Use of surfactant to decrease nitrate leaching and improve nitrogen use efficiency in potato production

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Abstract

Nitrate leaching under vegetable production on sand plains of Wisconsin, USA is of great concern since groundwater is relatively close to the soil surface, and in some cases it is within the root zone. The problem of nitrate leaching is very serious with respect to the environment as nitrate has been indirectly linked to the hypoxic zone in the Gulf of Mexico. A large section of the Gulf of Mexico at some period of most summers suffers a shortage of oxygen (thus, the term associated with this is hypoxia), which some scientists believe caused by an abundance of nitrogen in water entering the Gulf from the Mississippi River. Drainage water from several north central states such as Iowa, Illinois, Missouri, Minnesota, and Wisconsin contribute to this problem. We think much of the groundwater that feeds the Wisconsin River, which discharges into the Mississippi River, comes from groundwater recharged by drainage water with an abundance of nitrate from the sand plains, and thus leads to elevated levels of nitrate in the river, therefore affecting the aquatic life in the Gulf. Thus, there is an urgent need to reduce nitrate leaching from crop land. In most cases in potato production in Wisconsin, nitrogen is band-applied to the shoulder of the row. However, we discovered that in sandy soils with potato production the center of the row, where most of the potato plant roots are located, becomes nonwetting midway through the growing season causing greater water flow through the shoulders of the row resulting in excessive nitrate leaching. Following this discovery we used a wetting agent to keep the center of the row wettable throughout the growing season allowing water to move into this dry zone resulting in reduced nitrate leaching by as much as 50%. In addition to assessing N leaching we evaluated the use of surfactant under different levels of N fertilizer use. Surfactant treated plots had a similar yield as the control with less N-fertilizer. Yields were 45.9 Mg ha^{-1} at 134 kg ha^{-1} N with surfactant compared 46 Mg ha^{-1} at 202 kg ha^{-1} N for the control plot. The interaction terms of surfactant and N application rate have probability values of about 0.23, which is usually considered not statistically significant.

Keywords: nitrate leaching, solute flux, potato production, dry zone, soil water content

Introduction

Based on observations by farmers and our research data, an extremely dry zone of soil develops in a portion of a potato hill that contains the highest root density (Figure 1). We think the soil in this zone becomes hydrophobic and result in nonwetting conditions midway through the growing season. Similar findings have been reported by Robinson (1999). This dry zone is located about 25 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 fertilizer infiltration into this dry region.

It appears that this dry zone results in decreased productivity and increased nitrate (NO_3) leaching. Thus, it could potentially contribute to groundwater contamination.

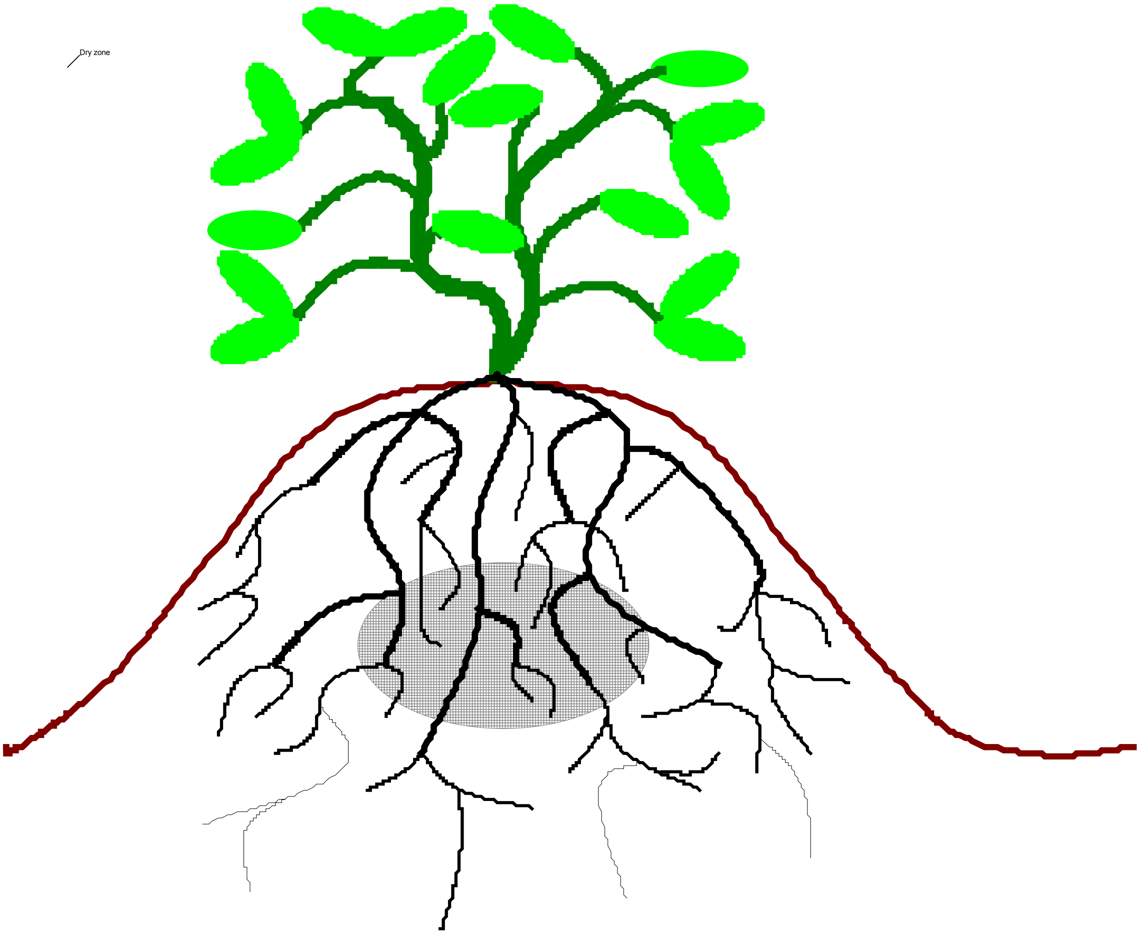

Figure 1 Schematic of dry zone associated with potato plant.

Cause of the hydrophobic zone

We hypothesized that there is a combination of four 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 reduces infiltration of precipitation and sprinkler irrigation water into the center of the hill. This increases water run off into the furrow. Third, the potato canopy which captures water and produces stem flow to the center portion of a potato hill collapse down as the growing season progresses and channels less water to the dry zone portion of the potato hill. Fourth, as the sandy soil becomes hydrophobic, the soil water content in the hill decreases thus, reducing water flow capacity because as soil water content decreases the ability of water to move through the soil decreases.

Management methods to reduce the dry zone

Dry zones or hydrophobic soils are not an uncommon occurrence and there are some management techniques that can be used to reduce this condition. The most common management practice for hydrophobic soil is application of a chemical that changes the surface tension of water. Scientists have shown that surfactants (surface active chemicals) can be used to increase water infiltration into hydrophobic soils (Pelishek *et al*., 1962; DeBano, 1971). A surfactant decreases the contact angle between soil water and soil particles by decreasing surface tension of soil water, thus increasing infiltration rates of unsaturated 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).

Test of surfactant

We started a study in the spring of 1998 where we applied a surfactant to potato hills to induce greater water infiltration into the dry zone. The study was conducted at two sites in Wisconsin USA, in the Lower Wisconsin River Valley on a Sparta sand; the second was located in a production field at Grand Marsh on a Plainfield sand. Preference, a non-ionic surfactant, was used at a rate 9.35 L ha^{-1}. A combination of three different application methods for surfactant to the potato hills was evaluated. There was a 20-cm spray-pattern of surfactant made over seed pieces, at planting, 23 cm below the soil surface at the Grand Marsh site. At Arena there were two spray patterns. A 20-cm spray-pattern of surfactant was made on sides of a potato hill prior to second supplemental nitrogen application and a 20-cm solid-stream spray-pattern of surfactant on the potato hilltop prior to second supplemental nitrogen application. These initial studies proved to be very successful. Thus, we investigated the potential for reducing nitrogen fertilizer when a surfactant is used. This study was conducted at the University of Wisconsin-Madison Hancock Research Station. Surfactant was applied at a rate of 9.35-L ha^{-1}, sprayed directly over the seed (20-cm depth) at planting. Four rates of N (0, 134, 202, and 269 kg ha^{-1}) 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.

To assess the impact of surfactants on NO_3 leaching, soil water samples were collected with porous-cup soil water samplers. Soil water content was measured and recorded with a dielectric capacitance technique, time domain reflectometry (TDR). The TDR system was used to monitor the volume of water in a unit volume of soil thus, water contents at various depths and positions in the potato hill was obtained in m^3 of water per m^3 of soil. 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. Soil water samples were collected from the porous-cup samplers weekly and analyzed for NO_3. We think that any material that reaches to the 1-m depth cannot be removed by potato roots. Thus, we anticipate that any NO_3 at this depth will likely leach to the groundwater.

Results

Results showed that the concentration of NO_3 in water that leached below the potato hills was markedly decreased where surfactant was applied (Figures 2 and 3). Based on absolute values, slightly greater yield and potato sizes were also observed with the use of surfactant (Tables 1 and 2) and less N needed (Table 3). However, statistical analyses of these data show p values ranging from 0.50 to 0.23, therefore these benefits must be considered trends.

Table 1 Grand Marsh yield data 1998.

Plot	Tuber yield (kg ha^{-1})
Control	53,800
Surfactant w/seed piece	56,800

Table 2 Arena yield data 1998.

Plot	Tuber yield(kg ha^{-1})
Control	19,000
Surfactant; banded hillside	20,000
Surfactant; stream hilltop	19,600

Table 3 Hancock yield data 2000-2001.

Plot	Applied N	Tuber yield	
	kg ha^{-1}		
Year		2000	2001
Control	0	26,880	39,424
	134	42,672	56,560
	202	46,032	56,112
	269	52,752	60,592
Surfactant	0	26,320	38,192
	134	42,920	56,224
	202	51,520	59,584
	269	52,080	60,928
		Pr>F	
Surfactant		0.14	0.64
N rate		<0.01	<0.01
SxN		0.23	0.50

Data from the TDR system showed an increase in soil water content in the dry zone of the hill in plots treated with surfactant. Plots treated with surfactant averaged 5% greater soil water content than in non-treated plots. Soil water content in the furrow was much less in surfactant treated plots. Thus, there was apparently greater infiltration of water into the potato hill and less runoff into the furrow in surfactant treated hills.

Graphs in Figures 2 and 3 show that concentration of NO_3 below the potato hills treated with surfactant was generally lower during the middle of the growing season than that under untreated potato hills. This is likely because of better utilization of nitrogen fertilizer because NO_3 moves with water and comes in contact with more roots in the center of the hill. Thus, it appears that with the surfactant more fertilizer and water solution penetrates the center of potato hills, and less water flow down the hillside into the furrow where there are few or no roots.

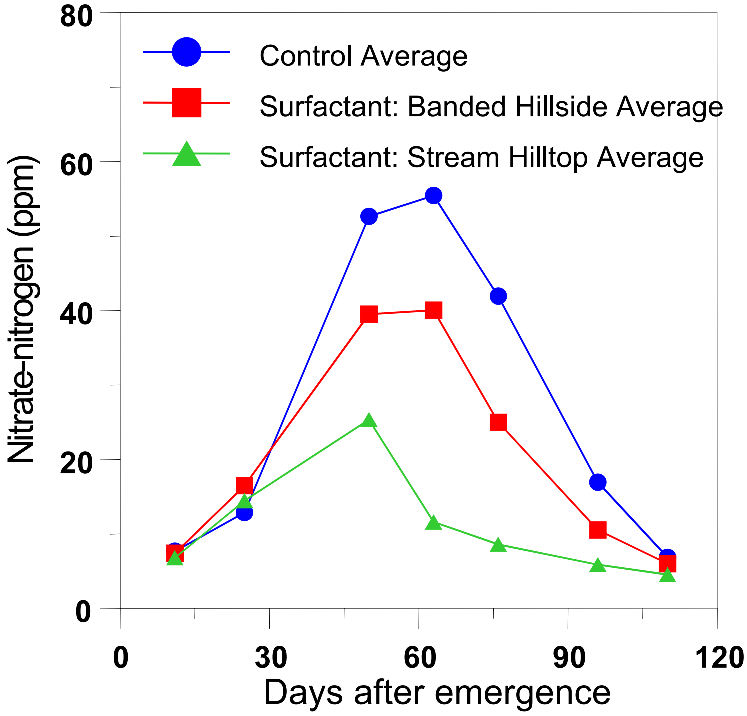

Figure 2 Nitrate-N concentration in water leaching from potato plots at Arena, Wisconsin, 1998.

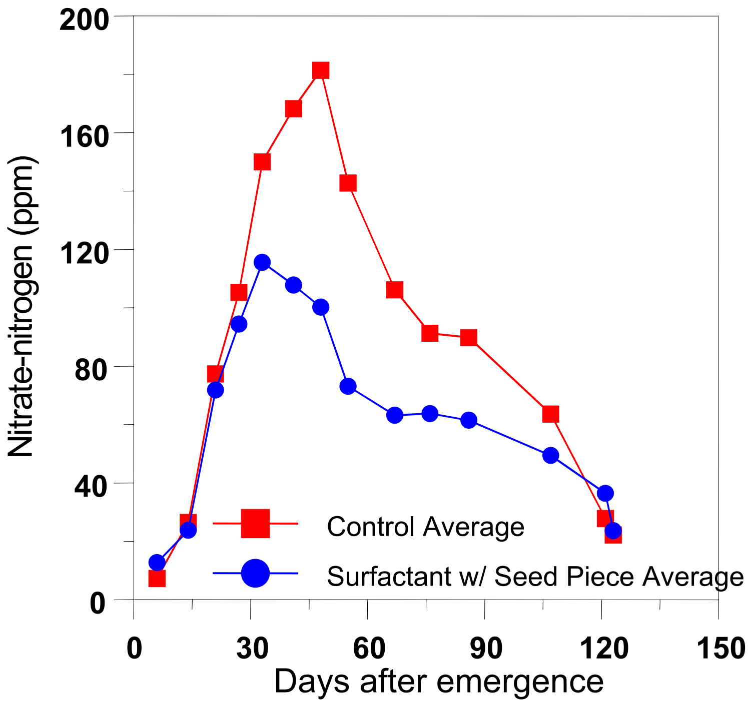

Figure 3 Nitrate-N concentration in water leaching from potato plots at Grand Marsh, Wisconsin, 1998.

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