Overview of Non-wetting Soils and Use of Surfactant to Increase Water and Nitrogen Use Efficiency in Potato Production

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Abstract: Preferential flow of water and excessive nitrate leaching commonly occur in potato production on sandy soils of Wisconsin, USA where groundwater is relatively close to the soil surface. The problem of nitrate leaching is serious with respect to the environment as nitrate has been linked to the hypoxic zone in the Gulf of Mexico. In potato production in Wisconsin, nitrogen is band-applied to the shoulder of the row in an effort to reduce nitrate leaching as this is a location where it is believed that less water infiltrates. However, we discovered that on these soils the center of the row, where most of the potato plant roots are located, becomes hydrophobic midway through the growing season causing greater preferential flow of water through the shoulders of the row resulting in excessive nitrate leaching. Following this discovery, we used a wetting agent applied to the center of the row, which increased soil water content in the center of the row by more than 50% at several locations over 3 years. This increase in water content remained throughout the growing season although the surfactant was only applied at planting. By improving water use efficiency we discovered as much as an 80% reduction in the peak soil nitrate nitrogen concentration at 1-m depth by using the surfactant in five out of 15 site-years, but the reduction was noted at three out of four different locations. We think this reduction in nitrate leaching was only observed in some years at different locations because the reduction is closely related to rainfall frequency and duration. However, we have not found a direct relationship between the use of surfactant and nitrate nitrogen concentration in the shallow groundwater. In addition to assessing N leaching we evaluated the use of surfactant in com-bination with different levels of N fertiliser use. In 2 of 3 years, surfactant-treated plots showed greater fertiliser N use efficiency than the non-treated plots and had a similar yield as the control with less N-fertiliser. Further research is needed to better understand if there is a potential benefit of using a surfactant to reduce nitrate leaching.

INTRODUCTION

Agricultural chemicals such as nitrate continue to be of concern as a nonpoint source of surface and groundwater contamination. Some researchers think this is the main factor contributing to increases in the Gulf of Mexico hypoxic zone. Data from the U.S. Geological Survey suggest that the upper Mississippi River basin is the source of 31% of the nitrogen entering the Gulf (NPM, 1998b). A large section of the Gulf of Mexico is void of marine life and believed to be caused by a lack of oxygen (thus, the term associated with this is hypoxia). The lack of oxygen is believed to result from an abundance of nitrogen in water entering the Gulf from the Mississippi River. Drainage water from major rivers in Midwestern states such as Iowa, Illinois, Missouri, Minnesota, Kansas, North and South Dakota, Nebraska, and Wisconsin contribute to this problem. A considerable amount of the groundwater that feeds the Wisconsin River comes from groundwater recharged by drainage water from the sandy soil vegetable-producing areas of the state that have an abundance of nitrate, and thus leads to elevated levels of nitrate in the river. In addition to the problem in the Gulf, we have a long-standing concern regarding elevated nitrate levels in the groundwater and wells of this area. Nitrate-nitrogen levels in 20 to 25% of domestic wells in the Central Sands Area, (Stevens Point, Whiting, and Plover area) exceed the USA drinking water standard (10 ppm nitrate-nitrogen). Nitrate levels will continue to increase in groundwater in much of this area unless better management practices are developed (NPM, 1998a). It appears that agriculture is the primary source of nitrate leaching to groundwater. As such, there is an urgent need to reduce nitrate leaching from crop land. Research results of over 20 years ago indicate that nitrate-nitrogen under potato production with irrigation is consistently above 10 ppm at the surface of the groundwater table (Saffigna and Keeney, 1977). We will present data from the past 3 years (2000, 2001 and 2002 growing seasons) that support this nearly three-decade-old data. Research results from potato production on Plainfield sand indicates that a single large precipitation event can result in a considerable amount of nitrate leached regardless of the fertiliser application method (Lowery *et al.*, 1998). Therefore, nitrogen fertiliser must be maintained in a zone in the soil where it is available for plant uptake to avoid leaching to groundwater.

Based on observations by farmers and our research, an extremely dry zone of soil develops in a portion of a potato hill that contains the greatest root density. We think the soil in this zone becomes hydro-phobic and results in nonwetting conditions in the latter part of the growing season. Similar findings have been reported in Europe by Robinson (1999). This dry zone is located about 30 cm below the top of the potato hill. This hydrophobic zone continues to desiccate over the course of the growing season, inhibiting proper water and fertiliser infiltration into this dry region. It appears that this dry zone results in decreased productivity and increased nitrate leaching. Thus, it could potentially contribute to groundwater contam-ination and we have shown that this hydrophobic zone can be reduced or eliminated with the use of surfactant.

It has been shown that a surfactant can be used to increase water infiltration and wetting front advancement in hydrophobic soils (Pelishek *et al.*, 1962; DeBano, 1971). The surfactant (surface active chemicals) acts as a hydrophilic agent thereby aiding in reduction of surface tension of soil water, thus increasing infiltration of water in unsaturated hydrophobic soils (Lowery, 1981). While surfactants increase water infiltration into hydrophobic or non-wetting soils, it may decrease water flux and aggregate stability in wettable soils (Pelishek *et al.*, 1962; Mustafa and Letey, 1969; Miller *et al.*, 1975).

We hypothesised that there is a combination of several factors that cause this hydrophobic zone in a potato hill. The first is the high root density in this region cause significant uptake of soil water from this zone. Second, hill geometry potentially reduces infiltration of precipitation and sprinkler irrigation water into the center of the hill. Third, the potato canopy which captures water and produces stem flow to the center portion of a potato hill in the early part of the growing season (Saffigna *et al.*, 1976) collapse down as the growing season progresses and channels less water to the center of the potato hill. Fourth, as the plant removes water, the sandy soil approaches a critical water content value that leads to the hydrophobic condition. Fifth, as the soil water content in the hill decreases water flow capacity (hydraulic conductivity) become a limiting factor for rapid re-wetting of the dry zone (Hart *et al.*, 1994).

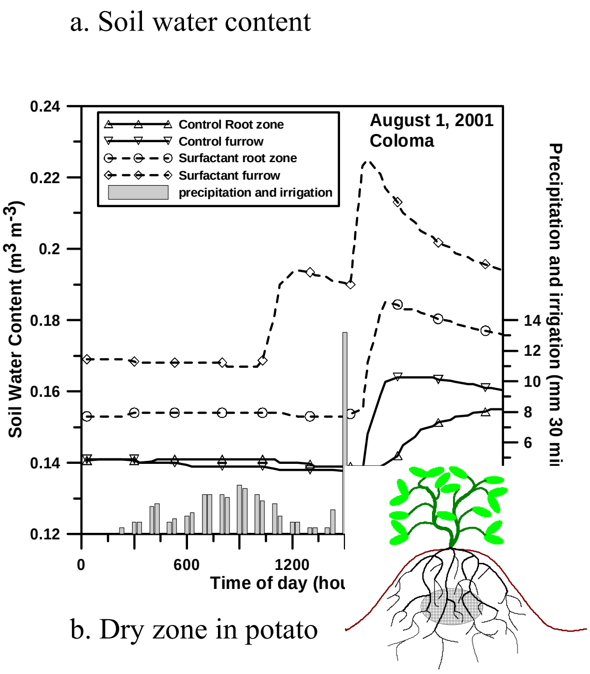
METHODS

Our studies were conducted at two different sand plain sites in Wisconsin USA, in the Lower Wisconsin River Valley (LWRV) on a Sparta sand, and in the Central Sand Area (CSA) on a Plainfield sand. Our first study on the impact of surfactant on water use and nitrate leaching was conducted in the spring of 1998 where we applied a surfactant to potato hills at planting in a 15- to 20-cm band directly over the potato seed. Preference®, a non-ionic surfactant, was used at a rate 9.35 L/ha in all the studies. As noted, there was a 15- to 20-cm spray-pattern of surfactant made over seed pieces, at planting, 23 cm below the soil surface. These initial studies were aimed at improving water use efficiency but proved to be very successful at reducing nitrate concentration below the root zone (Cooley and Lowery, 1999). Thus, we have continued to investigate the potential for reducing nitrogen with surfactant under several conditions in following years. Subsequent studies included a fertiliser rate study conducted at the Univ. of Wisconsin Hancock Research Station in 2000-2002 (Kelling *et al.*, 2003). In these studies, surfactant was applied at a rate of 9.35 L/ha, sprayed directly over the seed (20-cm depth) at planting. Four rates of N (0, 134, 202, and 269 kg/ha) were applied + or – a surfactant to plots that were 3-m wide by 6-m long. The plots were replicated four times in randomized complete blocks. In addition, we conducted further research at the Hancock Research Station in 2002 on large plots (15 by 15 m) with two N rates (0 and 202 kg/ha). These plots were replicated four times. Yet another study was conducted on three private farms, two in the CSA and one in the LWRV, in 2000 and 2001. The studies on the private farms consisted of dividing a field, which ranged in size from 14 to 55 ha, in half in 2000 and quarters in 2001. Surfactant was randomly applied to one-half of each of the fields in 2000, and to two of the quarters in 2001. Surfactant was applied at a rate 9.35 L/ha over the seed pieces in all cases, and all other crop production operations were performed by the farmers. In all the studies, we collected yield samples from randomly selected areas of the fields or plots.

To assess the impact of surfactant on nitrate concentration in the root zone, soil water samples were collected with porous-cup soil water samplers in each study in all years. Soil water content was measured and recorded with a dielectric capacitance technique, time domain reflectometry (TDR) probes connected to dataloggers in 1998, 1999, and 2001 in the large field studies. The TDR system was used to monitor the volume of water in a unit volume of soil thus, volumetric water contents at various depths and positions in the potato hill. Soil water content measurements were taken every 15 minutes during the growing season. Porous-cup samplers were installed at a 1-m depth below the top of the potato hill in all studies. In addition to suction-cup samplers at the private farms (CSA and LWRV) we installed groundwater monitoring wells in 2000 and 2001, and at the Hancock site in 2002. Soil water and groundwater samples were collected from the porous-cup samplers and groundwater wells weekly and analysed for nitrate using an ion chromatograph.

RESULTS

In the case of hydrophobic soil conditions, nonionic surfactants when applied to the soil are absorbed by the soil matric and offset the repellant conditions, resulting in greater water infiltration into hydrophobic soils (Letey, 1973). Our research results from field studies in 1998, 1999, and 2001 indicates that the nonionic surfactant Preference® resulted in increased soil water content in the dry zone of potato hills on plots treated with surfactant (Figure 1, data for 1998 and 1999 not shown). We also found that surfactant reduced nitrate leaching under some conditions (Figure 2) (Cooley and Lowery, 1999; Cooley and Lowery, 2000). However, this 80% reduction in nitrate concentration during peak leaching at 1-m below soil surface is not often the case (Figure 3). Conditions where nitrate leaching is reduced are probably the result of better utilisation of nitrogen fertiliser because it moves with water and it is available to plants in the root zone. We found significant reductions in nitrate leaching one third of the total 15 site years. One of the places we were not able to show a reduction was in our fertiliser rate study (2000, 2001, and 2002 growing seasons) (Figure 3). We hypothesise that this was due to above-average precipitation and the timing and duration of these events during these growing seasons. While we did not see a significant reduction in nitrate concentration below the root zone, we did find some improvements in N use efficiency (Kelling *et al.*, 2003).



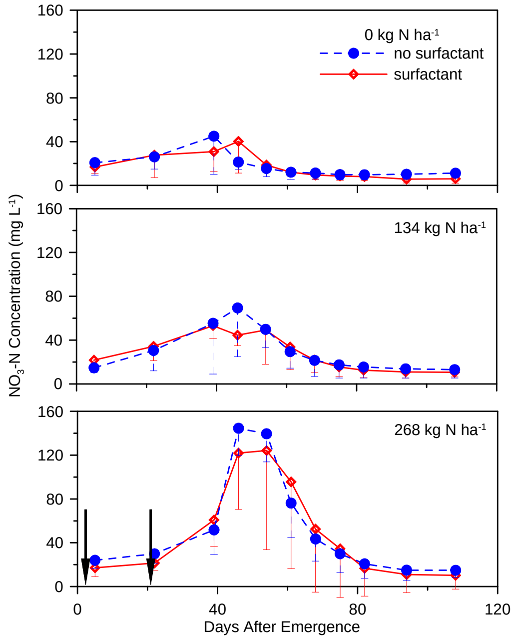
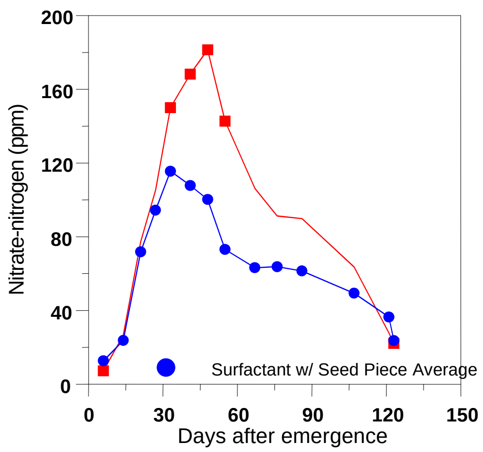


Figure 1. Soil water content in row and furrow with and without surfactant in Central Sand Area of Wisconsin, USA and schematic of dry zone in potato hill.

Figure 3. Effect of surfactant on nitrate-N concentration in soil water below the potato root zone (1.0 m) at three fertiliser N rates, Hancock, WI, 2000. Arrows indicate the timing of nitrogen fertilisation.



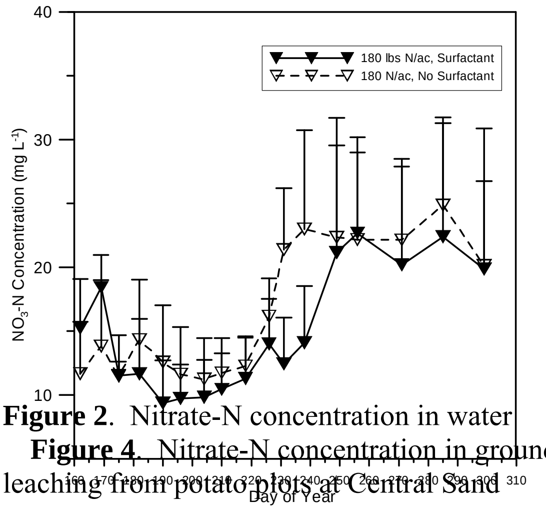


Figure 2. Nitrate-N concentration in water
Figure 4. Nitrate-N concentration in ground-
leaching from potato plots at Central Sand
water in the Central Sand Area, 2002.
Area ,1998.

In all cases where the groundwater was monitored we did not see a clear case of reductions in nitrate levels as a result of using surfactant (Figure 4, data for 2000 and 2001 not presented) (Nehls *et al.*, 2001; Lowery *et al.*, 2003). Data for 2002 were better than that for 2000 and 2001 in that the nitrate nitrogen concentrations in groundwater under the large field studies were much greater (up to 50 mg/L nitrate). Thus, the potential benefit of using the nonionic surfactant to reduce nitrate leaching to groundwater over a single growing seasons is yet to be proven.

The influence of surfactant on crop yield followed a trend showing that where there was an increase in yields, we also found a reduction in nitrate concentration in the soil 1-m below the root zone. In general, slightly greater yield and potato sizes were observed with the use of surfactant in many cases.

CONCLUSIONS

The positive result in 1998 that showed the concentration of nitrate in water that leached below the potato hills was markedly decreased where surfactant was applied were not noted in two-thirds of the total 15 site-years. In addition, we were not able to measure a reduction in nitrate leaching to groundwater with the use of surfactant. In general, however, nitrogen uptake was increased with surfactant use. The most significant finding of our research over the past 5 years is that water content is consistently increased within the potato hill with the use of surfactant. We think there are other potential benefits for using surfactant in potato production on sand plains, but a considerable amount of additional research is needed.

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