NITROGEN LOSS IN CORN PRODUCTION VARIES AS A FUNCTION OF TOPSOIL DEPTH

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ABSTRACT

Understanding availability and loss potential of nitrogen (N) for claypan soil landscapes that vary in topsoil depth could help producers make better decisions when managing crops for feed grain. While it has been well documented that topsoil depth on these soils plays an important role in storing plant-available water, it is not well known how this same soil property affects N loss for growing seasons that are abnormally wet, such as was the case in 2008 and 2009 for much of Missouri. This 2009 plot study was conducted to evaluate, for an excessively wet growing season, the influence of depth to claypan (DTC) on unaccounted for N (UN) in corn grain production. In order to understand this relationship, N recovered in grain and stover, grain yield, and SPAD chlorophyll meter readings were taken from corn grown on a range of topsoil depths (0 to 50 cm) and fertilized with 168 kg N/ha. Observations during this growing season showed that N stress to the corn crop increased as DTC decreased. Yield in the shallow DTC soils was also suppressed. The loss of inorganic N (IN) increased from 70 to 140 kg N/ha, as DTC decreased. We attribute the loss largely to denitrification. The significance of this research is that it helps to establish the need for site-specific N management strategies that can be targeted to landscape variations.

Keywords: depth to claypan (DTC), denitrification, N loss

INTRODUCTION

Nitrogen losses from volatilization, denitrification, and leaching may result in poor crop performance, and increase the risk of environmental contamination (Cassman et al., 2002). Nitrogen loss potential on claypan soils for abnormally wet years is not well known and its understanding could improve decisions when managing these soils for corn production. The dominant N fertilizer management system is still application of uniform rates over whole fields (Scharf et al., 2006). Further, most corn acres in the U.S. have N applied before the crop is planted. Uniform pre-plant N applications across fields and farms with varying N needs lead to frequent spatial and temporal mismatches between fertilizer-N applied and crop N needs.

While applying a blanket of N over a field that appears to have a relatively uniform soil seems like the ideal way to farm, this practice has been documented to have economic and environmental loss. Recent research has shown that the amount of N needed often varies widely within individual corn fields (Davis et al., 1996; Blackmer and White, 1998; Schmidt et al., 2002; Mamo et al., 2003; Scharf et al., 2005; Scharf et al., 2006). Plant N need across fields is not uniform (Scharf et al., 2005) and uniform N applications over variable landscapes is a major deficiency in current farming systems that creates opportunities for N loss to ground and surface waters (Power et al., 2001; Scharf et al., 2006). Claypan soils have a unique and complex hydrology controlled by a slow soil-matrix water flow through the restrictive layer generally located 0.15-0.6 m below the soil surface (Jamison et al., 1968; Kitchen et al., 1999). Because of this claypan, N is vulnerable to denitrification during extended wet periods of the spring and early summer. A better understanding of N loss potential under these conditions is needed.

Productivity of crops on claypan soils has been well documented (Thompson et al., 1991; Kitchen et al., 1999). In corn production, the yield on a claypan soil with no topsoil was half that produced with a topsoil thickness of 38 cm (Thompson et al., 1991; Kitchen et al., 1999). Three main soil factors of these soils are known to contribute to yield reductions: 1) decreased root-zone plant-available water capacity (Gantzer and McCarty, 1987; Thompson et al., 1991; Thompson et al., 1992; USDA-NRCS, 1995; Kitchen et al., 1999); 2) restricted root penetration due to clay accumulation and poor soil structure in the Bt horizon (Jamison et al., 1968; USDA-NRCS, 1995; Yang et al., 2003; Myers et al., 2007); and 3) low soil organic matter, fertility, and early-season oxygen levels needed for root growth (Jamison et al., 1968). While DTC and these factors are known to cause the decrease in yield for a dry- to normal-precipitation year, it is not well understood how wet growing seasons impact crop growth.

The understanding of varying DTC for Midwest claypan soils poses the question of the effects DTC has on N mineralization and loss potential for an excessively wet season. The main purpose of this study is to evaluate, for an excessively wet season, the effect that DTC has on N loss potential for claypan soil landscapes.

Photo 1. The layout of the 32 SPARC plots at the University of Missouri South Farm showing corn, soybean, and switchgrass growing on blocks of varying topsoil depth.

MATERIALS AND METHODS

This study was conducted at the University of Missouri South Farm, located near Columbia, MO on a study site known as Soil Productivity Assessment for Renewable energy and Conservation (SPARC). Precipitation data was collected at a long-term weather station located within one kilometer of the study location. This particular experiment was initiated in 2008 on plots which were originally used from 1982-93 to study corn and soybean production. The plots were uniquely constructed to have a range in topsoil depth from 0-40+ cm (Gantzer and McCarty, 1987). As seen in Photo 1, 16 blocks of different DTC are being used to compare corn, bean, and switchgrass production. This paper will focus solely on the 2009 corn production.

Soil core samples were taken from each block prior to planting using a Giddings hydraulic soil sampling device with a 5-cm diameter, 120-cm long tube. The soil samples were separated into three groups: topsoil, claypan, and subsoil below the claypan. The three distinct layers were separately put through a 5-mm screen. Fifty grams of subsample from each layer (topsoil, clay, subsoil) were air dried and pulverized in a soil grinder to pass a 2-mm screen for further NH_4 and NO_3 analysis and determining available inorganic N (IN).

Eight rows of Roundup Ready corn (590VT3 YieldGard VT Triple Hybrid) were planted on June 1, into 6.7x10 m plots with a 4-row planter. Corn was planted at 69,000 seeds/ha. Significant rainfall in May prevented earlier planting. Corn was fertilized at planting with 168 kg N/ha as ammonium nitrate. Weeds were sprayed with Roundup two weeks after planting. Corn was harvested in November using a two-row harvester with an onboard weigh bin when grain was approximately 16% moisture. Internal 4 rows were harvested to avoid any edge effects. Yield was corrected to 15.5% moisture.

During the growing season, height and SPAD (Minolta 502 SPAD Chlorophyll Meter) readings were taken, within the harvest area, on July 22 from 20 random plants to help quantify the N health status of the crop. Just before the combine harvest, eight corn plants with grain were randomly hand-harvested for determining total plant N uptake. The grain was dried for 48 hours at 40°C to approximately 5% moisture, ground in a Wiley mill and analyzed for total N. Stover was dried then put through a chipper shredder and a subsample was further dried and ground in a Wiley mill and similarly analyzed for total N content

Given the chlorotic condition of the crop leading up to harvest, we presumed little IN was available at the end of the growing season. A partial N budget was determined by the following equations:

Available N= IN + FN
Unaccounted N (UN)= (FN + IN) – PN
Potential denitrified N= UN- LN- RN

Where: IN=Inorganic N, FN=Fertilizer N, PN=Plant N, UN=Unaccounted for N, LN=estimated Leaching N, RN=estimated Runoff N

RESULTS AND DISCUSSION

Rainfall at the study site was much higher for 2008 and 2009 than the long-term average (Fig. 1). Most important were the high amounts of rainfall that occurred these years during the normally hot and dryer month of July, when crop water needs peak. For these two years, monthly precipitation for June and July ranged from 5 to 16 cm more than the long-term average. The precipitation data for 2008 is shown to help illustrate full water profile of the study site prior to planting in 2009.

Saturation of the claypan soil profile can be a major contributor to N loss via denitrification (Hong et al., 2007). The two sources of N in which denitrification can be derived from are the fertilizer N (FN) applied and the inorganic N (IN) that is mineralized within the soil. The IN is the sum of NO_3-N and NH_4-N. Initial soil sampling of the plots showed there was a steady increase in the amount of NO_3-N and a decrease in NH_4-N as the DTC increased (Fig. 2). Saturated soils with shallow DTC evidently had less O_2, preventing the NH_4-N from being converted to NO_3-N. This resulted in smaller amounts of NO_3-N in the profile when less topsoil was present. Total IN was not appreciably different by DTC.

While it is well known that lack of water with a decreasing DTC will have a negative effect on crop grown and yield, (Thompson et al., 1991; Jiang et al., 2008), excess water along with shallow DTC can cause a different stress that can also result in yield loss. As shown in Fig. 3, we found yield to increase as DTC increased, with an R^2 value of 0.57. This relationship was most notable from 0 to 25 cm DTC. We also found that the largest variability in yield for areas with similar DTC was found when DTC was < 20 cm (Fig. 3). Thompson et al., 1991 found a similar decrease for DTC < 12.5 cm. The standard deviation for <20 cm and >20 cm were 1.74 Mg/ha and 0.77 Mg/ha, respectively.

For the 2009 growing season, the most significant factor of yield reduction with decreasing DTC was N stress caused by N loss from the soil-crop system. Visual analysis of the corn plants showed N deficiency signs even before tasseling, and we ascertained this stress would cause yield to be compromised. With visible observations, chlorophyll measurements using a SPAD meter were taken to help monitor the degree of corn N stress. Normally, absolute SPAD readings are not used to determine N stress, but readings are transformed into a sufficiency index. However, studies indicate corn with SPAD readings less than 52-58 have N deficiency (Hawkins, et al., 2007). In this study, SPAD readings indicated greatest N stress with lower DTC (Fig. 4). However, generally all plants showed some degree of N stress due to N; the shallow DTC plants were just substantially more stressed. The relationship here of chlorophyll measurements and DTC was similar to the relationship shown between yield and DTC (Fig. 3).

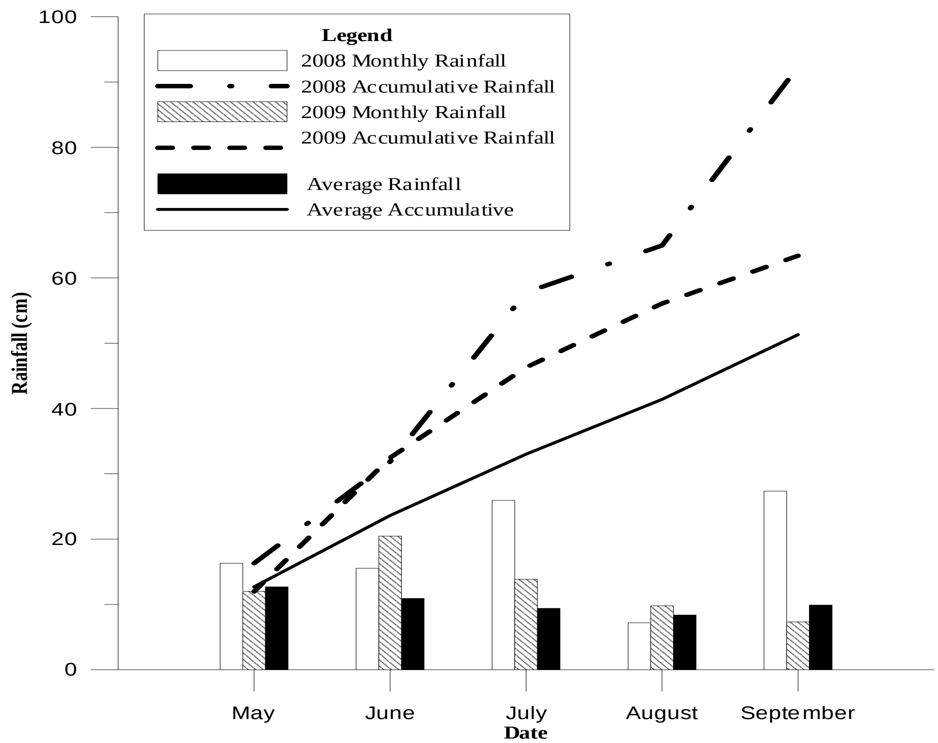
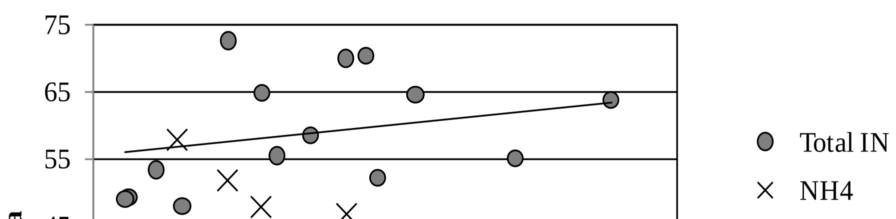


Fig. 1. Rainfall during the growing season at the study site for 2008, 2009 and long-term averages. An accumulative precipitation line graph is shown above the bar graph. Notice June and July were substantially higher than the average, causing an increase in the potential for denitrification.



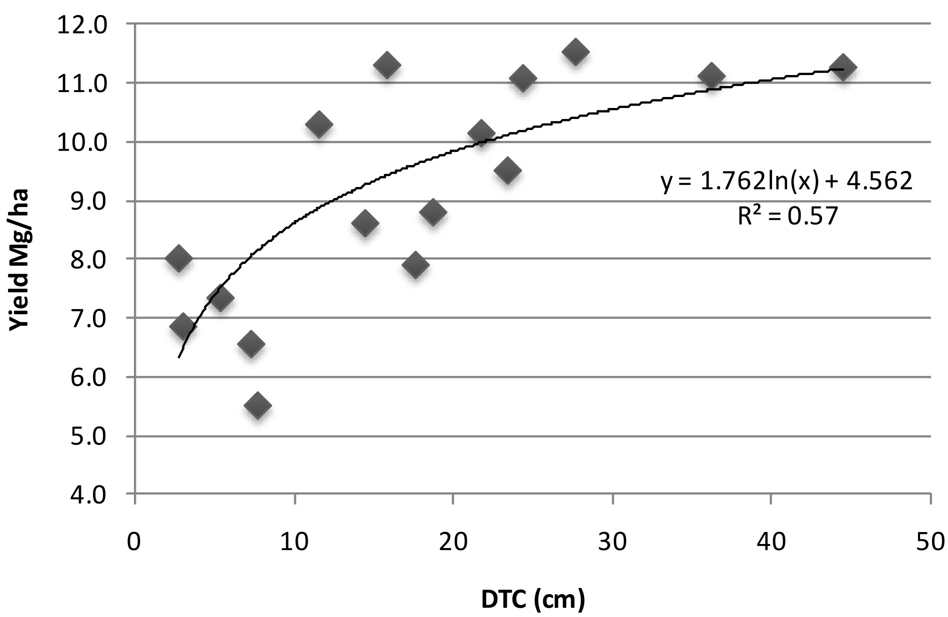


Fig. 3. Corn yield results for 2009 shown in relation to DTC.

The DTC was classed into four groups consisting of 0-10, 10-15, 15-25, and 25+ cm of topsoil. The total N that was available to the plants at planting for all classes was no less than 215 kg N/ha (Fig. 5). Unaccounted for N decreased as DTC increased. Shallow DTC resulted in approximately 130 kg N/ha lost; that number decreased by half for topsoil measuring > 25 cm. Shallow DTC resulted in less N taken up by the plant which in turn explained the decrease in yields (Fig. 3). Yield reached a maximum at about 20 cm of topsoil. With the yield and SPAD data (Fig. 4), we speculate that the deepest DTC held high amounts of water which may have also increased the propensity for denitrification, but less than that observed with the shallow DTC (Fig. 4).

From the study, DTC was shown to have a large effect on yield, but as importantly on the amount of N that was unaccounted for. We propose this N was lost to the environment by denitrification. While some of the N lost to the environment could be through leaching and runoff, these have not been shown to be a significant loss pathway for claypan soils. For normal to wetter than normal growing seasons, loss by runoff is less than 5% of total available to the crop (Blevins, et al., 1996). In-season N loss by leaching for these soils is generally less than 10% of the total available to the crop (Kitchen, et al., 1998). Thus, denitrification becomes the largest component of the N that is being lost to the environment (Fig. 6). Nitrogen loss from denitrification was also the conclusion of Blevins (1996).

In Fig. 7, UN is shown as a function of DTC. We project 80 to 90% of the UN to have denitrified (Fig. 6). As the DTC decreases, the amount of N lost increases. Depth to claypan <20 cm showed the greatest degree of UN.

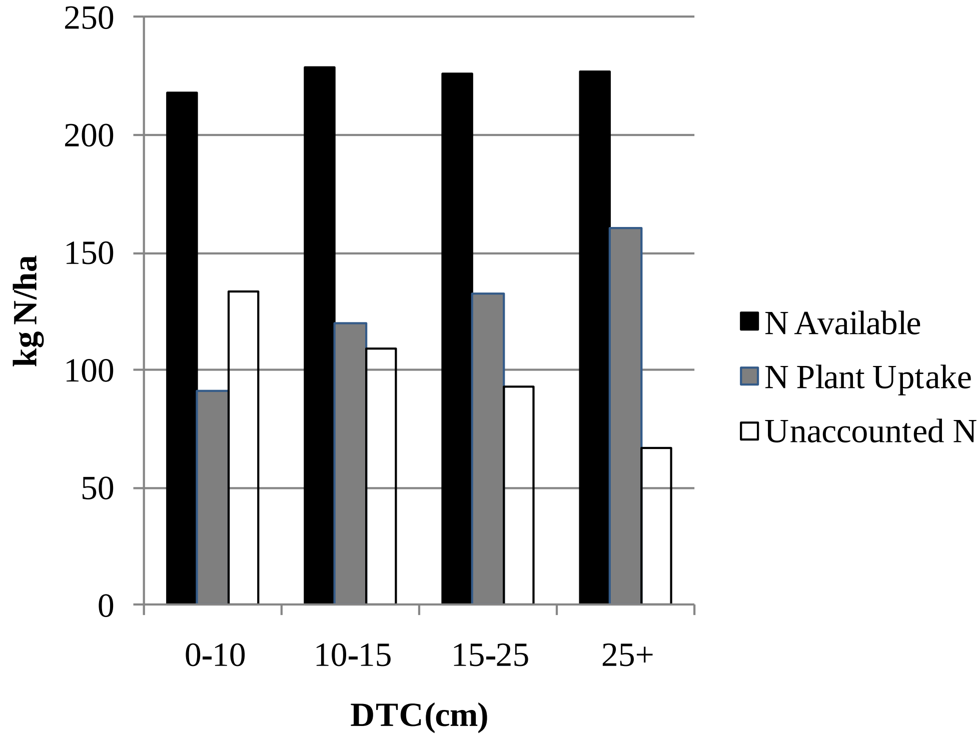


Fig. 5. Nitrogen available to crop, plant N uptake, and unaccounted for N shown in relation to DTC classes. Unaccounted for N would primarily be lost by leaching, runoff, and denitrification (Fig. 6).

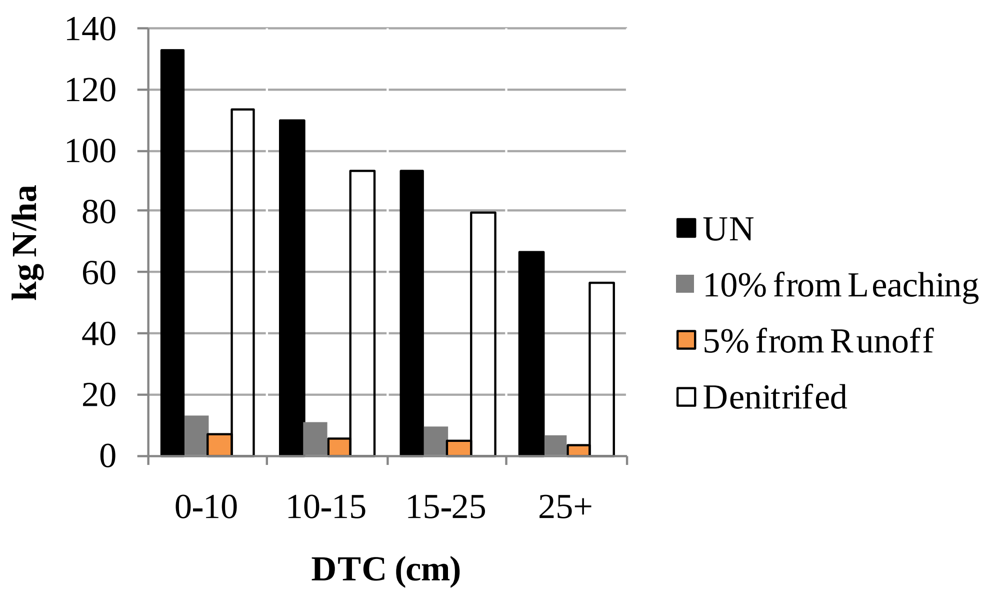


Fig. 6. Quantities of UN estimated for the major loss pathways of leaching, runoff, and denitrification.

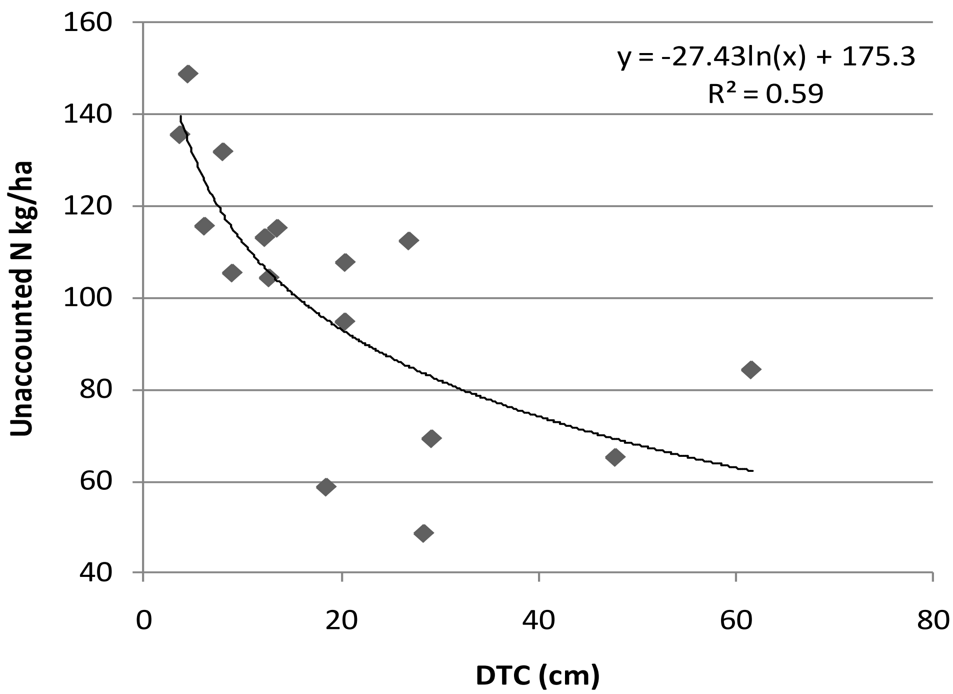


Fig. 7. Unaccounted N as a function of DTC.

CONCLUSION

While insufficient water is an issue for claypan soils in dry to normal precipitation years, the effects of excessive water on claypan soils can be also detrimental to yields and the environment. Of particular concern would be denitrified N that left the soil as N_2O, a greenhouse gas. The significance of this research is that it helps to establish the need for site-specific N management strategies that can be targeted to landscape variations, such as varying DTC on claypan soil landscapes.

DISCLAIMER

Mention of trade name or commercial products is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture or the University of Missouri.

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