RESIDUAL SOIL NITROGEN AND NITROGEN RESPONSE OF CORN ON SANDY LOAM SOIL

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INTRODUCTION

Groundwater contamination is an ever-increasing concern on a national level as well as locally. Increasing amounts of nitrate-nitrogen (NO_3-N) being delivered by rivers, including the Mississippi, have resulted in an oxygen-depleted area or hypoxic zone in the Gulf of Mexico. (Turner and Rabalais, 1994b). This nutrient loading has caused nitrogen-limited phytoplankton to bloom. Decom-position of these blooms depletes oxygen levels forming seasonal hypoxic conditions (Rabalais et al., 1996). Nitrogen (N) loading studies analyzing the sources and losses of N to the Mississippi River basin show the Midwest corn and soybean producing area to be the largest total contributor of N (Burkart and James, 1999). Therefore the land-use practices and management at the local level can influence NO_3-N contributions to distant river basins. The concern for water quality protection and the association of groundwater contamination with widespread use of N fertilizers for crop production, make the development of practices that reduce NO_3-N contamination a high priority.

Agriculture is, without question, the major source of NO_3-N contamination locally as well as nationally. Nitrogen is an important and essential nutrient to all agricultural systems. Crops that cannot produce their own nitrogen must rely on N inputs from other sources. In an ideal world, the addition of N to crops would equal that used by the crops. But in reality crop recovery at optimum yield levels or removal seldom exceeds 60% (Wolkowski et al., 1995). Unrecovered N has the potential to leach to groundwater. Cook (2000) found that approximately 35% of applied nitrogen fertilizer to agricultural fields was leaching to groundwater while following University of Wisconsin-Extension nitrogen recommendations. Nitrate-N concentrations in groundwater correlated closely to stream and private well water quality data based on the percentage of agricultural use within each sub-basin of the Tomorrow/Waupaca River Watershed, located in Central Wisconsin.

In an effort to improve N management in corn production, soil N availability tests were developed to measure inorganic N (usually NO_3) in the soil before planting or at a specific time in the development of a crop (Bundy and Sturgul, 1994). Humid areas of the Midwest and eastern United States have higher annual rainfall that increases the likelihood of leaching or denitrification. It was thought that N fertilizer applied in humid areas would not be retained over-winter within the effective rooting depth of the soil profile even though early studies showed substantial amounts of residual NO_3-N on medium and fine textured soils (silt loam and loam) in these areas (Peterson and Attoe, 1965; Olsen et al., 1970; Olson et al., 1976). Recent studies in humid regions have reaffirmed that residual NO_3-N is present in medium and fine textured soils and significantly effects crop N response (Bundy and Malone, 1988; Klausner et al., 1993; Liang et al., 1991; Roth and Fox, 1990; Sheppard and Bates, 1986; Vanotti and Bundy, 1994). Other studies have shown low NO_3-N carryover on coarse textured soils due to the high probability for leaching during the over-winter period (Bundy et al., 1993; Olsen et al., 1970; Sexton et al., 1996).

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Corn N recommendations for Wisconsin are based on soil-specific response data from the six major soil groups within the state. In most areas of the United States, yield goal is the primary factor used in determining corn N recommendation. Vanotti and Bundy (1994a) recommended N rates be based on N response data for a particular soil rather than yield goal. Further research showed that optimum N rates did not change from year to year although corn yields varied considerably from year to year (Vanotti and Bundy, 1994b).

Very little information is available as to the ability of intermediate textured soils (sandy loam) to retain residual soil NO_3-N and N response data of corn. Large areas of central and northern Wisconsin are dominated by sandy loam soils making the need for further N response data critical for improving corn N recommendations that will improve economic returns and minimizes NO_3-N losses to groundwater. The specific objectives of this study are to improve corn N recommendations on sandy loam soils by: (i) determining background soil N content for pre-plant nitrate test (PPNT) adjustments; (ii) determining the critical soil N-sufficiency concentration for the pre-sidedress soil nitrate test (PSNT); (iii) evaluating the potential for residual soil N; iv) determining the economic optimum nitrogen rate (EONR).

MATERIALS AND METHODS

On-farm field experiments for three cropping years were established in eastern Portage and western Waupaca counties in central Wisconsin (1997 to 1999). All sites were planted into either a Billett sandy loam (coarse, loamy, mixed , mesic, Mollic Hapludalf) or Rosholt sandy loam (coarse-loamy, mixed, Typic Glossoboralf) which are the predominant soil types in the region. Corn was planted to evaluate yield response to applied nitrogen and residual soil NO_3-N and ammonium-nitrogen (NH_4-N) before (April), during (June), and after the growing season (October), as well as the following spring (April after winter period) to determine NO_3-N losses under different crop rotations. Crop rotations were: (i) continuous corn (> 3 yr) without a history (> 10 yr) of manure (C/C/C) and (ii) first year corn into alfalfa (A/C) with a recent history of manure (< 3 yr). Table 1 shows the cropping, manure and alfalfa management for each location.

Experimental design was a randomized complete block design with three replications used at each of the 14 locations. Before planting, a routine soil test and pre-plant soil NO_3-N and NH_4-N samples were collected from each replicate in 1-foot increments to a total depth of 3 feet. Alfalfa stand densities (plants/ft^2) were measured before planting or tillage (10 measurements/replication).

Corn was planted from late April to early May at all locations (Table 1) and plant densities ranged from 24,000 to 32,000 plants per acre. Starter fertilizer was applied at planting approximately 2 inches to the side and 2 inches below the seed. Starter fertilizer varied from 9 to 50 lb N/acre, 8 to 44 lb P/acre, and 10 to 65 lb K/acre. Ammonium nitrate was used as the nitrogen source for all nitrogen treatments and applied when corn was 12 to 18 inches tall. In 1997, N treatments were 0 to 160 lb N/acre in 40 lb N/acre increments. In 1998-1999, N treatments were 0 to 200 lb N/acre in 50 lb. N/acre increments for C/C/C locations and 0 to 120 lb N/acre in 30 lb N/acre increments for A/C locations. Pre-sidedress soil NO_3-N and NH_4-N samples were collected in June (approximately 12 to 18 inches tall) from the 0 lb N/ac plot within each replication and collected as described for pre-plant soil NO_3-N and NH_4-N samples (Bundy and Andraski, 1995). Herbicides or mechanical weeding were used to control weeds.

After physiological maturity, corn grain yields were obtained by hand-harvesting the center two rows of each plot in late October or early November. Soil samples to a depth of 3 feet were collected from all plots in mid-October to early November and analyzed for NO_3-N and NH_4-N. April of the following growing season, soil samples to the same depth were collected from each plot and analyzed for NO_3-N and NH_4-N. These spring sample results were compared to NO_3-N and NH_4-N concentrations from the previous fall samples that were collected after the growing season. Soil samples were collected as described for pre-plant soil NO_3-N and NH_4-N samples (Bundy and Andraski, 1995).

An analysis of variance (PROC ANOVA) was performed to show N rate and management system effects on corn grain and silage yields as well as whole plant (grain and stover) N uptake (SAS, 1988). Regression analysis was used to determine economic optimum N rate (EONR) and grain and silage yields at the EONR. Linear-response plateau (LRP) and quadratic -response plateau (QRP) models using PROC NLIN, and quadratic regression using PROC REG were compared to determine EONR and yield at EONR (SAS, 1988).

RESULTS AND DISCUSSION

Background Soil N for adjustment to PPNT

Pre-plant soil NO_3-N tests are a direct measurement of residual N from the previous growing season. The pre-plant soil NO_3-N test is recommended on medium or finer textured soils when corn follows corn in the crop rotation and previous climatic conditions increase the likelihood of NO_3-N carryover. A portion of the soil NO_3-N measurement is credited against the N needs of the subsequent crop. In Wisconsin, a background level of 50 lbs N/ac is subtracted from the soil NO_3-N measurement to calculate an adjusted N need. This study found relatively low pre-plant soil NO_3-N contents at all locations (Fig. 1 and Table 2). Pre-plant soil NO_3-N content collected at C/C/C locations, 0- to 3-ft depth, ranged from 21.7 to 45.9 lb N/acre with an average of 26.9 lb N/acre across all locations for 1998 to 1999. This suggests that background levels on these sandy loam soils in this study need to be lowered from the present 50 lb N/acre to 30 lb N/acre. Therefore, no NO_3-N credit would be given at any C/C/C locations.

Pre-plant soil NO_3-N content collected at the A/C locations, 0- to 3-ft depth, ranged from 20.4 to 83.5 lb N/acre, averaging 46.9 lb N/acre across all locations for 1997, 1998 and 1999 (Table 2). Due to the abilities of alfalfa to utilize residual N and the low early season mineralization of the alfalfa residue very little NO_3-N was present up to the pre-plant sampling. Levels at the A/C locations were slightly larger than C/C/C especially at the 0- to 1-ft depth, probably due to increased mineralization of fall killed alfalfa at some locations.

Critical Soil N-Sufficiency Value for PSNT

Pre-sidedress soil NO_3-N tests differ from pre-plant soil NO_3-N, because the NO_3-N concentration is used as an index of N availability from organic N sources (manure or legumes) to the subsequent crop (Bundy and Meisinger, 1994). Pre-sidedress soil NO_3-N content for the C/C/C locations, 0 to 3 ft, ranged from 28.2 to 63.6 lb N/acre while averaging 51.3 lb N/acre, 1998-1999 (Table 2). This represents a net increase of only 24.4 lb N/acre between sampling periods. The small increase in NO_3-N within the 0- to 1-ft depth could be due to the high carbon - nitrogen ratio of corn residue resulting in microbial N immobilization, leaching, low air temperatures decreasing mineralization rates and/or crop uptake.

Pre-sidedress soil NO_3-N content from A/C locations, 0 to 3 ft, ranged from 78.0 to 145.3 lb N/acre with an average of 113.2 lb N/acre, 1997-1999 (Table 2). An average increase of 66.3 lb N/acre between sampling times shows that alfalfa is providing a substantial amount of N with a range of 31.2 to 92.3 lb N/acre across all locations, 1997-1999. Although most of the increase occurred in the 0- to 1-ft level, considerable increases occurred within the 1- to 2- and 2- to 3-ft depths at some locations ranging from 5.3 to 29.2 and 2.1 to 35.3 lb N/acre, respectively.

Several studies have shown the usefulness of the pre-sidedress nitrate test (PSNT) in identifying N sufficient sites. These studies have placed a value of 21 to 30 parts per million (ppm) soil NO_3-N concentrations (0 to 1 ft) as being adequate for maximum corn yields (Bundy and Andraski, 1995; Magdoff, et al., 1984; El-Hout and Blackmer, 1990; Klausner et al., 1993). Pre-sidedress soil NO_3-N concentrations (0-1 ft) at A/C locations ranged from 9 to 22 ppm with two locations above the critical 21 ppm level (Table 2). Although six out of eight locations were below the 21 ppm level, only one location showed a response to applied N probably due to a poor alfalfa stand density (approximately 1.5 plants/ft^2).

When comparing relative yield to PSNT levels (0 to 1 ft) at all locations (Fig. 2), the observed critical soil NO_3-N level in this study was found to be 17 ppm with a R^2 value of 0.68. This suggests that the critical PSNT level (0 to 1 ft) on sandy loam soils in this study needs to be 17 ppm rather than the 21 ppm standard established by other studies. Bundy and Andraski (1993) also found a lack of yield response on sandy loam soils when levels were below 21 ppm at A/C sites. This is probably due to leaching of mineralized N from the 0- to 1-ft depth to the 1- to 2- and 2- to 3-ft depths and/or low air temperatures slowing legume N mineralization. Since corn yields did not respond to applied N, it is believed that legume N continued to mineralize after the PSNT to provide adequate N for the remainder of the growing season.

Bundy and Andraski (1993) found that a soil NO_3-N sampling depth of 1 ft at pre-sidedress time might be sufficient to determine legume N mineralization. Although most of the increase in soil NO_3-N concentrations occurred within the 0- to 1-ft depth in this study, substantial increases also occurred within the 1- to 2- and 2- to 3-ft depths. When comparing relative yield to PSNT levels (0 to 2 ft) at all locations (Fig. 3), the R^2 values improve to 0.79 with an average critical PSNT level of 11 ppm. This suggests that the PSNT should be sampled to a depth of 2 ft on these sandy loam soils to improve the prediction of N sufficient locations. When comparing critical PSNT levels calculated in this study to the actual PSNT values, five to seven and six of seven A/C locations would be non-responsive to N at the 17 ppm (0 to 1 ft) and at 11 ppm (0 to 2 ft), respectively. This confirms that sampling to a depth of 2 ft would improve the prediction of non-responsive locations.

For all C/C/C locations in 1998 and 1999, pre-sidedress soil NO_3-N concentrations (0 to 1 ft) were well below the 21 ppm level and ranged from 4 to 10 ppm (Table 2). These are appropriate concentrations due to the lack of organic additions at these locations. Small increases in soil NO_3-N concentrations occurred at the 1- to 2- and 2- to 3-ft depths, suggesting that very little mineralized N was available to be leached or that little organic mineralization was occurring at these depths.

Potential N Carryover on Sandy Loam Soil

Fall soil NO_3-N contents increased with increasing N rates across all locations, 1997, 1998 and 1999 (Fig. 4 to 6). LeClerc (1987) found similar data that as N rates increased fall NO_3-N contents also increased. This is especially true at A/C locations with application rates of 120 to 160 lb N/acre plus available alfalfa N credits far exceeds crop N needs. This resulted in residual NO_3-N contents ranging from 85 to 190 lb N/acre of across all locations in 1997, 1998 and 1999. It is also important to note that under both rotations, the high N rates (90 to 200 lb N/acre) resulted in considerably more NO_3-N being found in the 1- to 2- and 2- to 3-ft depths. This suggests that NO_3-N is being leached to greater depths for the high N rates as compared to lower N rates.

The potential to retain fall residual NO_3-N during the over-wintering period is very low in the soils used in this study. Since the soils in this study retain only about 1.2 to 1.6 inches of available water per foot of soil, a very small amount of rainfall and /or irrigation could move NO_3-N through the soil profile to a depth below the effective rooting depth of the crop. This is easily seen in the spring soil NO_3-N contents in 1997 and 1998 (Fig. 4 and 5). Soil NO_3-N losses at A/C locations in 1997 and 1998 ranged from 5.0 to 94.6 lb NO_3-N /acre. The greatest loss occurred within the 0- to 1-ft and 1- to 2-ft depths and at the 90 to 120 lb N/acre rates. Similar research has shown that spring NO_3-N losses increase with increasing fall residual NO_3-N contents, and that losses can be explained by location (soil type) and fall NO_3-N content 96 % of the time (LeClerc, 1987). It is also important to note that losses occurred during years of below normal over-winter precipitation, which suggests that, under years of normal or above normal over-winter precipitation, losses could be greater.

In 1998, C/C/C locations show a loss of 4.0 to 62.9 lb NO_3-N/acre, at all locations (Fig. 5). Again losses increased with increasing N rates and were greatest at the 150 to 200 lb N/acre rate. Similar to the A/C locations, NO_3-N losses were greatest in the 0- to 1- and 1- to 2-ft depths that suggest substantial leaching from these depths from fall to spring.

In 1999, spring NO_3-N contents actually increased during the over-wintering period regardless of rotation (Fig. 6). Spring soil NO_3-N contents increased due to below normal over-winter precipitation which decreased NO_3-N leaching and above normal fall and spring air temperatures which increased mineralization of remaining alfalfa residue, corn stovers, corn roots and soil organic matter. Across all locations and N rates, spring NO_3-N contents increased an average of 22 lb NO_3- N/acre (0 to 3 ft). The majority of the NO_3-N gain occurred in the 1- to 2- and 2- to 3-ft depths, while a decrease at the 0- to 1-ft depth was especially true at the higher N rates. This suggests that leaching did occur in the 0- to 1-ft depth but was retained within the 1- to 2- and 2- to 3-ft depths due to below normal over-winter precipitation. Reports of over-winter retention of soil NO_3-N have been reported by Smita and Watts (1978), Read and Cameron (1979), and Bundy and Malone (1988).

Economic Optimum N Rate (EONR) on Sandy Loam

EONR averaged 0 lb N/acre for all A/C locations (1997-1999) accept for one location that showed a response level of 117 lb N/acre (Table 3). Grain yields (irrigated and non-irrigated) were considered above normal (normal ~120-150 bu/acre) for this area even though weather conditions during the growing season were slightly below normal. The exception was the Onan location that experienced below normal precipitation during the 1998 growing season and caused below normal grain yields regardless of N rate.

All C/C/C locations (1998 to 1999) showed a corn grain yield response to N. The economic return and N recovery of applied N increased with increasing N to an average EONR of 171 lbs N/ac for irrigated locations and 106 lb N/acre for the non-irrigated locations. Current UWEX N recommen-dations for C/C/C on these soils in this study recommend 160 to 180 lb N/acre on irrigated sites and 120 to 150 lb N/acre for non-irrigated sites. This suggests that current UWEX N recommendations are 20 to 50 lb N/acre above the EONR for non-irrigated but within the acceptable range for irrigated locations found in this study.

Annual groundwater recharge in this region is estimated to be 9.5 inches per year. With this information, one can calculate the amount of NO_3-N (lb/acre) needed to raise NO_3-N concentrations in the recharge water above the federal action limit of 10 ppm. The leaching of only 21.5 lb NO_3-N/acre is needed to increase the annual recharge water above the 10-ppm Federal action limit. When comparing

1997 and 1998 fall to spring NO_3-N losses, we find that N applications above 40 lb N/acre for A/C and 100 lb N/acre for C/C/C locations resulted in losses above 21.5 lb NO_3-N/acre. It should be mentioned that the 9.5 inches of recharge water is an annual estimate, while the NO_3-N losses in this study are from fall to spring. This suggests that fall to spring NO_3-N losses should be considered a portion of the overall NO_3-N losses and could be greater due to the potential for additional losses during growing season.

Present University of Wisconsin Extension (UWEX) corn N recommendations is intended to produce economically optimum yields. Corn N recommendations for non-irrigated sandy loam soils within the state of Wisconsin are 120 to 150 lb N/acre. This is 20 to 50 lb N/acre above the 100 lb N/acre water quality N rates calculated in this study. If society chooses to regulate N applications for water quality impacts to the 100 lb N/acre level at C/C/C locations, then who will pay for the economic hardship this restriction will impose? The average corn grain yield will be reduced by 24 bu/acre ($48/acre) and 9 bu/acre ($18/acre) for 1998 and 1999, respectively. It should be noted that society is already paying to remove NO_3-N from public and private drinking water supplies at considerable costs. A possible solution is to reward farmers who apply N rates at or below the EONR established in the study. Cost-sharing could be provided to offset the economic losses accrued by a reduction in N rates. Rewarding farmers to reduce N rates for water quality concerns while at the same time maintain economic viability could be a win-win situation.

CONCLUSIONS

1) Pre-plant soil NO_3-N contents (0 to 3 ft) at all locations were relatively low. Background levels need to be lowered to 30 lb N/acre from the present 50 lb N/acre on these sandy loam soils.

2) The observed critical soil NO_3-N level in this study was found to be 17 ppm (0 to 1 ft) and 11 ppm (0 to 2 ft). The critical PSNT levels on sandy loam soils is below the 21 ppm (0 to 1 ft) and 15 ppm (0 to 2 ft) standards and needs to be lowered.

3) Fall soil NO_3-N contents (0 to 3 ft) increased with increasing N rates across all locations and years. This is especially true at A/C locations where an application rate of 120 to 160 lb N/acre plus available alfalfa N credits far exceeds crop N needs.

4) The potential to retain fall residual NO_3-N during the over-wintering period is very low in the soils used in this study. The greatest loss occurred within the 0- to 1- and 1- to 2-ft depths and at the 90 to 120 lb N/acre rates for A/C locations and 150 to 200 lb N/acre for C/C/C locations. It is also important to note that these losses occurred during years of below normal over-winter precipitation, which suggests that under years of normal or above-normal over-winter precipitation losses could be greater.

5) In 1999, spring NO_3-N contents increased during the over-wintering period regardless of rotation. Increases were likely due to below-normal over-wintering precipitation that decreased NO_3-N leaching and above normal fall and spring air temperatures that increased mineraliza-tion of remaining alfalfa residue, corn stovers, corn roots, and soil organic matter.

6) Only 21.5 lb NO_3-N/acre needs to be leached on these soils to increase the annual recharge water above the 10 ppm federal action limit. When comparing 1997 and 1998 fall to spring NO_3-N losses, we find that N applications above 40 lb N/acre for A/C and 100 lb N/acre for C/C/C locations resulted in losses above 21.5 lb NO_3-N/acre.

7) Current UWEX N recommendations (120 to 150 lb N/acre) are 20 to 50 lb N/acre above the EONR for non-irrigated locations calculated in this study but within the acceptable range (160 to 180 lb N/acre) for irrigated locations. If corn N recommendations were decreased to 0 lb N/acre for A/C locations and 100 lb N/acre for C/C/C locations for water quality impacts, N recovery would increase, fall soil NO_3-N concentrations would decrease, but economic returns would decrease at C/C/C locations only. If Society chooses to regulate N applications for water quality impacts, then who will pay for the economic hardship this restriction will impose? Cost-sharing could be provided to offset the economic losses accrued by a reduction in N rates. Rewarding farmers to reduce N rates for water quality concerns while at the same time maintain economic viability could be a win-win situation.

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