure 8. 2005 corn yield of FI and DI as a function of N fertilizer rate.

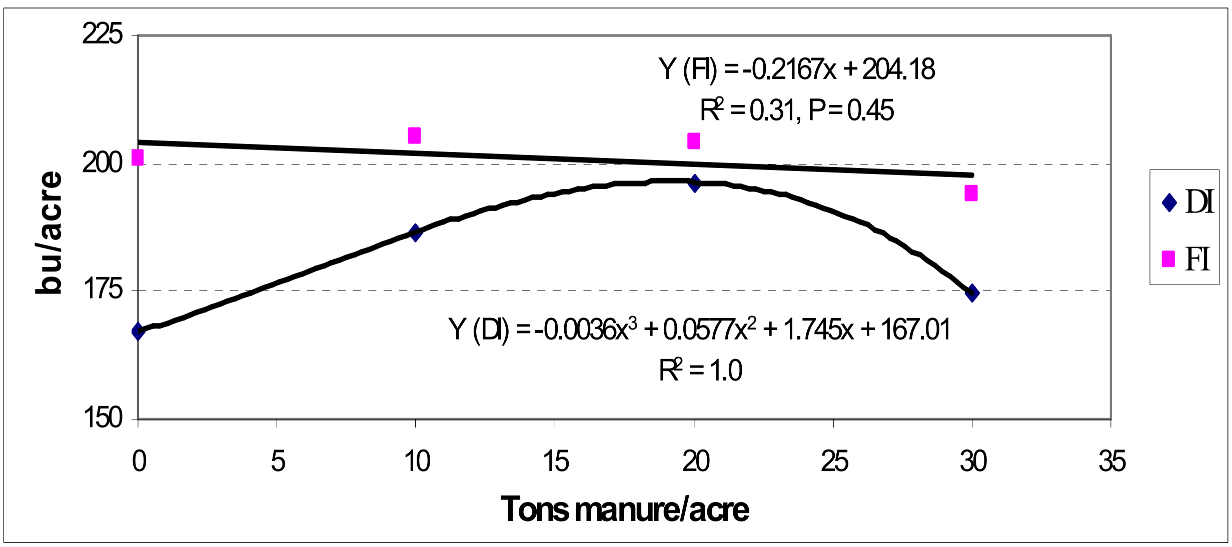

Figure 9. 2005 corn yield of FI and DI as a function of manure rate.

Corn N uptake was significantly higher in 20T and 30T manure treatments than in the other treatments, probably due to more available N at the high manure rates (Table 1).

Table 1. Corn grain N uptake in 2005 at AVRC as affected by N or manure rate.

Treatment	Checks	N treatments	10T	20T & 30T
lb N/bu	0.74c*	0.77b	0.78b	0.82a

*Values followed by a different letter are significantly different at P=0.05

Plant population at harvest:

The generally lower corn yields with manure, particularly at the highest rate of 30 t/a, could be attributed in part to low plant population (Fig. 10). Harvest plant population was significantly lower at 20T and 30T than at the other treatments, with either FrI or SDI; even though the whole experiment was furrow-irrigated at the start of the season to ensure adequate corn seed germination. There were skips in the corn rows of the manure treatments and some of the seedlings were clearly stressed and eventually died. Figure 11 shows that water in 30T did not move as much laterally as it did in the non-manure treatments, particularly with SDI. Most of the manure was located near the soil surface since the field was not moldboard plowed after manure application, hence, more water may have been required to imbibe the seedbed due to high organic matter content, compared to the non-manure treatments.

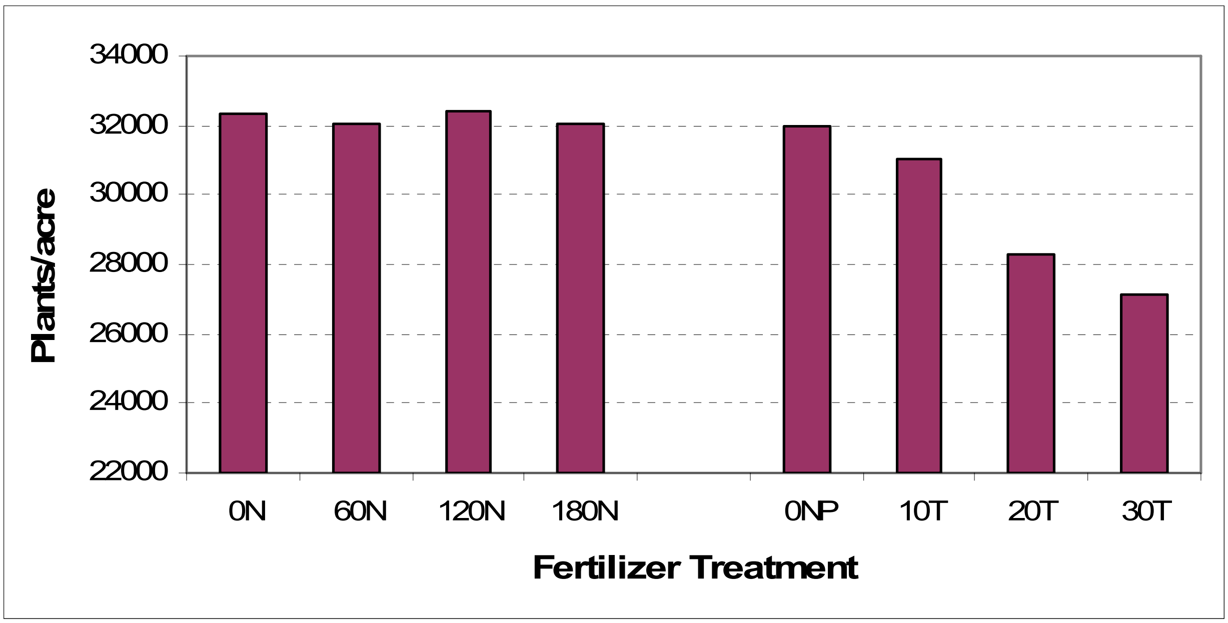

Figure 10. Harvest corn plant population in 2005 at AVRC as affected by N or manure rate.

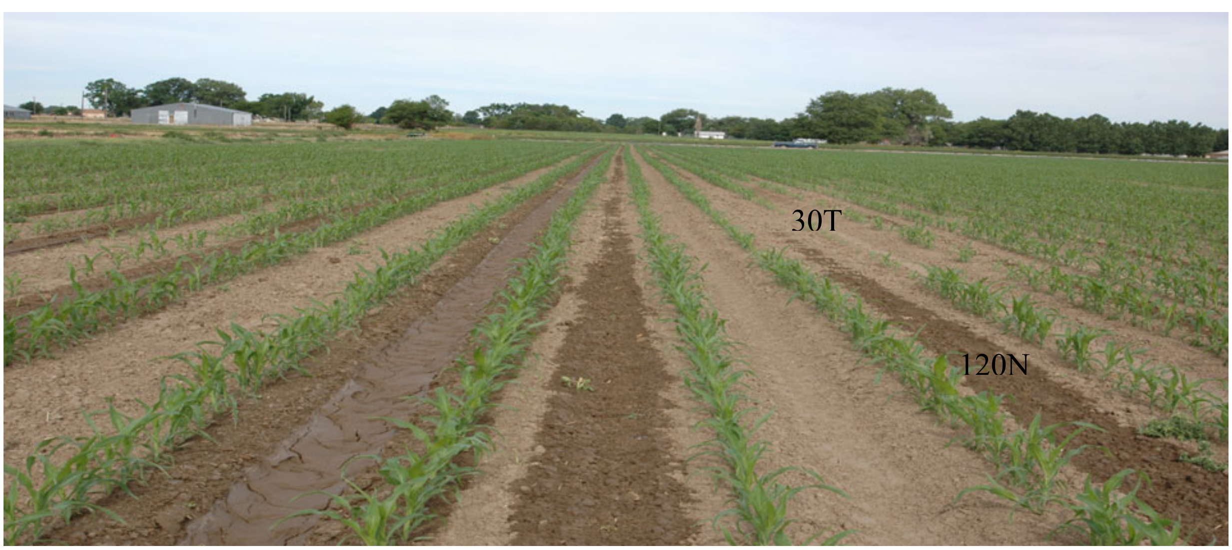

Figure 11. Early-season corn stand shortly after an irrigation event.

Soil salinity:

Soil ECe was substantially higher in 20T (and by inference 30T) than in 120N early in the season, particularly with SDI (Fig. 12), which may have adversely affected corn population and yield. ECe values were much lower after corn harvest, which would indicate a downward movement of salts in the soil profile, due to rain and irrigation (Table 2). Furthermore there was no significant difference between 20T and 120N (data not shown), whereas ECe varied with irrigation type and sampling depth and position on the bed. ECe generally increased with depth, with the exception of FrI in the middle of the bed (Table 2). Subsurface drip irrigation had higher ECe than FrI in the furrow and to lesser extend the corn row, while FrI had higher ECe in the middle of the bed, although the relative ranking varied with depth. On average, SDI had significantly higher ECe than FrI at the 4- to 6-ft. depth, which could be due to leaching of salts with FrI.

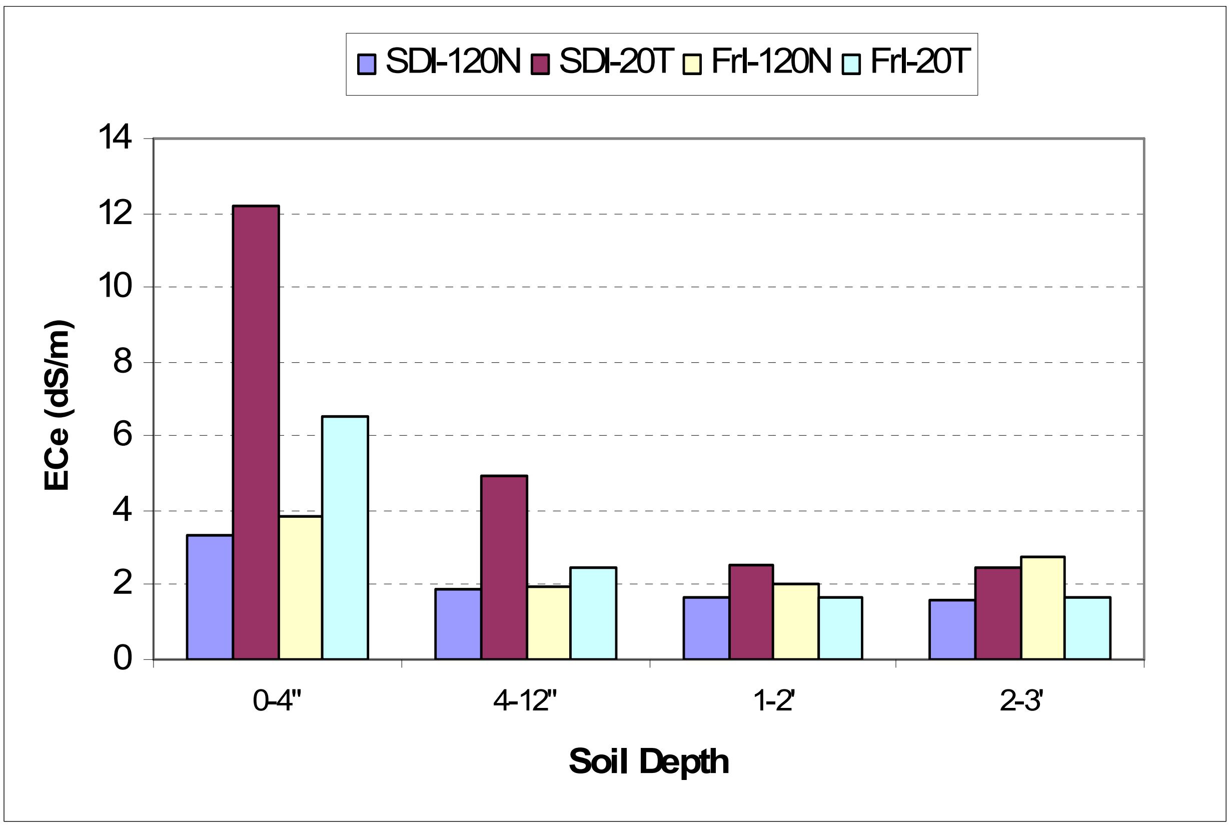

Figure 12. June 2005 ECe under SDI and FrI in 120N and 20T.

Table 2. Post-harvest soil ECe (dS/m) under SDI and FrI as affected by sampling depth and position.

Soil Depth	SDI			FrI		
	Furrow	Row	Bed Center	Furrow	Row	Bed Center
	ECe (dS/m)					
0-6”	2.59	1.53	1.95	1.38	2.01	4.25
6-12”	2.01	1.49	1.28	1.61	1.28	2.62
1-2’	2.06	2.38	1.12	2.02	1.49	1.83
2-3’	2.46	2.94	1.28	2.03	1.91	1.52
3-4’	2.65	2.85	1.95	2.30	2.23	1.65
4-5’	3.32	3.63	3.26	2.76	2.85	2.09
5-6’	3.35	3.72	3.49	2.58	2.94	2.01

Soil NO_3-N concentration:

Post-harvest soil NO_3-N concentration was significantly higher in 20T, 30T, and 180N than in 0N at the 0- to 1-ft and 0- to 3-ft depths (Table 3). There was also substantially more NO_3-N under SDI than under FrI, similar to that reported by Halvorson et al. (2006); however the difference was only significant in the top foot (P=0.1). There was no significant difference in soil NO_3-N concentration between FrI and SDI in the spring of 2006, prior to fertilizer (manure) application (Fig. 13). Nitrate-N soil concentration in 0- to 4-ft depth was much higher in the spring of 2006 than in the fall of 2005, in all the treatments (Fig. 14), possibly due to corn residue decomposition and mineralization of N. Treatments 30T and 20T had significantly more NO_3-N than 10T, 180N, 120N, and 60N, which in turn had more NO_3-N than 0N.

Table 3. Soil NO_3-N concentration after corn harvest in 2005.

Fertilizer	Soil depth/lb NO_3-N		
Treatment	0-1'	0-3'	0-6'
0N	13.5	24.4	113.1
60N	16.4	92.6	190.6
120N	37.0	61.3	248.9
180N	96.6	147.0	192.2
10T	56.7	85.5	225.2
20T	109.9	155.3	231.6
30T	124.0	168.7	228.4
Average	**64.9**	**105.0**	**204.3**
Pr>F	0.01	0.08	0.81
FrI	37.3	70.7	149.0
SDI	81.3	120.3	238.7
Pr>F	0.1	0.19	0.39

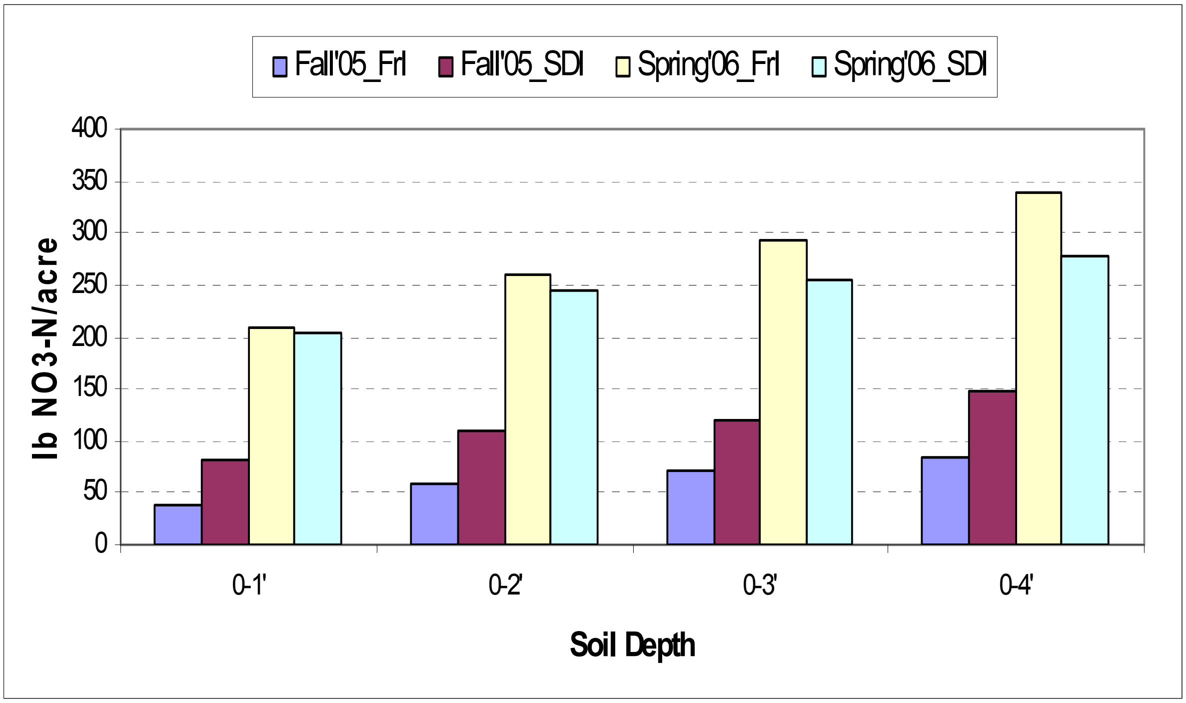

Figure 13. Soil NO_3-N concentration under SDI and FrI after corn harvest in the fall of 2005 and prior to fertilizer application in the spring of 2006.

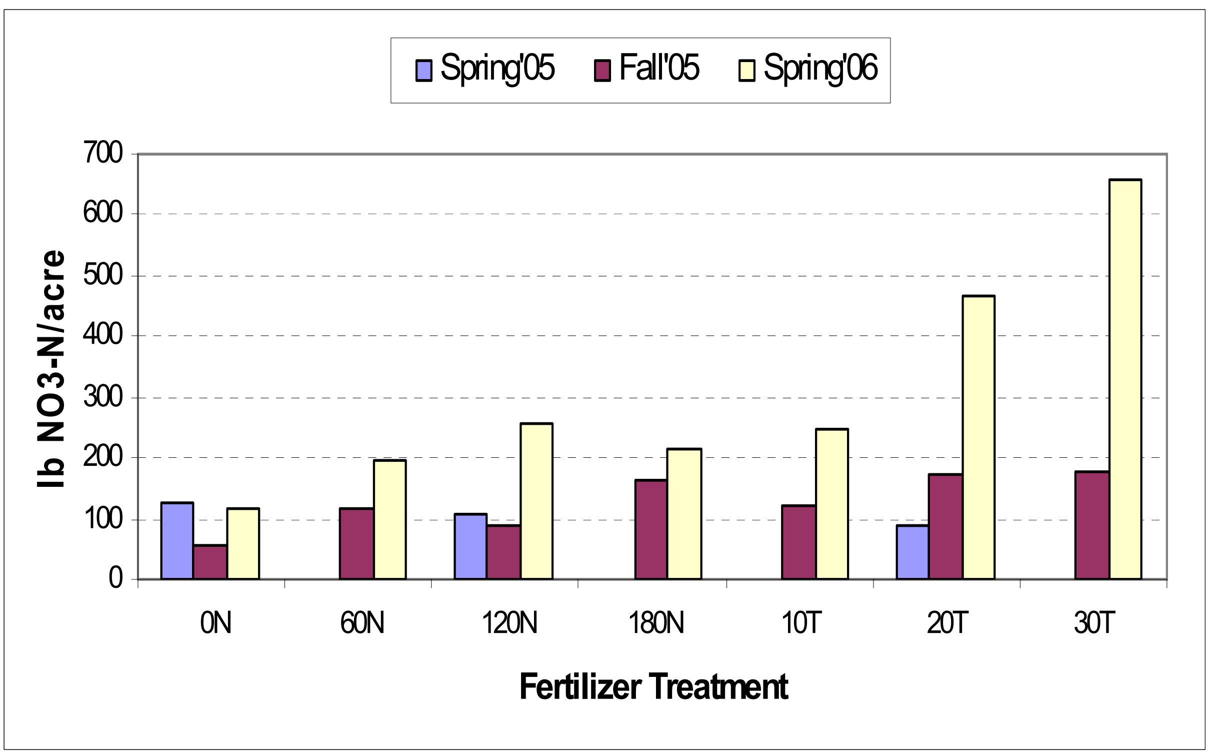

Figure 14. Soil NO_3-N concentration as influenced by N or manure application rate, in 0- to 4-ft depth after corn harvest in the fall of 2005 and prior to fertilizer application in the spring of 2005 and 2006.

PRELIMINARY CONCLUSIONS

There was no significant difference in corn yield between FrI and SDI even though nearly twice as much water was applied with FrI. Deficit irrigation decreased corn yield by an average of 20 bu/acre. Corn yield generally increased with increasing N fertilizer rates, but leveled off quicker with SDI or DI than with FI or FrI. The highest yield of 233 bu/acre was achieved with full irrigation and 180 lb N/acre. Manure at 30 t/acre depressed corn yield with either SDI or DI. Manure at 10 or 20 t/acre increased corn yield significantly with both irrigation types and scheduling regimes when compared to 0N, but only with FrI or DI when compared to 0NP. The relatively high corn yield of 0NP with FI or SDI could not be explained at this writing.

Corn population in 20T and 30T was significantly lower to that of the other treatments and may have been due in part to high salt concentration early in the season. The fact that manure was not plowed in after application in 2005 may explain the high ECe values at or near the seedbed in 20T, and by extension 30T. Manure was applied earlier (Nov.'05) in 2005-06 and plowed in; consequently corn population was more uniform in 2006 than in 2005, but it was still significantly lower in 30T than in the other treatments (data not shown). Similarly, ECe values were higher in 20T and 30T than in the other treatments (data not shown). After corn harvest in 2005, ECe values were not significantly different between 20T and 120N. There appeared to be salt build-up at the 4- to 6-ft depth with SDI, which was not the case with FrI, possibly due to leaching. Soil NO_3-N concentration was also higher under SDI than under FrI, but the difference was only significant in the top foot. There was much more NO_3-N in the top 4 ft. of soil in the spring of 2006, prior to fertilizer application, compared to the fall of 2005; probably due to corn residue decomposition and mineralization of N. Subsurface drip irrigation and FrI had similar soil NO_3-N concentrations in the spring of 2006, while the high manure-rate treatments had significantly more residual NO_3-N than the non-manure treatments. More results will be available after corn harvest in 2006.

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