QUANTIFYING NITRATE LEACHING IN SANDY SOILS AS AFFECTED BY N AND WATER MANAGEMENT

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ABSTRACT

Efficient use of nitrogen (N) fertilizer for corn production is important for maximizing economic return and minimizing NO_3 leaching to groundwater, especially on irrigated, sandy soils. The objectives of this study were to quantify the NO_3 leaching for a sandy soil typical of Kansas' tributaries, under current and alternative N and water management strategies for irrigated corn. Six fields were selected in 2001 and 2002 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, 185, and 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, one for each of two irrigation treatments (optimal and 25 % greater than optimal). At this site, porous-cup tensiometers and solution samplers were installed in each plot of 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 indicated a split application of 185 kg N ha^{-1} was sufficient to achieve maximum corn yield at every location. Water samples collected throughout the growing season indicated after July 15 soil water NO_3-N concentration at the 150-cm depth increased to 2-3 times greater with the single pre-plant N applications as compared to the split N applications. Total N fluxes at the 150-cm depth exceeded 100 kg N ha^{-1} when water and N were applied in excess of that required for maximum yield, particularly with the single, pre-plant N applications.

INTRODUCTION

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 NO_3 leaching, particularly on sandy-textured soils that are susceptible to rapid downward movement of water. When N fertilizer is applied before 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. 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 %) in the Lower Arkansas River Basin with NO_3-N concentrations exceeding 10 mg L^{-1} – the US EPA threshold for drinking water quality. Common to this same area are sandy-textured soils supporting irrigated corn production.

As little as 2.5 cm of irrigation or rainfall can move soil NO_3 15 to 20 cm in a loamy sand (Endelman et al., 1974). Average May rainfall (1999-2003) in Barton Co, KS, is 10 cm (Kansas State University, 2003), 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 (137 cm; 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.

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, so the amount of NO_3 leaching under these fields was difficult to quantify. Quantification of NO_3 losses below the root zone is essential to education programs that seek to minimize the adverse environmental impacts of N fertilizer applications. Porous-cup solution samplers are relatively noninvasive and are less expensive than more elaborate lysimeter collectors, and provide an approach to monitor a large number of treatments and replications (Andraski et al., 2000). By determining the hydraulic conductivity and measuring hydraulic head at depths above and below the solution sampler, NO_3 flux down the soil profile can be determined.

Combining N and water management practices that minimize NO_3 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) quantify NO_3 leaching in a sandy soil typical to Kansas' tributaries 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.

MATERIALS AND METHODS

Corn was grown in 2001 and 2002 at six Kansas locations 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 was in a corn-soybean rotation prior to this study. 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 blocks 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 Pretty Prairie and St. John to accommodate producer management practices, so that total N applied was similar to intended rates. St. John received 35 kg N ha^{-1} applied as a starter at planting. Pretty Prairie East and West received 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). Plot locations were identical between years.

Three porous-cup tensiometers and one solution sampler were installed at Ellinwood 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. Irrigation and rainfall were measured with 8 non-evaporative rain gauges in each irrigation treatment and 1 rain gauge at the field edge (outside the sprinkler range). Tensiometer measurements were collected at 7-10 day intervals during the growing season, and soil solution was collected every 10-14 days.

Water flux at Ellinwood was determined using a drainage plot located centrally to the entire plot area. A 4 x 4 m area was flooded to obtain saturated flow throughout the soil profile. As the soil profile drained, water tension and water content (using neutron probes) were monitored. Change in water content in the drainage plot was used to determine hydraulic conductivity as a function of water tension. This relationship was then used to determine water flux in the plot area.

Soil samples were collected three times during the study year for NO_3-N analysis. Samples were collected at planting and after harvest to a depth of 240 cm in 30-cm increments. At Ellinwood, 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. 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. After harvest soil samples consisted of one 5-cm i.d. core taken from each plot at all sites except Ellinwood. All soil samples were dried at 50° C and ground to pass a 2-mm sieve. Soil NO_3-N was determined by flow injection analysis of 1 *M* KCl extracts (QuikChem® Methods, Lachat Instruments, Milwaukee, WI).

Grain yield was determined by hand harvesting a 6-m length of each of the middle two rows from each plot. The middle two rows of each plot at Rossville were harvested 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 0.10 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.

RESULTS AND DISCUSSION

A split application of 185 kg N ha^{-1} was sufficient to achieve maximum corn yield at every location (Fig. 1, data not shown for St John and Pretty Prairie), and in some instances a split application of 125 kg N ha^{-1} was sufficient. Optimum N rates observed in this study were generally less than corresponding N recommendation from Kansas State University (KSU). Using KSU's (2003) formula for each location, N recommendations ranged between 175 to 325 kg N ha^{-1}. These recommendations corresponded to observations between near optimum N rates to 140 kg N ha^{-1} in excess of that required to achieve maximum grain yield. Although the split applications may provide some measure of N use efficiency not accounted for in KSU's formula, a single pre-plant application of 250 kg N ha^{-1}, 65 kg N ha^{-1} less than the maximum recommendation, was sufficient to achieve maximum corn yield on these irrigated sands.

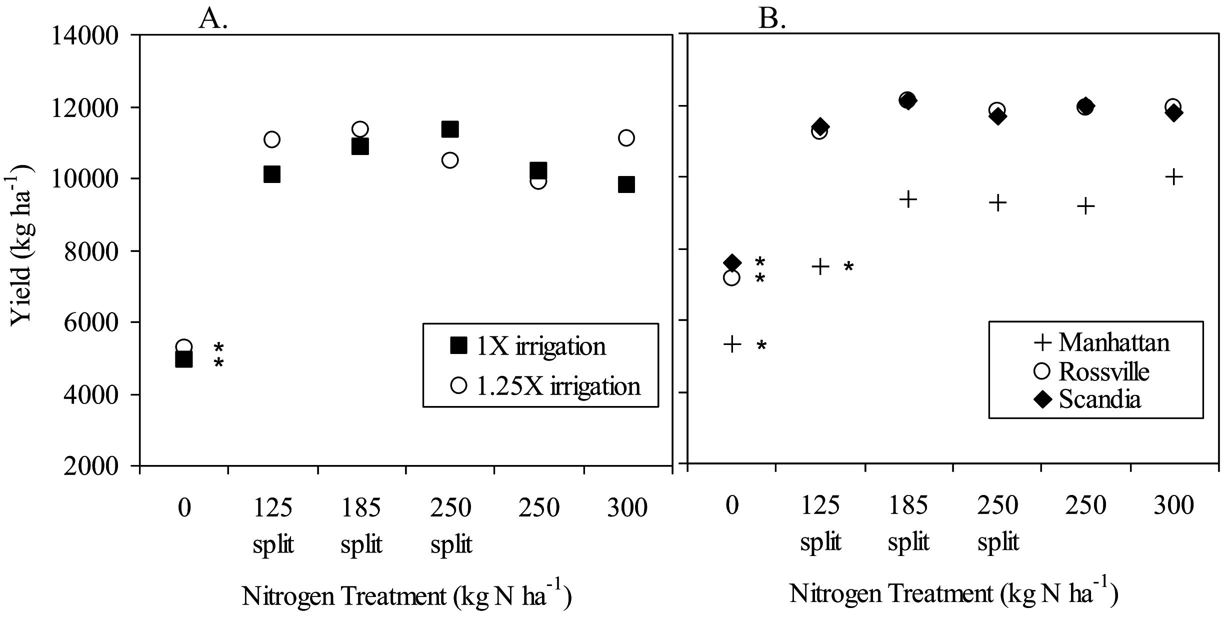

Figure 1. Average grain yield (2001 and 2002) response to N treatments for the two irrigation treatments at Ellinwood (A) and at Manhattan, Rossville, and Scandia (B). * indicates that yield for a N treatment is significantly less than the next adjacent treatment (to the right).

Soil water NO_3-N concentration (150-cm depth) early in the growing season at Ellinwood ranged from 37 to 53 mg N kg^{-1} in 2001 and from 13 to 20 mg N kg^{-1} in 2002 (Fig. 2). However, as early as 26 June 2001, there was a significant difference in water NO_3-N concentration among N treatments. Single pre-plant N applications resulted in consistently greater NO_3-N concentration at the 150-cm depth compared to split N applications. This trend was consistent throughout the growing season in both years, and by late July and early August, NO_3-N concentrations were exceeding 100 mg N kg^{-1} for the single pre-plant N applications.

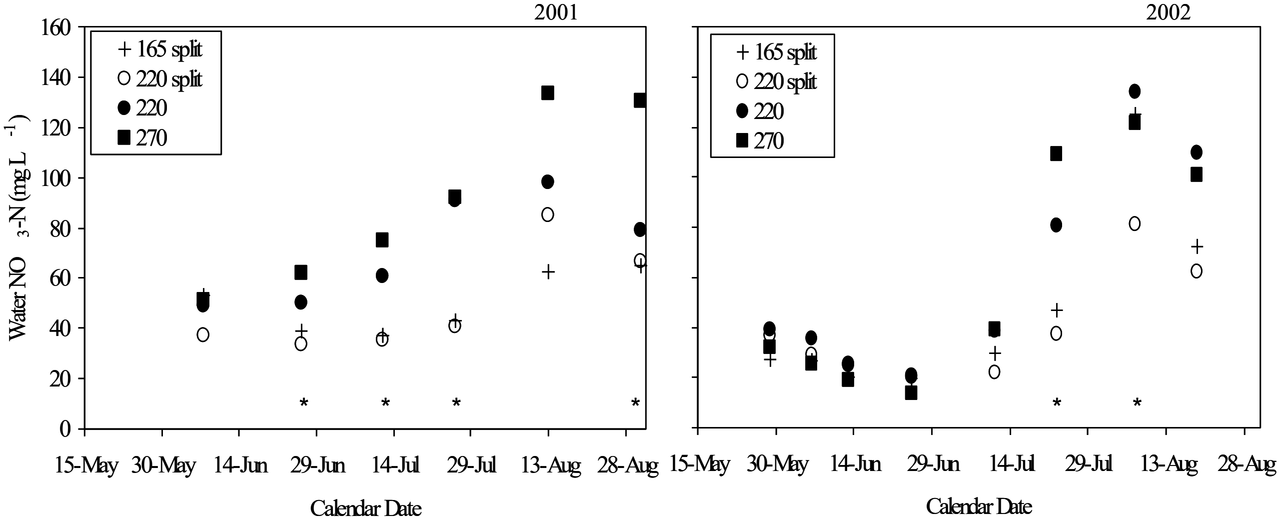

Figure 2. Water NO_3-N concentration at the 150-cm depth at Ellinwood. * indicates a significant N treatment effect on a specific sampling date.

While the water NO_3-N concentration with the 1.25 X irrigation treatment was generally greater than with the 1.0 X irrigation treatment, averaging 23 and 13 mg kg^{-1} greater across all sampling dates in 2001 and 2002, respectively, the results depicted in Fig. 3 illustrate the most dramatic interaction observed between the N and irrigation treatments. With 25 % more irrigation water, the water NO_3-N concentration (150-cm depth) was 3 to 4 times greatest for the single pre-plant N applications, reaching almost 200 mg N kg^{-1}. Increasing soil water NO_3-N concentrations down the soil profile as a result of additional water and the single pre-plant N applications translates to greater potential for NO_3 leaching during the growing season.

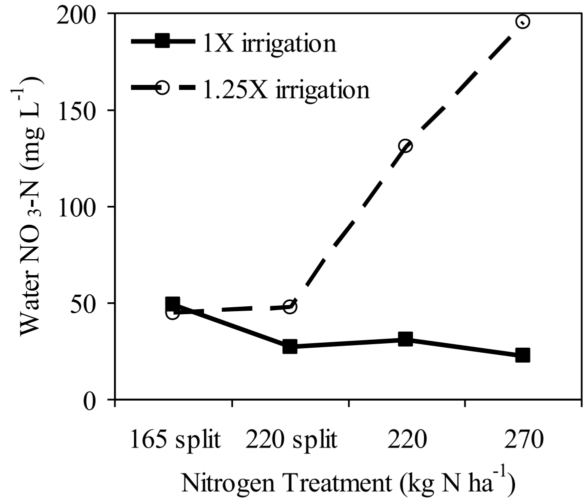

Figure 3. Water NO_3-N concentration at the 150-cm depth on 23 July 2002 at Ellinwood. The irrigation by N treatment interaction was significant.

Irrigation amounts at Ellinwood for the 1.25 X and 1.0 X irrigation treatments were 31 and 24 cm (2001) and 23 and 19 cm (2002), respectively. An additional 30 and 20 cm of rainfall occurred in 2001 and 2002, respectively. Average water flux during the growing season for each irrigation treatment was always in the downward direction (Fig. 4). While generally less than 1.5 mm d^{-1}, after two consecutive early season rainfalls (5.5 and 4.1 cm) within a week in 2001, the water flux spiked to greater than 4.0 mm d^{-1}. Total drainage with the 1.25 X irrigation treatment exceeded drainage in the 1.0 X treatment by 3.3 and 9.4 cm in 2001 and 2002, respectively. Despite receiving considerably less water during 2002, yield was the same or slightly greater than in 2001. The additional water did not increase grain yield on this Pratt loamy fine sand (sandy, mixed, mesic Lamellic Haplustalfs), but resulted in additional water drainage.

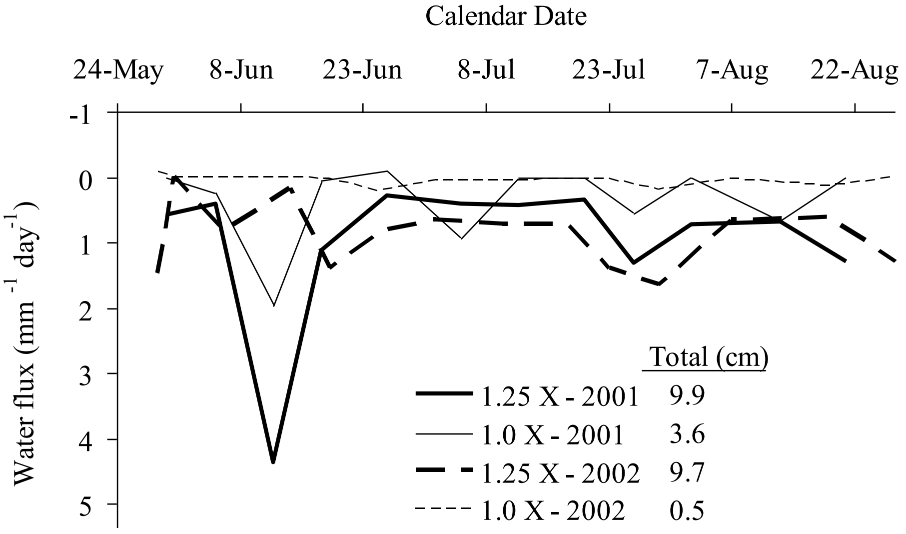

Figure 4. Water flux at the 150-cm depth, Ellinwood site.

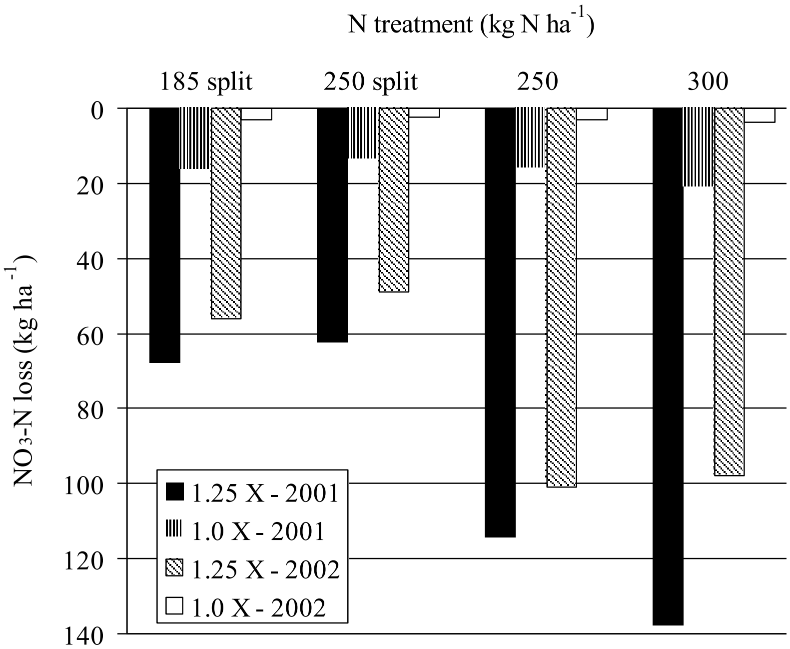

Figure 5. Total NO_3-N flux at the 150-cm depth during the growing season. Determined by multiplying NO_3-N concentration by average water flux between sampling dates.

When N fertilizer was applied in excess of that required for maximum grain yield (Fig. 1) at Ellinwood, and as a single application prior to planting, soil water NO_3-N concentrations (150-cm depth) increased substantially (Fig. 2). Because water flux at the 150-cm depth was continually in the downward direction throughout the growing season, and when slightly more water was applied (Fig. 4), total N flux at the 150-cm depth was exacerbated (Fig. 5). The 1.25 X irrigation treatments in both years resulted in the greatest NO_3-N fluxes, always exceeding 40 kg N ha^{-1}. Nitrate-N fluxes were equal to or exceeded 100 kg N ha^{-1} when N was applied pre-plant and at rates more than required for maximum yield. Although the 1.0 X irrigation treatment resulted in NO_3-N fluxes less than 20 kg N ha^{-1}, regardless of N treatment, these results reflect observations recorded only during the growing season. Nitrate-N remaining in the soil as a result of N rates in excess of crop requirements will be susceptible to leaching as illustrated here for the 1.25 X irrigation treatment.

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