UTILIZING FERTILIZER TECHNOLOGIES TO REDUCE NITRATE LEACHING IN THE CENTRAL SANDS REGION OF WISCONSIN

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Abstract

Leaching of nitrate into the groundwater has been a continuing – and extensively researched -- problem in the sandy soils of Wisconsin. However, no proven solution to this problem has been identified as yet. Research results from our studies in 2009 showed that several products had potential in reducing nitrate-nitrogen (NO_3-N) leaching. Although not always statistically significant, one slow-release fertilizer, Environmentally Smart Nitrogen (ESN), produced greater yields than conventional fertilizer. Moreover, NO_3-N concentrations in leachate from the ESN treatment were also significantly less that other treatments.

Introduction

Leaching of nitrate from agricultural production systems to groundwater is a primary water quality concern in Wisconsin. This is especially true in the Central Sands Region of the state, where there is an inherent risk of leaching due to the physical properties of the soil. Elevated levels of NO_3-N in groundwater (>10 ppm) can cause severe problems for infants and long-term ingestion of water with high nitrate levels is not recommended (Bundy et al., 1994). The United State Environmental Protection Agency has placed a standard of 10 ppm as the maximum allowable nitrate concentration for drinking water, yet in many rural areas dominated by production agriculture nitrate concentrations in drinking water wells exceed this concentration. Not only has this problem appeared to have worsened over the past 20 years, but little has been done to improve nitrogen management in order to mitigate this problem (Rupert, 2008).

Efficient use of nitrogen fertilizer in agricultural systems remains a top research objective. Improved nitrogen use efficiency usually overlaps with improved economic efficiency of production and reduced nitrogen losses to the environment. This is especially true for potato production on sandy soils in central Wisconsin. Nitrogen use on this high N demand crop has both agronomic and environmental consequences. Growers typically apply N in excess of 250 lb ac^{-1} yr^{-1} to achieve optimal yields; but this increase in yield has had an environmental cost. Saffinga and Keeney (1977) discovered that groundwater below irrigated potato production consistently exceeds 10 ppm. While N management in potato production systems has certainly improved since then, through improvements in application timing, leaching losses of nitrate continues to be a problem on these soils (e.g. Lowery et al., 1998; Arriaga et al., 2009; Cooley et al., 2009). Kraft and Stites (2003) determined that >178 lb ac^{-1} of nitrogen was transported to groundwater under potato production. Fertilizer applied to sandy soils has an inherently high risk of leaching to groundwater. Andraski and Bundy (1999) determined that 53% of applied N was leached to groundwater in potato production systems on sandy soils.

Kraft and Stites (2003) discussed management options that would be required to decrease nitrate leaching losses such as decreasing total fertilizer rates, splitting fertilizer N inputs, and altering irrigation management. The authors clearly stated why each of these potential methods would have little impact on reducing nitrate concentrations in groundwater. The authors also mentioned that nitrification inhibitors (another fertilizer technology) have been shown by Kelling (1998) to be somewhat effective, but decrease potato quantity and quality. However, fertilizer technologies do exist that have been shown to improve nitrogen use efficiency in potato and reduce nitrate leaching losses, but have not been fully evaluated in Wisconsin's agroecosystems. This fertilizer technology exists as polymer-coated urea (PCU), in which urea granules are encapsulated in a plastic polymer that is resistant to breakdown. As the polymer breaks down over time, as a function of soil temperature and moisture, the urea is slowly exposed to the soil environment where it is able to be taken up by the crop. Polymer-coated fertilizers tend to release nutrients consistently over time and lead to an increase in nitrogen use efficiency (NUE) (Jacobs, 2005). Products such as PCU have been found to increase potato yields over traditional fertilizers in other potato growing areas of the country (Shoji et al., 2001; Hutchinson et al., 2003; Zvomuya and Rosen, 2001; Wilson et al., 2009). Furthermore, Zvomuya et al. (2003) discovered the added benefit of reducing nitrate leaching using PCU over traditional fertilizers in sandy soils in Minnesota. As a result of this research, PCU has become the most common nitrogen fertilizer source in central Minnesota (personal communication C. Rosen). The potential exists for beneficial use in Wisconsin. It should be noted that the sandy soils in Minnesota contain higher levels of soil organic matter (SOM) and silt and clay compared to the sandy soils in Wisconsin. The lower SOM content in the Central Sands means that less nitrogen can be supplied directly from the soil and the lower silt and clay content means these Wisconsin soils have a reduced capacity to retain nutrients. An evaluation of the use of PCU in this region is necessary to evaluate the benefits of PCU in Wisconsin sand plains. Thus, the objective of the study is to evaluate the leaching potential on sandy soils in potato production with slow-release N sources and surfactant treatments.

Materials and Methods

The study was conducted during the 2009 and 2010 growing season and was located on a private farm near Grand Marsh, Adams County, Wisconsin. The study was laid out in a randomized complete block design, with five treatments in three blocks. The treatments consisted of an unfertilized control, ammonium sulfate-ammonium nitrate (AS/AN) as the conventional fertilizer treatment, and three controlled-release fertilizer products (Agrotain®, SuperU®, and ESN®). The controlled-release products use different techniques to control nitrogen release. SuperU® (Agrotain International LLC) contains N-(n-Butyl)-thiophosphoric triamide, a urease inhibitor that delays the conversion of urea to ammonia, and dicyandiamide, a nitrification inhibitor that slows down the conversion of ammonia to nitrites, and, subsequently, nitrates. Agrotain® is a liquid fertilizer additive that also relies on N-(n-Butyl)-thiophosphoric triamide to reduce nitrogen volatilization loss. The ESN®, or Environmentally Smart Nitrogen (Agrium Advanced Technologies, Agrium Inc.), is a granular urea fertilizer that controls nitrogen availability through the use of a thin polymer coating that degrades over time.

All fertilizer treatments were applied at the rate of 250 lb ac^{-1} of N, which is within the recommended rate range for sandy soils. The treatments were applied to four row plots measuring 12 by 20 feet. The ammonium sulfate-ammonium nitrate, Agrotain®, and SuperU® treatments were split into two applications; ESN® was applied once.

In order to assess nitrate concentration in the leachate, pan lysimeters were installed in all treatments. The lysimeters were custom fabricated to include a porous stainless steel top, a sampling line, and a vacuum line (Fig. 1) (Brye et al., 1999). The lysimeters were interconnected and the entire system was connected to a vacuum pump that maintained a constant suction. The suction allowed the lysimeters to capture water as it moved through the soil profile. The lysimeters were installed at the depth of 30 inches below potato hill top prior to potato plant emergence. Any potato seeds disturbed during the installation process were placed back into the appropriate rows to ensure uniform plant distribution.

Water samples were collected weekly May through November in 2009 and 2010. These samples were analyzed for nitrate using ion chromatography. Precipitation and air temperature data were also recorded both in and outside the field. Four sets of petiole samples were collected during the growing season to assess the N status of the plant. Aboveground biomass samples were collected twice during the growing season for N and dry matter mass analyses. Selected areas of each plot were harvested for crop yields measurements. Yield measurements included total potato tuber yield, grading, and specific gravity.

Results and Discussion

In 2009, potato yields showed some significant treatment effects (Table 1). The ESN® produced the greatest potato yields, followed by the conventional fertilizer treatment, Agrotain®, SuperU®, and the untreated control, in that order. There were no statistically significant differences in yield between ESN® and the conventional fertilizer treatment at the 10% confidence level. Agrotain®, SuperU®, and the untreated control also had no significant differences in yield. Potato yields were quite lower in 2010 compared to 2009. This was likely caused by several intense rainfall events that leached N out of the root zone. An additional 120 lb ac^{-1} of N was applied by the landowners through fertigation; this did not appear to improve yields relative to 2009 standards, but likely caused our non-fertilized control sample to yield similarly to our fertilized treatments.

Nitrate concentrations in the pan lysimeters exhibited different patters between 2009 and 2010. In 2009, nitrate concentrations spiked in early June as a result of a large rainfall event that occurred shortly after the second application of fertilizer (as ammonium nitrate or urea) (Fig. 2). In 2010, nitrate concentrations spiked later in the season around mid-July, which occurred in conjunction with a large storm event (>3.5 in) (Fig. 3). As a result, NO_3-N concentrations were much greater during the 2010 growing season compared to the 2009. The large amount of NO_3-N may explain, in part, why yields were suppressed in 2010. The greatest NO_3-N concentrations were observed in the conventionally fertilized plots (Fig. 2, Fig. 3), where peak concentrations in both years approached or exceeded 300 mg L^{-1} of NO_3-N. ESN® and SuperU® had the lowest NO_3-N concentrations among the fertilized treatments during the growing season in 2009 and 2010, respectively. Cumulative leaching of NO_3-N for all treatments were greater during 2010 compared to 2009. In 2009, cumulative NO_3-N loss from the conventionally fertilized plots (179 lb ac^{-1} of N) was more than double the NO_3-N loss from SuperU® (80 lb ac^{-1}) and ESN® (70 lb ac^{-1}) (Fig. 4). The same trend was apparent in 2010 (Fig. 5). Greater NO_3-N losses in 2010 may also be attributed to the 120 lb ac^{-1} of N that was applied through fertigation.

Conclusion

Fertilizer technologies, specifically ESN® and SuperU® have the ability to suppress in-season nitrate losses from potato production systems. Although the products tested in this study have a higher upfront cost than conventional fertilizer, some of them, like ESN®, carry the advantage of a one-time application, saving on equipment and fuel costs. The one-time application of ESN® appears to be a satisfactory application method, while the split-application of urea with SuperU® was not able to maintain yields. Future research will be devoted to management of these fertilizer technologies with respect to rate and application timing.

Figure 1. Pan lysimeter prior to installation.

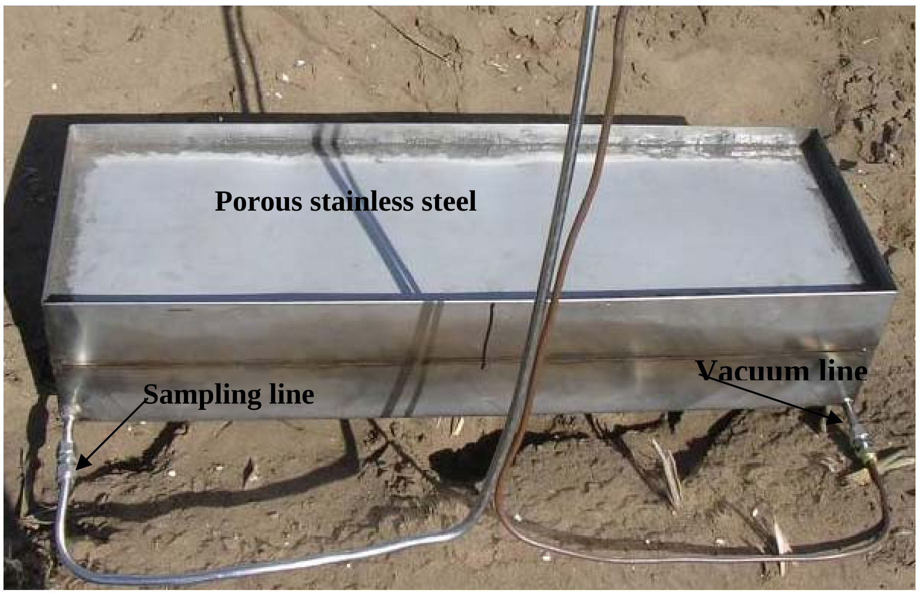

Table 1. Total harvestable potato yields in 2009 and 2010 from Adams County, WI [within columns, yields with the same letter are not significantly different according to LSD (0.10)]

	Yields	
Nitrogen Source	2009	2010
	---- cwt ac^{-1} ----	
ESN ®	740 a	452
AS/AN	681 ab	359
Agrotain	630 bc	365
Super U	616 c	339
0 N (Control)	585 c	432
Pr≥F	0.0034	0.527
LSD	63.8	

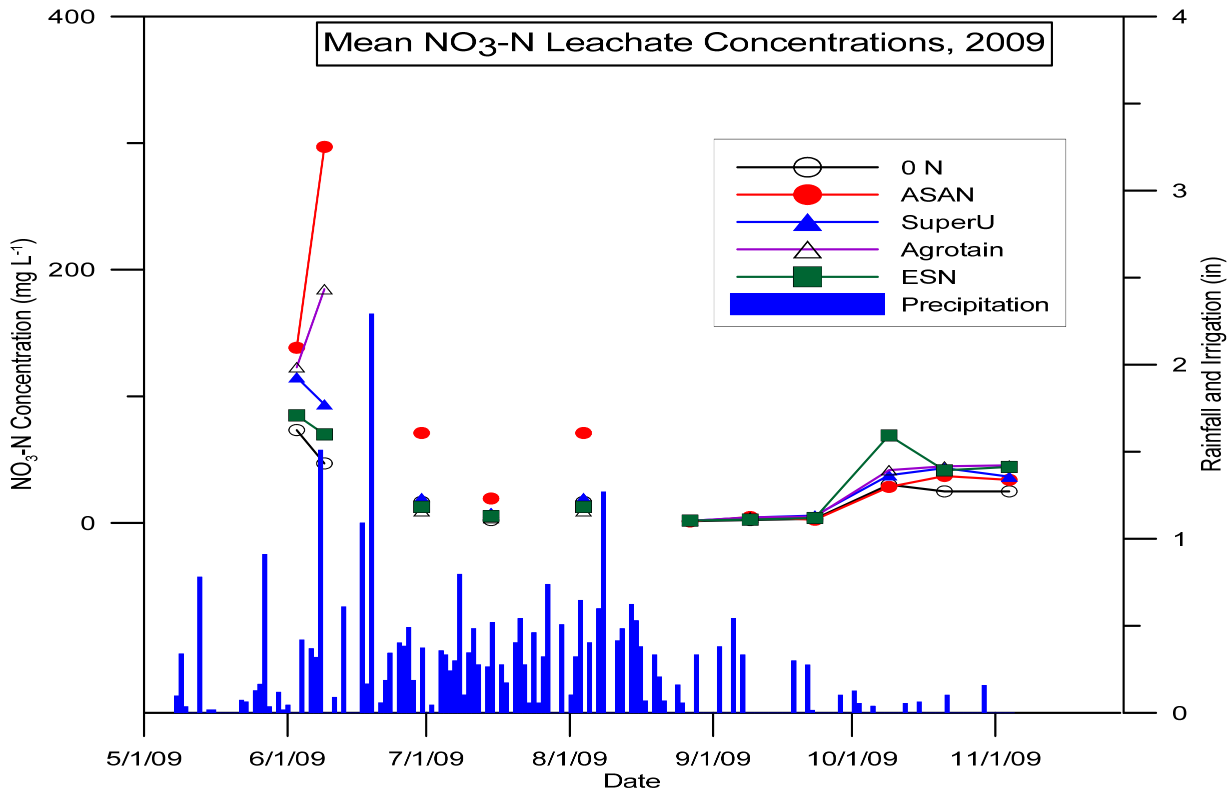

Figure 2. Mean nitrate-nitrogen (NO_3-N) concentrations collected from pan lysimeters 75 cm below the surface during the 2009 growing season from plots fertilized with different N sources.

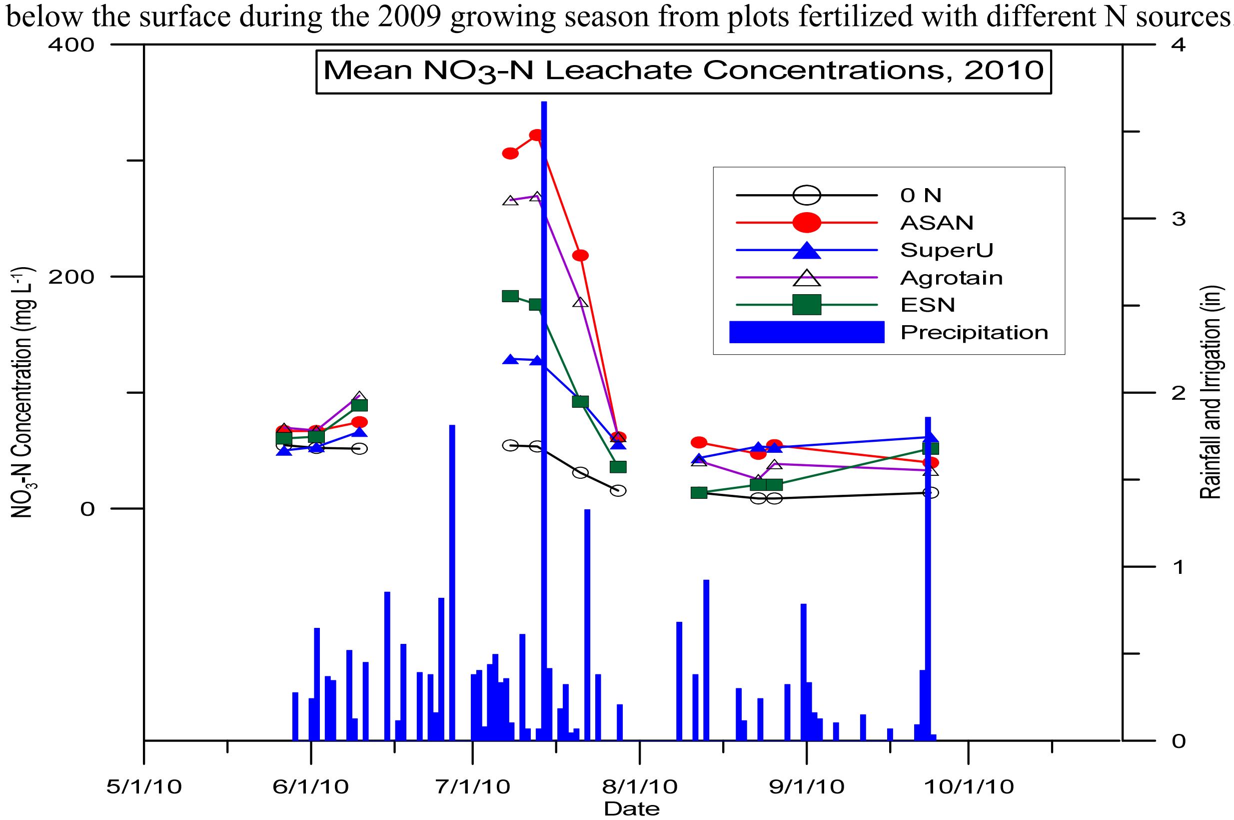

Figure 3. Mean nitrate-nitrogen (NO_3-N) concentrations collected from pan lysimeters 75 cm below the surface during the 2009 growing season from plots fertilized with different N sources.

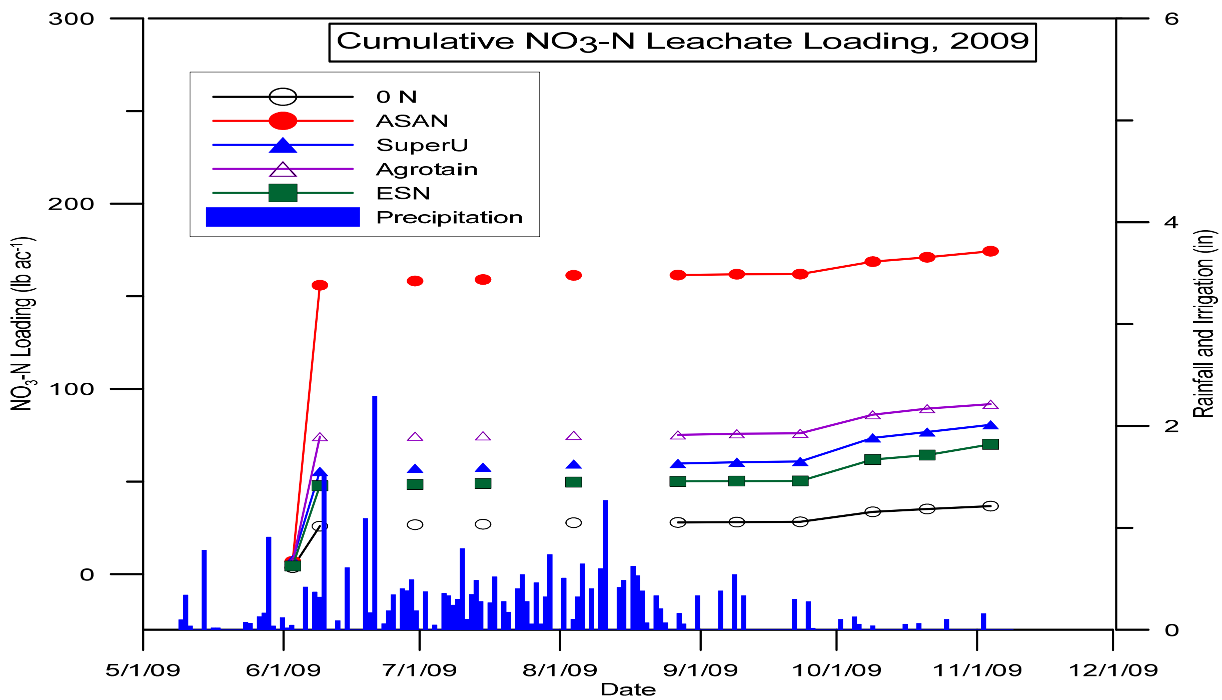

Figure 4. Cumulative nitrate-nitrogen (NO_3-N) loss during the 2009 growing season from plots receiving different N fertilizer sources.

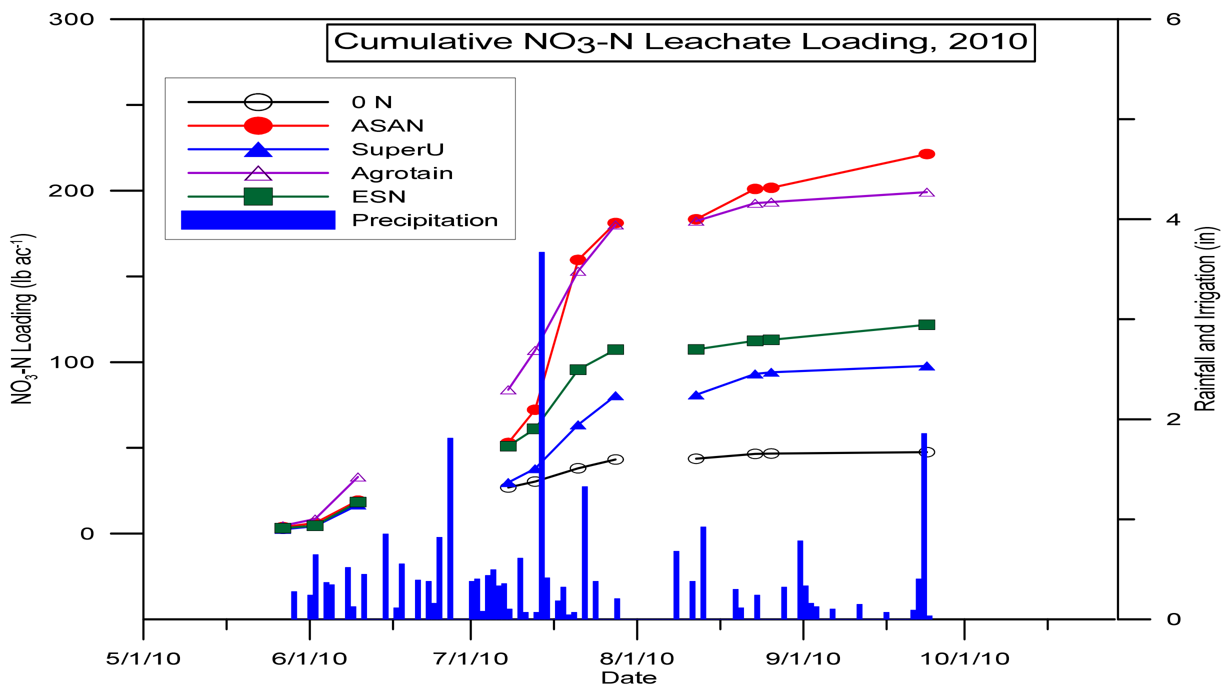

Figure 5. Cumulative nitrate-nitrogen (NO_3-N) loss during the 2010 growing season from plots receiving different N fertilizer sources.

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