NITRATE LEACHING CHARACTERISTICS FOR VARIOUS NITROGEN MANAGEMENT STRATEGIES ON IRRIGATED CORN

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Abstract

Efficient use of nitrogen (N) fertilizer for corn production is important for maximizing economic return to the producer and minimizing NO_3 leaching to groundwater. This is especially important on irrigated, sandy soils due to the high infiltration and saturated conductivity and potential risk to the local water supplies. This study is being conducted to quantify the NO_3 leaching potential in the irrigated sands along Kansas' waterways under current and alternative N and water management strategies for corn. Six fields were selected in 2001 along the Republican (1), Kansas (2), and Arkansas Rivers (3). Nitrogen was surface applied as NH_4NO_3 and treatments included 300 kg N ha^{-1} applied pre-plant; 250 kg N ha^{-1} applied pre-plant; 250 kg N ha^{-1} applied pre-plant and sidedress; 185 kg N ha^{-1} applied pre-plant and sidedress; 125 kg N ha^{-1} applied pre-plant and sidedress; and 0 kg N ha^{-1}. At one field site, the N treatments were duplicated for each of two irrigation treatments (optimal and 25% greater than optimal). Also at this site, porous-cup tensiometers and solution samplers were installed in each plot for the four highest N treatments. Grain yield and soil NO_3-N (before and after the growing season) to a depth of 240 cm were determined for all plots. Yield results from the first year indicate that 185 kg N ha^{-1} was sufficient to achieve maximum corn yield at every location. Water samples collected throughout the growing season indicated that, after July 15, concentration of NO_3-N in soil water at the 150-cm depth was 2-3 times greater with the single pre-plant N applications as compared to the split N applications. Post-harvest soil samples indicated that NO_3-N was leaching to below the 150-cm depth for the N treatments greater than 185 kg N ha^{-1} and for the higher irrigation treatment.

Introduction

The potential for NO_3 leaching is greatest when NO_3 concentration in the soil is high and water supply exceeds that needed for evaporation and transpiration, producing conditions for downward water movement. In recent years, research evidence has implicated irrigated agriculture as a contributor to the contamination of surface and groundwater through excessive inputs of both fertilizers and water (Ferguson et al., 1991; Schepers et al., 1991). Timing of N fertilizer application is central to minimizing N leaching, particularly on sandy-textured soils that are susceptible to rapid downward movement of water. When N fertilizer is applied prior to planting, the period prior to rapid plant growth (late April to late May) represents a period of high soil NO_3 concentration and high rainfall, so NO_3 leaching potential can be relatively great. Subsequent to early June, rapid plant growth results in greater root exploration, greater transpiration rates, less water movement down the soil profile, and diminished NO_3 leaching potential.

Recent reports by the Kansas Department of Agriculture (Emmons, 2000) and the United States Geological Survey (Pope et al., 2001) have identified groundwater wells (as many as 15%) with

NO_3-N concentrations exceeding 10 mg L^{-1} - the US EPA threshold for drinking water quality. The study area included the Lower Arkansas River Basin. Common to this area are sandy-textured soils supporting irrigated corn production. Because the observed NO_3 levels are greater than natural background levels and land use is predominantly agriculture, agricultural practices are implicated as a contributing NO_3 source.

Previous studies on similar sandy-textured soils along the Platte River, NE (Ferguson et al., 1991; Schepers et al., 1991), identified direct relationships between N management practices for irrigated corn and groundwater NO_3 levels. These relationships were developed based on rather large geographic regions, and the amount of NO_3 leaching under these fields was not quantified. Quantification of NO_3 loss below the root zone is necessary to determine the contribution of agricultural practices to NO_3 contamination of ground water. Several studies have incorporated various methods of measuring NO_3 concentrations in soil and drainage water. Porous-cup solution samplers are relatively noninvasive and are less expensive than more elaborate lysimeter collectors, allowing use over a large number of treatments and replications (Andraski et al., 2000). By determining the saturated hydraulic conductivity and measuring hydraulic head at depths above and below the solution sampler, N flux down the soil profile can be calculated for an accurate assessment of NO_3 leaching.

As little as 1 inch of irrigation or rainfall can move soil NO_3 6 to 8 inches in a loamy sand (Endelman et al., 1974). Average May rainfall (1993-1997) in Barton Co, KS, is 5.3 inches (National Climatic Data Center, 2000), so the depth to which NO_3 could potentially move early in the growing season is almost as great as the average corn rooting depth (54 inches; Leonard and Martin, 1963). Maximum corn rooting depth does not occur until about tasseling, by which time only 60% of total N uptake has occurred (Hoeft et al., 2000). Any rainfall / irrigation in May above average rainfall increases the potential for NO_3 leaching to a depth exceeding the average corn rooting depth.

Current N recommendation models were developed to accommodate management practices that probably consisted primarily of applying N fertilizer prior to planting. With greater awareness of environmental concerns (Emmons, 2000; Pope et al., 2001) related to NO_3 levels in groundwater supplies, improved N recommendation models should reflect a greater understanding of in-field, in-season N dynamics. With the availability of more sophisticated management practices, irrigated corn producers are more likely to accommodate environmental concerns while simultaneously maximizing economic return.

Combining N and water management practices that minimize the nitrate leaching potential in corn production along environmentally sensitive tributaries in Kansas will be essential to maximizing economic return for producers and minimizing adverse effects on groundwater quality (a benefit to all downstream water users). Objectives of this study include (i) quantification of NO_3 leaching potential in the irrigated sands along Kansas' waterways under current and alternative N and water management strategies for corn, and (ii) evaluating yield response to alternative N and water management practices for irrigated corn production.

Methods and Materials

Field sites were selected at six Kansas locations in 2001 along the Republican (Scandia), Kansas (Manhattan, Rossville), and Lower Arkansas (Ellinwood, Pretty Prairie, St. John) Rivers. Soils at the locations ranged in textural class from silt loam to fine sand. Continuous corn is the crop rotation at every site except Scandia, which has a corn-soybean rotation, and each field is sprinkler-irrigated. All P and K fertilizer, corn variety selection, herbicide application, and water management was determined by individual producers and were typical for these areas.

Plots at each field site were arranged in a randomized complete block design (RCBD) with four replications of six N treatments. Nitrogen was surface applied as NH_4NO_3 and treatments included 300 kg N ha^{-1} applied pre-plant; 250 kg N ha^{-1} applied pre-plant; 250 kg N ha^{-1} applied pre-plant (½) and sidedress (½); 185 kg N ha^{-1} applied pre-plant (⅓) and sidedress (⅔); 125 kg N ha^{-1} applied pre-plant ($^1/_5$) and sidedress ($^2/_5$, $^2/_5$); and 0 kg N ha^{-1}. Treatments were adjusted at the Pretty Prairie and St. John sites due to producer management practices, so that total N applied was similar to intended rates. The St. John location had 35 kg N ha^{-1} applied as starter at planting. The Pretty Prairie East and West sites had 12 kg N ha^{-1} applied as starter, as well as 51 and 70 kg N ha^{-1} applied through the irrigation system, respectively. The N treatments at the Ellinwood site were duplicated for each of two irrigation treatments (optimal water rate and 25% greater than optimal water rate).

Three porous-cup tensiometers and one solution sampler were installed at the Ellinwood site in each replication of the four highest N treatments. Tensiometers were placed at depths of 30, 135, and 165 cm and solution samplers at 150 cm. In addition, irrigation gauges (16 total) were placed at the ends of each block to measure rainfall and irrigation during the growing season. Tensiometer measurements were collected at 7-10 day intervals during the growing season, and solution was collected every 10-14 days.

Soil samples were collected three times during the study year for NO_3-N analysis. Samples were collected at planting to a depth of 240 cm in 30-cm increments. At the Ellinwood site, two cores were collected and combined in each plot using a hydraulic probe with a 5-cm i.d. core. At the other sites, pre-plant soil samples were collected only from the highest (300 kg N ha^{-1}) and the control (0 kg N ha^{-1}) treatments in each block. Soil samples were collected prior to fertilizer application at the V-6 to V-8 growth stage to a 60-cm depth in 30-cm increments. Six, 2.5-cm cores were taken in each plot at all sites. Following harvest, soil samples were collected to a depth of 240 cm in 30-cm increments. One, 5-cm i.d. core was taken in each plot at all sites except Ellinwood, where two cores were taken and combined for a composite sample of each plot. All soil samples were dried at 50°C in a forced-draft dryer and ground to pass a 2-mm sieve. Nitrate-N in the soil samples was determined by flow injection analysis of 1 *M* KCl extracts (QuikChem® Methods, Lachat Instruments, Milwaukee, WI USA).

Grain yield was determined by hand harvesting a 6-m length of each of the middle two rows in each plot. The entire plot area was harvested at the Rossville site with a combine modified for plot work.

Statistical analyses were performed using General Linear Procedures (SAS® Institute Inc., 1998). F-tests for analyses of variances were considered significant at the 5% probability level. PROC GLM (SAS® Institute Inc., 1998) was used to analyze treatment differences in grain yield, soil water NO_3-N concentrations, and post-harvest soil NO_3-N concentrations.

Preliminary Results (2001)

Yield results from 2001 indicated that 185 kg N ha^{-1} was sufficient to achieve maximum corn yield at every location (Fig. 1). At the Ellinwood site, the 125 kg N ha^{-1} (as three split applications) was sufficient to achieve maximum yield in the lower (1X) irrigation treatment but not in the higher (1.25X) irrigation treatment. The 125 kg N ha^{-1} (as three split applications) treatment was also sufficient to achieve maximum yield at the East and West Pretty Prairie sites. The rates required to achieve maximum yield in this study were 55 – 80 kg N ha^{-1} less than typically applied by producers in the study area.

Water samples collected at the 150-cm depth throughout the growing season at Ellinwood indicated that after July 15, concentration of NO_3-N in soil water for the 1.25-X irrigation treatment increased to 2-3 times greater (as much as 160 mg L^{-1}) with the single pre-plant N applications as compared to the split N applications. This increase was not as pronounced in the 1-X irrigation treatment, although NO_3-N in soil water was noticeably higher for the 300 kg N ha^{-1} treatment after July 15 (Fig. 2).

Post-harvest soil samples collected to 240 cm (30-cm increments) indicated that NO_3-N was leaching to below the 150-cm depth at N rates greater than 185 kg N ha^{-1} for the higher irrigation treatment at the Ellinwood site and at N rates greater than 185 kg N ha^{-1} at the Scandia site (Fig. 3). Also, the relatively high NO_3-N levels in the 50-150 cm depth at the Scandia site indicate a potential for additional leaching loss between fall and spring. At the East Pretty Prairie site, NO_3-N concentrations were highest at depths above 60 cm for N rates greater than 185 kg N ha^{-1}, probably a consequence of a soil horizon with much greater clay content below 90 cm. Because the west site at Pretty Prairie received similar N treatments and had much lower yields, excess N may have already leached below the sampled profile. The post-harvest soil samples from Rossville also suggest that NO_3-N levels had already leached from the profile to below 240 cm.

Summary

Maximum corn yield was achieved with N rates generally less than currently applied by producers, especially at higher-yielding sites. Nitrate leaching is increased by irrigation in excess of that required for optimum grain yield, and the potential for N loss below the root zone is increased when a single application of N fertilizer is applied prior to or at planting, rather than split applications at planting and at V-6. With the NO_3 leaching potential quantified and alternative N and water management strategies evaluated, producers will better appreciate the economic loss associated with N leaving the root zone, providing an incentive and the confidence to improve N management strategies that reduce the overall N rate applied but maintain maximum yield.

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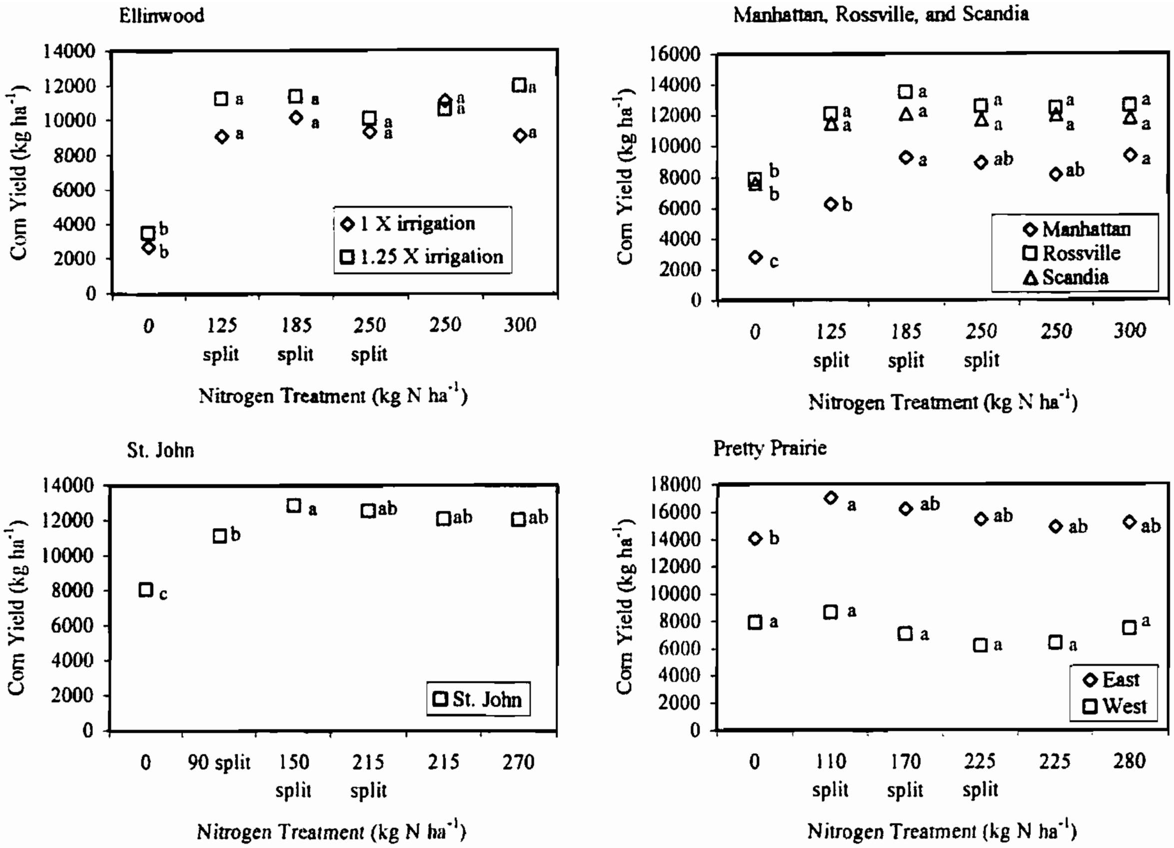

Figure 1. Grain yield as affected by N treatments for two water treatments at the Ellinwood site and one water treatment at five other sites. At each site, treatments with the same letter are not significantly different at α=0.05.

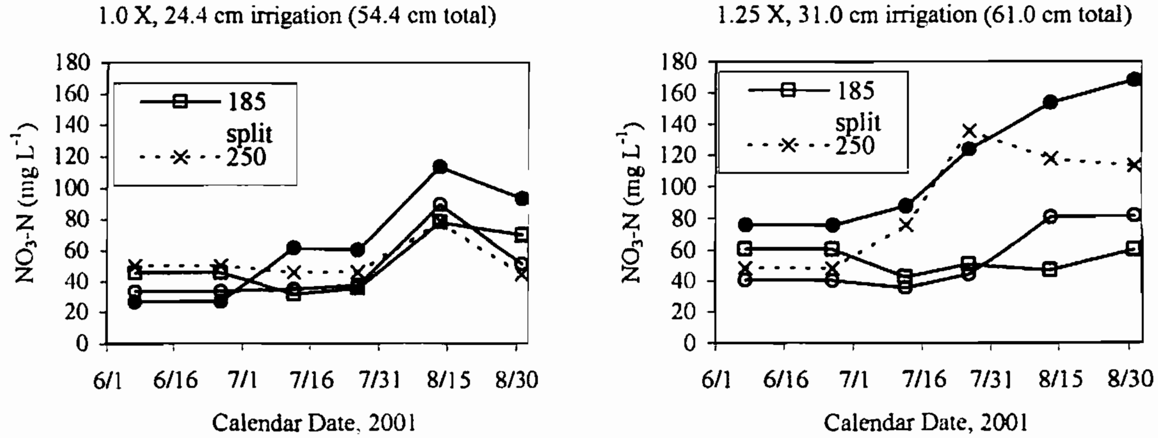

Figure 2. Soil water NO_3-N concentration at the 150-cm depth collected during the growing season at the Ellinwood site.

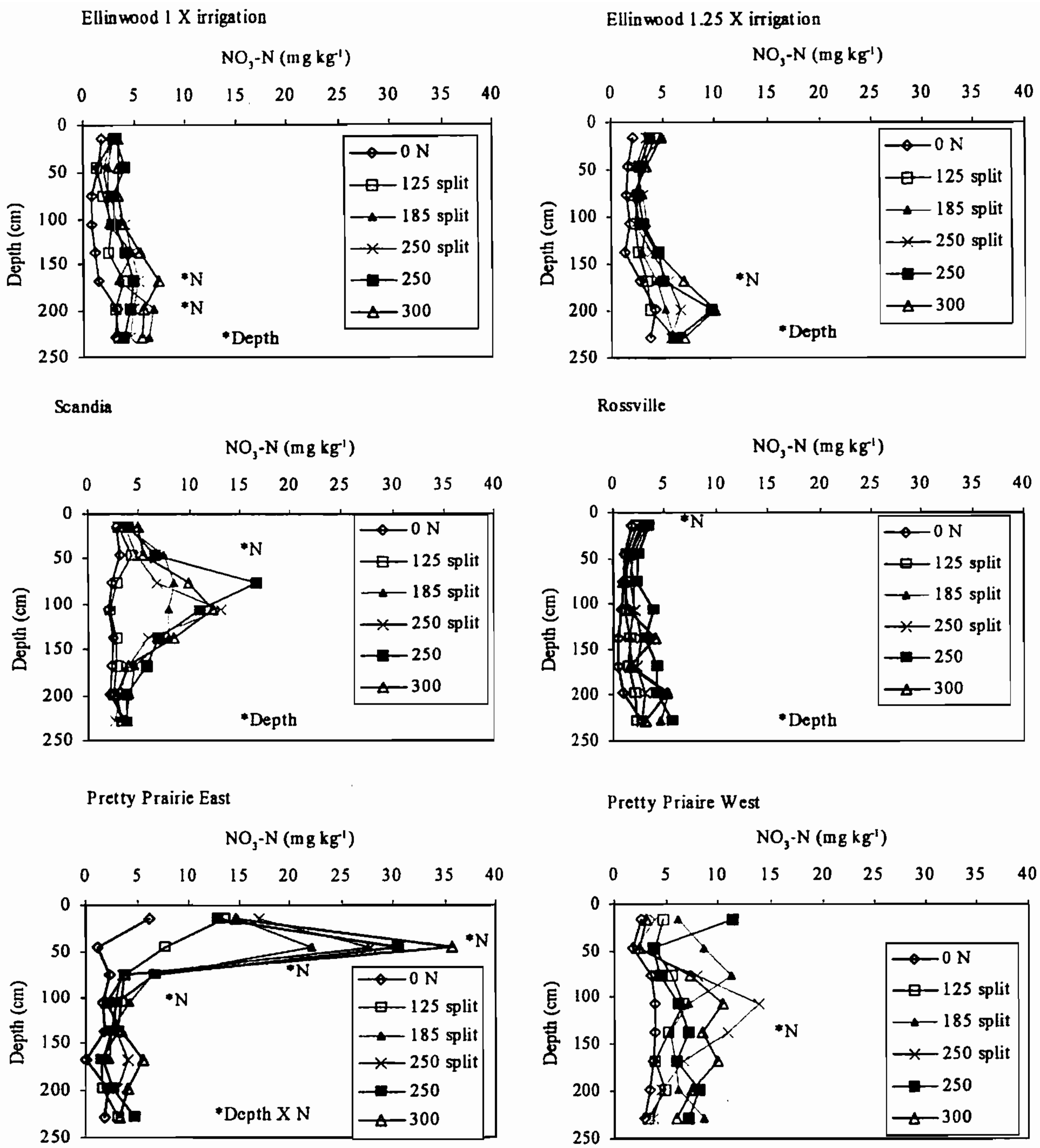

Figure 3. Post-harvest soil NO_3-N to 240 cm depth, collected in 30-cm increments. Statistical significance at α=0.05 is indicated by **N* for treatment interactions at a given depth, **Depth* for depth interactions, and **Depth X N* for treatment by depth interactions.

PROCEEDINGS OF THE

THIRTY-SECOND NORTH CENTRAL EXTENSION-INDUSTRY SOIL FERTILITY CONFERENCE

Volume 18

November 20-21, 2002
Holiday Inn University Park
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