RAPID REMOVAL OF SUBSOIL N BY CONVENTIONAL AND NON-N-FIXING ALFALFA

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ABSTRACT

Nitrate contamination of groundwater is an increasingly serious health issue in the Central High Plains. Although better water and fertilizer management techniques have reduced the rate of leaching from many irrigated fields, high concentrations of residual nitrate accumulating are still observed just below the root zone of irrigated row crops, particularly in fields with a history of animal waste application. Alfalfa (*Medicago sativa* L.) may be the ideal crop for removing large amounts of residual nitrate from the subsoil, and may allow higher N-based rates of animal waste application than any other crop, if it can be established that alfalfa preferentially removes residual nitrate when it is available, and that a mature alfalfa stand can be terminated without returning a significant quantity of nitrate to the deep soil profile. In the fall of 2001 we established a alfalfa stand using a locally adapted variety under three irrigation regimes (dryland 18" limited allocation, and unlimited allocation) on plots that had been pre-treated to provide a wide range of initial nitrate conditions. After a single season, alfalfa had removed 65-75% of residual nitrates to a depth of 8 ft under limited or full irrigation, with a total reduction of >1000 lb of residual N in plots with an initial content of >1500 lb N acre^{-1}. This reduction is far greater than the amount of N removed as hay, indicating that much of the removed N is being sequestered in non-harvested roots and crowns, or has been lost from the system through denitrification. In addition, the data strongly suggests that high initial nitrate concentrations inhibited N fixation, resulting in much greater uptake than would otherwise be possible. Direct measurements of N-fixation at this site are being made using non-N-fixing alfalfa and should be available for presentation at the conference.

INTRODUCTION

The USGS National Water Quality Assessment Program has undertaken a series of studies in the High Plains Kansas, Oklahoma and Texas that clearly show how the downward movement of nitrate-rich water from 50 years of irrigation development is reaching the upper saturated boundary of the Ogallala Aquifer and causing widespread contamination (McMahon, 2001, Litke, 2001). While many domestic and municipal wells in the region are still providing high quality drinking because of their great depth and the great saturated thickness of the aquifer, in areas where the aquifer has already been substantially depleted by irrigation, as in the Western Kansas Groundwater Management District #1 in Greeley, Wichita, and Scott Counties, contamination beyond the 10 ppm nitrate-N drinking water standard has become common. Indeed, the City of Scott City has repeatedly been unable to meet this standard consistently over the last two years and has thus been forced to repeatedly issue bottled water to its most at-risk clients - families with pregnant women and young children. A high concentration of animal feeding operations also appears to be a risk factor. In a recent study of irrigated cropland in Western Kansas, Schlegel et al. (1999) found excessive nitrate accumulation to a depth of 10 ft or greater in all fields with at least a 5 year history of swine effluent or feedlot manure application, whereas nearby fields that received inorganic fertilizers had much lower subsurface nitrate levels. On the other hand, we have observed many cases where high concentrations of nitrate have accumulated below the root zone in commercially fertilized fields in Western Kansas. Under adequate irrigation, the effective root zone of most field crops is only 2-3 ft (ref) and anything that leaches below 4 ft is essentially lost to irrigated, row-crop production.

Alfalfa has consistently been one the most profitable crop in SW Kansas over the last several years (Dumler et al., 2003), and its potential for remediating soils with high levels of subsurface nitrate is outstanding. Alfalfa roots been shown to remove water and residual N to depth of at least 25 ft in Kansas (Grandfield and Metzger, 1936), and may grow as deep under irrigation as under dryland conditions in the great plains (Weaver, 1926). Irrigated alfalfa typically produces 8-12 tons of dry biomass per acre per year in the Central High Plains, resulting in the annual harvest of 400-900 lb N acre^{-1} year^{-1} depending on crude protein content. Part of this nitrogen will be supplied by the soil and part by atmospheric N-fixation. In a recent review, Carlsson and Huss Danell (2003) noted that values reported for the percent of monoculture alfalfa N derived from atmospheric fixation ranged from 10 – 90% with an average of just over 50%. Even if 50% of alfalfa N comes from N_2-fixation, the removal of soil N by alfalfa would be more rapid than its removal by high yielding corn (apx. 190 lb acre^{-1} at 250 bu acre^{-1}). Moreover, N-fixation should decrease in the presence of free soil nitrate. Numerous studies have shown that soil nitrates inhibit nodule formation, decrease the ratio of nodule to plant mass, and decrease nitrogenase activity, resulting in decreased N-fixation (Steeter, 1988). If it can be shown that high nitrate levels decrease N-fixation predictably in commercial alfalfa varieties, then the usefulness of alfalfa as a sponge crop for high-N animal waste, and its effectiveness as a remediation tool for high nitrate subsoil will be greatly enhanced.

MATERIALS AND METHODS

In September 2001, we initiated a study designed to document the residual N removal capacity of alfalfa across a range of residual N conditions under three irrigation scenarios: dryland, 18” limited allocation, and unlimited allocation. A locally adapted conventional alfalfa variety (“Key”; Drussell Seed Co., Garden City, KS) was drilled at a rate of 20 lb acre^{-1} into plots previously used in a corn fertilization and irrigation study under a variable rate, center pivot sprinkler in Garden City, KS. The four fertility treatments from the previous study (0N, 1x N fertilizer, 1x beef feedlot manure, and 2x manure based on soil test) served as pre-treatments for the current study and resulting in a range of residual N contents from 400-3000 lb in a 0-10 ft profile that was apportioned equally to each new treatment combination. Dryland, limited irrigation (0.5x ET replacement), and full irrigation (1x ET replacement) plots from the previous study were converted into the corresponding irrigation treatments in the current study, whereas plots previously receiving excessive irrigation (1.5x ET) were assigned at random to one of the new irrigation treatments. Four P-fertilization methods (annual topdressing with commercial P-fertilizer, beef feedlot manure, or composted manure, vs. a single 3x manure application without topdressing), were added to test the hypotheses that topdressing increases weed pressure and decreases stand longevity. These treatments involved very small differences in N application and were not expected to have any impact on N removal. Fertilization treatments were established 15 x 50-60 ft plots which were watered in pairs, creating 30 x 50-60 ft irrigation plots. Hay production was measured by hand harvesting near the center of each irrigation plot prior to swathing at 4 cutting dates in 2002 and analyzed for relative feed value (including N content) at Servi-Tech Laboratories of Dodge City, KS. Irrigation water was applied through low-pressure sprinklers on 5 ft spacing with a 12 ft throw-radius. Irrigation timing was set by neutron probe readings supplemented with the KanSched ET-based irrigation scheduling program (Clark et al., 2002). Soil Samples were collected to a depth of 10 ft in 1 ft increments using a hydraulic probe (Giddings Machine Co, Inc., 2 cores per plot) and analyzed for nitrate and ammonium at all depths. Treatment effects were assessed using the univariate ANOVA procedure (UNIANOVA) provided in the SPSS Statistical Software Package (Ver. 11, SPSS Inc, 2001) in a completely randomized design with pre-treatment used as a replication in assessing p-fertilization effects and p-fertilization treated as a replication in assessing pre-treatment effects. Additional analyses were performed using the SPSS GLM and REGRESSION procedures.

RESULTS AND DISCUSSION

As is often the case, increased irrigation (Table 1) resulted in increased yield but decreased forage quality in the initial year of hay production. Both the amount of N removed from soil and the amount of hay harvested increased with irrigation and yield, but were otherwise not closely related. As can be seen in Figure 1, the reduction in residual N was largely a function on initial N content, and was this significantly related to pre-treatment. Neither yield nor hay quality were affected by these factors in any way, meaning that soil N reduction was essentially unrelated to yield. From a spatial perspective (Figure 2) we can see residual soil N was reduced to a depth of approximately 8 ft. Again, the greatest quantity of N was removed from precisely those treatments and depths that had the highest initial N concentrations.

Table 1. Irrigation effects on 2002 alfalfa performance (4 cuttings), N content, and residual soil N removal. Letters indicate significant difference by LSD at p=0.05.

Irrigation Treatment	Yield†	Crude Protein	Harvested N	Relative Feed Value	Change in Residual N	Ratio of Removed to Harvested N
	Tons acre^{-1}	%	lb acre^{-1}		lb acre^{-1}	
Dryland	4.5 c	25.4 c	313 c	211 a	541	1.75
Limited	7.6 b	23.9 b	532 b	157 b	767	1.43
Full	8.4 a	22.9 a	587 a	146 c	782	1.34

† Hay yield is adjusted to %15 moisture
‡ Apparent ET = water applied during season (rainfall + irrigation) – change in soil moisture
§ Water use efficiency = Yield / Apparent ET

On average, the removal of N from the soil profile exceeded the removal of N as hay by 46%, and in some individual plots the difference was two- to three-fold. Obviously, some of this N must have been sequestered in non-harvested plant tissues such as root and crowns, but there is

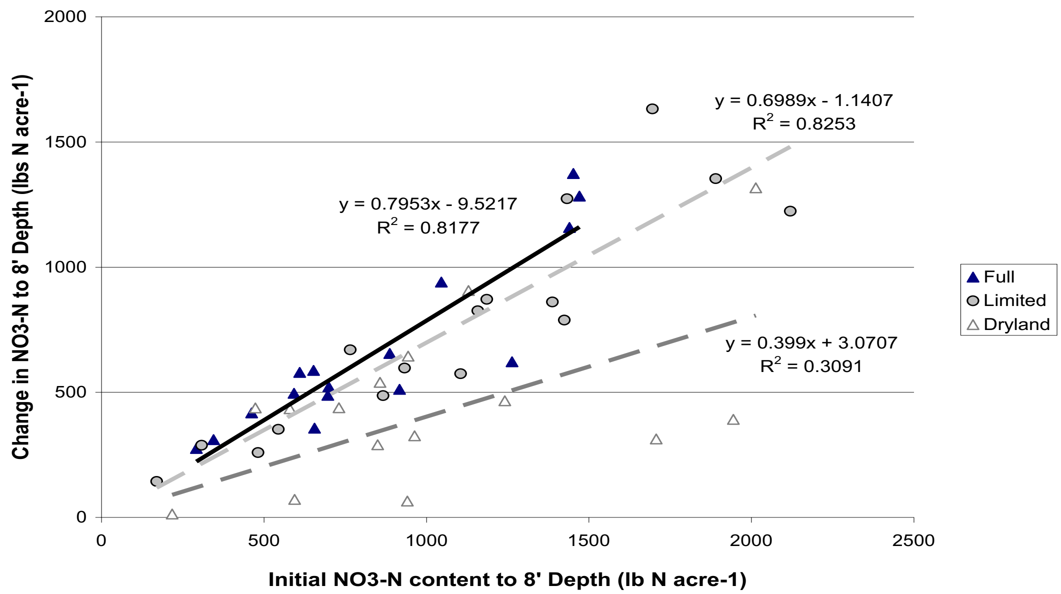

Figure 1. Residual N removal is a function of initial residual nitrate content

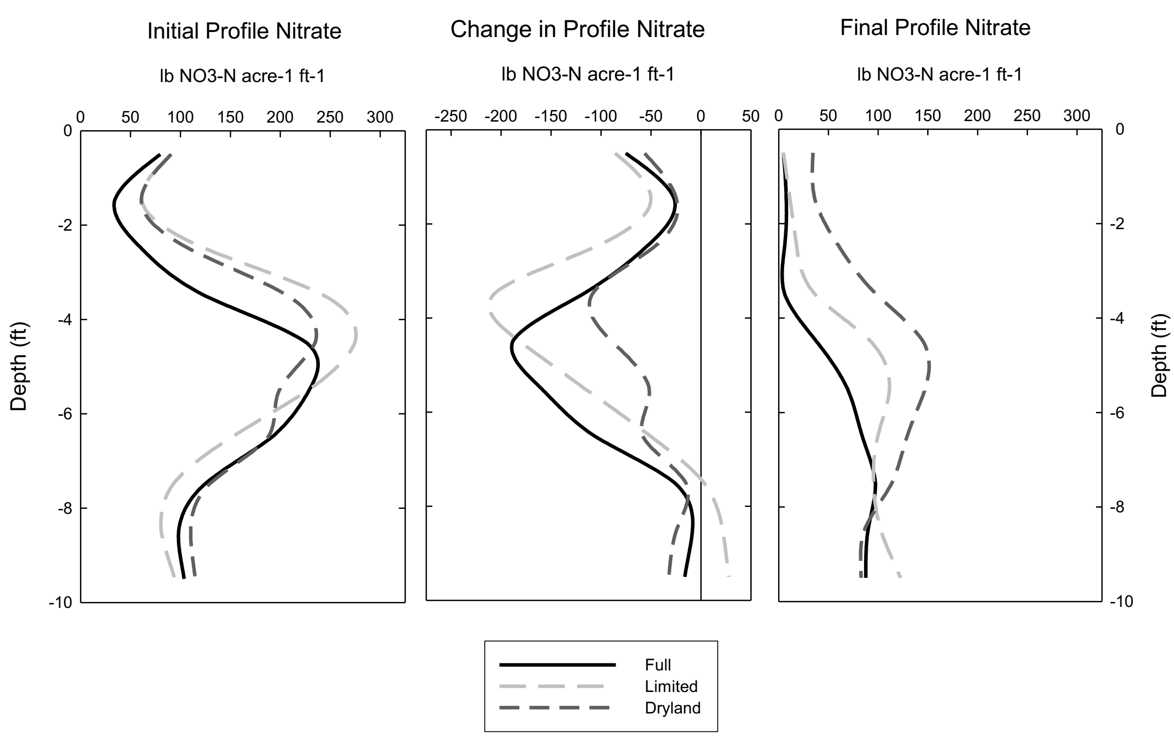

Figure 2. Change in residual nitrate by depth during 1 year of alfalfa production.

no reason to expect that the crop would preferentially sequester nitrogen in roots and crowns rather than foliage. The response of most plants is just the opposite: to increase the shoot:root ratio (S:R) when external nutrient availability is greater.

If we assume that the roots, crowns, and foliage in a given plot have approximately the same N content, and the same %Ndfa; and we assume that both mineralization and denitrification are small compared to plant uptake, we can derive the a mathematical relationship between %Ndfa and the shoot:root N ratio (S:R) for each plot such that %Ndfa = (1-ΔNsoil/(N harvested (1+1/S:R))) * 100, where ΔNsoil is the change in residual N in the profile, and N harvested is the N removed as hay, both expressed as lb N acre-1. In essence this equation predicts all of the combinations of shoot:root ratio and %Ndfa that can explain the available soil and plant N data. For example, if all plots had a shoot: root ratio of 0.5 (twice as much N was unharvested as was harvested) %Ndfa would vary as shown in Figure 3. While this seems to be an unlikely scenario, consider that a greater shoot:root ratio (e.g. 1) would require negative values for %Ndfa at high nitrate levels, and that a variable shoot:root ratio (one that decreased with increasing nitrate concentration) would require an even greater range of %Ndfa than shown in Figure 3.

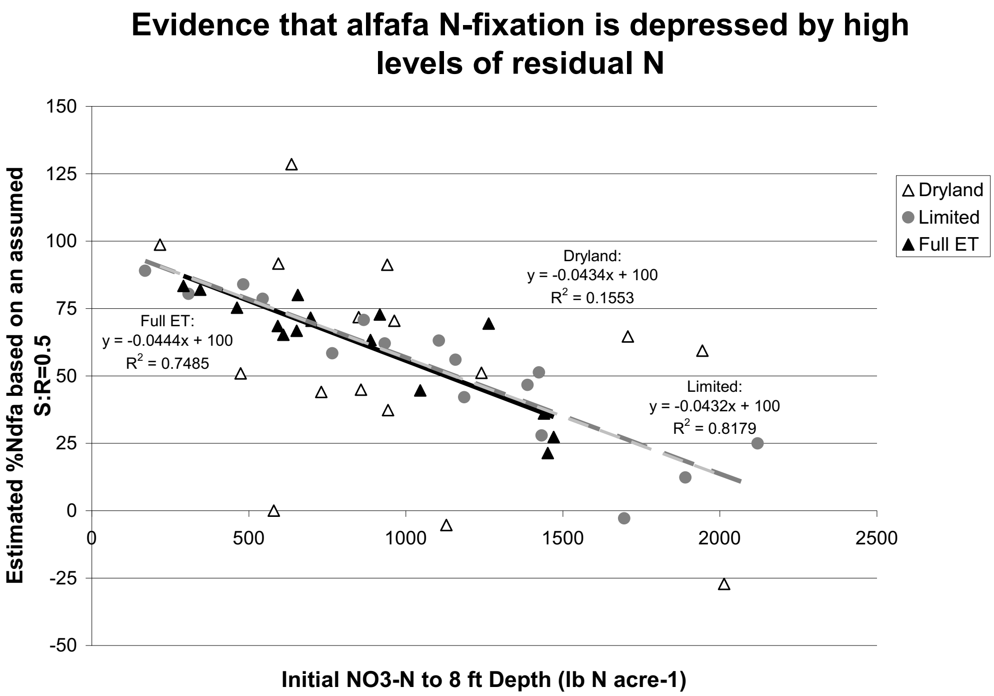

Figure 3. %Ndfa estimated from equation 1based on the assumption of a fixed shoot:root ratio of 0.5. Note that all three irrigation treatments show exactly the same response to external nitrate levels.

Ideally, we would like to be able to verify the predictions of Figure 3 based on independent measurement of %Ndfa. To that end we have initiated a second study at the Garden City site that uses “ineffective Saranac,” a non-N-fixing alfalfa variety (USDA Plant Science Research Laboratory, St. Paul, MN) to allow the direct measurement of %Ndfa by the difference and ^{15}N natural abundance methods. Unfortunately, a lack of pre-treatment at that site resulted in a relatively uniform nitrate content of apx 500 lb N acre^{-1}, and the initial estimate of 20% Ndfa by the difference method is much lower than predicted in Table 3. Similar analyses were performed by Lamb et al (1995) and Blumenthal et al (1999) in Minnesota using the "ineffective agate" variety. Both studies showed only a small range of Ndfa response to a fairly wide range of nitrate additions.

The other process that might explain the data in figures 2 and 3 is denitrification. Ordinarily we expect N loss by denitrification to be small in agricultural soils (Robertson, 1997). In addition to nitrate availability, denitrification requires low oxygen concentrations, and the availability of an energy-rich soluble carbon source. While these conditions might be expected to occur in irrigated surface soils, especially after a manure application, they would be much less prevalent in the sub soil and very rare in a dryland production system. On the other hand there is growing physiological evidence that nitrate in solution stimulates denitrification inside of root nodules (Lukinski et al., 2002). While there is much speculation about why this activity might be beneficial to either the plant or the bacterium, there has been little attempt to estimate the quantity of N that might be denitrified on a field scale. We hope to have more information on this possibility in the near future.

Whatever the mechanism, it is clear from this study that alfalfa is much more effective in sequestering external nitrate then we had imagined. Assuming that this result is reproducible, and that a mature stand can be terminated without simply returning the sequestered N to the soil profile, then we will have an extremely effective and profitable tool to prevent further leaching on nitrates from irrigated cropland in the central High Plains.

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