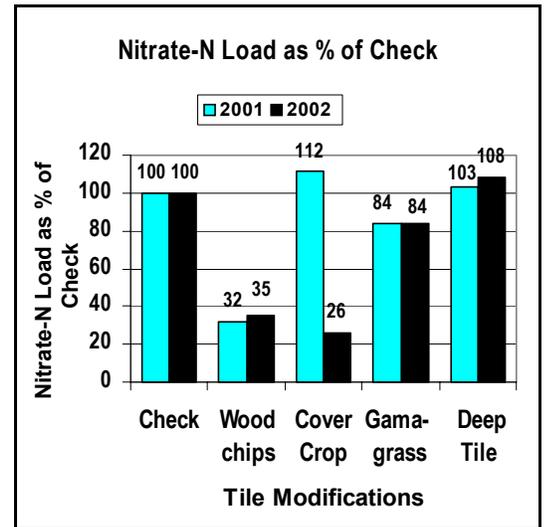


Reducing Nitrate Levels in Subsurface Drain Water with Organic Matter Incorporation



Installing wood chip trench.



Gamagrass strip in early spring



Rye cover crop in early spring

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Reducing Nitrate Levels in Subsurface Drain Water with Organic Matter Incorporation

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PROJECT SUMMARY

Nitrate-nitrogen (nitrate-N) in water leaving subsurface tile drain systems often exceeds the 10 mg L⁻¹ maximum contamination level (MCL) set by EPA for drinking water and has been implicated in contributing to the hypoxia problem within the Gulf of Mexico. Much of the nitrate present in surface waters within the Midwest cornbelt is from subsurface field drainage. Because fertilizer management alone does not seem to be adequate for reducing nitrate-N concentrations in subsurface drainage below the MCL, additional methods need to be devised for reducing nitrate-N concentration and load. The overall objective of this research was to develop alternative tile drainage system designs and management strategies and to evaluate their effectiveness for nitrate-N removal rate and capacity in agricultural soils. We proposed to reduce nitrate-N concentrations in tile drainage water by modifying the design and management of tile drainage systems to enhance denitrification and to increase uptake of nitrate by plants. This research focused on two methods for enhancing denitrification within tile drain systems and two approaches for increasing plant uptake of nitrate. First, deep drain tile installation was investigated for its potential to decrease nitrate concentrations in drainage waters. Drain tiles were installed approximately 0.6 m deeper than currently practiced, while maintaining the drain outlets at the same depth as normal tiles. We had hypothesized that the deep drain tiles would be more efficient in drawing water from deeper saturated zones where denitrification occurs naturally and nitrate concentrations are often much lower. Second, the effectiveness of woodchip trenches installed on both sides of subsurface drains as denitrification biofilters was also evaluated. We had hypothesized that providing soil microorganisms with wood chips as a carbon source would enhance denitrification and reduce nitrate concentrations of water passing through the trenches. Two approaches for increasing plant uptake of nitrate were also investigated. Rye cover crops were overseeded into both corn and soybean main crops before harvest and allowed to grow until planting of the following main crop. Another approach was to plant eastern gamagrass as a permanent vegetation strip over drainage tiles. Because both the rye cover crop and the gamagrass strip would grow and take up nitrate when the normal crops were not present, we felt that this would reduce the amount of nitrate reaching the drainage tiles. Initial results from the first three years are promising. In 2000, the first year after installation only sporadic drainage occurred because of lack of precipitation. In 2001 and 2002, all drainage tiles had significant flow. The woodchip trench treatment consistently reduced nitrate-N concentrations below 10 mg L⁻¹ and also reduced cumulative nitrate-N load to drainage water. In 2002, the rye cover crop treatment also reduced nitrate-N concentrations below 10 mg L⁻¹ and reduced nitrate-N loads. In 2001, the rye cover crop had no effect on nitrate-N concentrations and load because of poor establishment and growth of the cover crop due to dry fall conditions. The other tile treatments had no significant effects on nitrate-N concentrations or loads. There was some evidence that the gamagrass treatment may have somewhat reduced nitrate-N loads because of a small reduction in cumulative water flow. Monitoring of the site and data collection will continue through 2003 and 2004. Based on initial results it seems that wood chip trenches and rye winter cover crops have the potential to reduce nitrate-N concentrations and loads in tile drainage water in a corn-soybean rotation.

Need for Research

Non-point contamination is a major water quality concern in the Midwest cornbelt (Humenik et al., 1987). The 2000 national water quality inventory (U.S. EPA, 2000) notes that in the rivers studied, 18% of the water quality problems were attributed to agriculture. Plant nutrients, especially nitrogen in the form of nitrate (NO_3) have been identified as contaminants of surface water throughout the Midwest (Baker, 1988; Thurman et al., 1992; U.S. EPA, 1992; Goolsby and Battaglin, 1993). Excessive nitrate-N contamination of surface waters at concentrations greater than the EPA maximum contamination level (MCL) of 10 mg L^{-1} for drinking water can require costly water treatment facilities and procedures. Accelerated nitrate loading in the Mississippi River has been linked to the spread and increased severity of hypoxia within the Gulf of Mexico (Rabalais et al., 1996).

In areas of the United States with drained cropland, nitrate-contaminated water from drainage tiles in agricultural fields is a primary source of nitrogen contamination of surface waters. Numerous studies have shown significant edge-of-field losses of nitrate (Hanway and Laflen, 1974; Gast et al., 1978; Miller, 1979; Benoit, 1973; Logan et al., 1980; Baker and Johnson, 1981; Bergström, 1987; Kanwar et al., 1988; Drury et al., 1996). For example, Baker et al. (1975) found average nitrate-N concentrations of 21 mg L^{-1} in subsurface drainage tile water leaving fields planted in corn-soybean or corn-oat rotations. Our studies of a 5,130 ha watershed on the Des Moines lobe in central Iowa showed flow-weighted nitrate-N concentrations in field and county tile drains were often greater than the 10 mg L^{-1} MCL (Jaynes et al., 1999). Total nitrate-N losses from this agricultural watershed ranged from 4 to 66 kg ha^{-1} per year. Within the eight state North Central Region, from Iowa east through Ohio, there are currently >41,000,000 acres of crop land drained by subsurface drainage systems (USDA, 1987). Originally called tiles or clay tiles because they were made from fired clay, the drains are now slotted plastic tiles installed 3 to 5 feet below the surface. Individual drains are linked to larger drains or tiles that eventually empty into streams or drainage ditches. At the watershed scale, tile drainage can account for a significant portion of the streamflow in areas with extensive drainage systems. These drained crop lands are some of the most productive in the world, but only if adequate drainage is provided. Thus, crop production and surface water quality within the North Central Region of the cornbelt are intimately intertwined.

Attempts to reduce nitrate concentrations in field drains have focused on nitrogen fertilizer rate, placement, and timing issues. However, Baker et al. (1975) showed that even under low N-fertility management, nitrate-N concentrations in drain water often exceeded 10 mg L^{-1} . These observations were confirmed by Gast et al. (1978) who observed only a 20% decrease in nitrate-N loads to drain water when changing fertilizer rates from the recommended rate of 112 kg ha^{-1} to 20 kg ha^{-1} . Similarly, Jaynes et al. (2001) found that nitrate-N levels exceeded the 10 mg L^{-1} in tile drainage water at economic optimum N fertilizer rates and concluded that economic corn production could not be maintained in the study field without producing tile drainage water that exceeded the MCL. Insensitivity of nitrate-N concentrations in drainage water to nitrogen fertilizer rates was also cited by Keeney and DeLuca (1993) who found about a 10% increase in nitrate-N levels in the Des Moines River between 1945, before intensive fertilizer use, and the

1980s. They concluded that intensive agriculture as a whole rather than just fertilizer use was the major source of nitrate in water. Thus, while fine-tuning fertilizer application for corn production has shown modest reductions in nitrate concentrations in drain waters, it seems that these approaches will not be able to reduce nitrate-N concentrations below the 10 mg L⁻¹ MCL.

Because fertilizer management alone cannot significantly reduce nitrate contamination, additional methods of nitrate removal from the subsurface drainage water are needed. Numerous methods for removing nitrate from water have been identified including ion exchange, biological denitrification, assimilation by plants, chemical denitrification, reverse osmosis, electrodialysis, and catalytic denitrification (Kapoor and Viraraghavan, 1997). Of these, only biological denitrification and assimilation by plants seems suitable for wide spread application in agricultural systems to reduce contamination of drainage water.

Literature Review

Biological denitrification is the conversion of nitrate into nitrogen gas by microorganisms. Because the capability to carry out this process is widely distributed among soil and sediment bacteria, the requirements for denitrification are (1) a carbon source and (2) oxygen-deficient conditions. Because soil surrounding tile drains is usually saturated and oxygen-deficient when water is flowing through the tiles, the amount of carbon (C) in the soil is usually the factor that is limiting the rate of denitrification in many cases. Thus, addition of a carbon source to the soil surrounding tile drains has the potential to increase denitrification and to decrease the concentration of nitrate in water flowing to tile drains.

Organic Matter Incorporation

Robertson and Cherry (1995) filled a 0.6-m wide trench that extended 0.75 m below a shallow water table with sand containing 20% v/v coarse sawdust and measured the concentration of nitrate-N in ground water before and after flowing through the mixture. Very high nitrate-N concentrations (57-62 mg L⁻¹) were reduced to much lower concentrations (2 - 25 mg L⁻¹) in ground water passing laterally through the bioreactor. They attributed the removal of nitrate to heterotrophic denitrification with the sawdust serving as the labile carbon source and estimated that this “denitrification wall” would have an effective lifetime of from 20 to 200 yr. However, they offered only indirect evidence that denitrification was the primary removal mechanism, citing only reduced O₂ and SO₄⁻² concentrations in water passing through the wall.

Recently, Schipper and Vojvodic-Vukovic (1997) found that a similarly constructed denitrification wall reduced nitrate-N concentrations from 5 to 16 mg L⁻¹ to less than 2 mg L⁻¹ in shallow ground water passing through it. They too attributed the removal process to denitrification and measured denitrifying enzyme activity to plateau at 906 ng g⁻¹ h⁻¹ after 6 months of operation.

Use of readily available, low value solid carbon sources may have applicability to *in situ* field treatment systems. Solid organic carbon sources could be added to fields to increase denitrification. Ideally they would be incorporated below the root zone throughout the field to capture and remove excess nitrate leaching below the root zone. However, a more practical

approach would be to follow the concept of Robertson and Cherry (1995) and add the carbon sources as backfill or mixed with soil as backfill when subsurface drain tiles are installed. This would in essence create a denitrification wall surrounding the drain tiles that would continuously remove nitrate from drainage water entering the drain tiles.

An alternative to using buried carbon sources would be to use a renewable carbon source. Plants and their root systems could be used to incorporate organic matter into the soil around either new or existing drain tiles. Plant roots are continually leaking organic matter into soil through a process called exudation. Additionally, root turnover (i.e. death and decay of old roots) during a plant's life cycle and the roots left in the soil when a plant matures or dies also add organic matter to the soil. Lastly, plant roots also have the advantage of taking up water and nitrate directly and this would also prevent it from leaving in the drainage water. Thus, plant roots have the potential to enhance both biological denitrification and assimilation of nitrogen by plants. These root processes also occur to some extent with normal cropping of corn and soybean. But, to reduce nitrate levels below their current levels, it will be necessary to increase organic matter inputs and to extend the time for nitrate uptake by planting either off-season cover crops over the entire field or by planting permanent grass strips over the drain tiles. Permanent grass strips might consist of water-tolerant species such as lowland switchgrass or eastern gamagrass cultivars. The use of winter cover crops is a management practice, which has been shown to reduce nitrate losses and subsequent contamination of water supplies (Brandi-Dohrn et al., 1997; Herbert et al., 1995; McCracken et al., 1995; Meisinger et al., 1991). Cover crops reduce nitrate losses by taking up nitrate during growth and by immobilizing nitrate when their residues decompose. Information on winter cover crop effects on nitrate losses in tile-drained fields in the upper Midwest is limited. Small grain cover crops such as oat, wheat, or rye can be successfully seeded either late in the growing season or after harvest and then would be killed before planting the next crop (Johnson et al., 1998).

Drainage System Depth

Naturally occurring denitrification can also be significant within the soil below subsurface drained fields. Robbins and Carter (1980) noted that denitrification in a silt loam soil in south central Idaho reduced nitrate-N concentrations in water leaving the rootzone by about 10 mg L⁻¹ before entering subsurface drains. In Iowa, Parkin and Simpkins (1995) measured complete nitrate removal by denitrification from water infiltrating the unoxidized till in central Iowa. Observations of shallow ground water below fields in this area also show a dramatic decrease in nitrate-N concentrations in water below 3 m (Cambardella et al., 1999). Figure 1 illustrates the dramatic reduction in nitrate-N concentrations in ground water between 1.5 and 2.6 m below the soil surface in this field. Subsurface field drains are normally installed 1 to 1.5 m below the surface. However, if drains were installed approximately 0.5 to 1 m deeper while maintaining current outlet elevations, a lowering of nitrate-N concentrations in the drainage water may occur.

Thus, there is evidence that nitrate in subsurface drainage can be reduced by denitrification under anaerobic conditions by incorporating a carbon source either from waste material or plant root residue or by installing submerged drains deeper in the saturated soil profile where nitrate concentrations are naturally lower. While a review of the literature is promising in regards to these approaches, research to date has been inadequate to quantify the exact mechanisms responsible for nitrate removal and for determining the potential removal rates over both the long- and short-term.

Rationale and Objectives

Subsurface drainage systems are one of the primary sources of nitrate contamination in surface waters within the North Central

Region of the cornbelt. Research has shown that fertilizer management alone will not significantly reduce the nitrate-N concentration and load in these waters. Thus, additional management strategies are needed for reducing nitrate-N concentrations in tile drainage water. Our overall objective is to develop alternative tile drainage system designs and management strategies and to evaluate their effectiveness for nitrate removal rate and capacity in agricultural soils. We propose to reduce nitrate-N concentrations in tile drainage water by modifying the design and management of tile drainage systems to enhance denitrification and to increase uptake of nitrate by plants.

Denitrification is a natural process that has been documented to reduce nitrate-N concentrations in shallow water tables and in subsurface drainage systems. We hypothesize that the natural rate of denitrification in the soil surrounding the subsurface drains can be increased by adding organic matter to soil to serve as a carbon source for the microorganisms. We propose two approaches for doing this. One approach would be to mix a labile C source, such as wood chips into the soil surrounding the tile when they are installed. A second approach would use a permanent vegetative strip planted over the tile to increase the organic matter content of the soil surrounding the tile. A plant such as eastern gamagrass is tolerant of wet conditions and the roots of this plant would increase the organic matter of the soil surrounding the tile over time.

Another possible approach for enhancing denitrification is to install the tiles approximately 0.6 m deeper in the soil profile than currently practiced while maintaining the drain outlet at the normal depth, this is what we have referred to as “deep tiles”. The greater depth of deep tiles will change the flow path of water to the tiles, increasing the contribution of water from deeper in the saturated zone. This deeper water has been shown to be depleted in nitrate due to

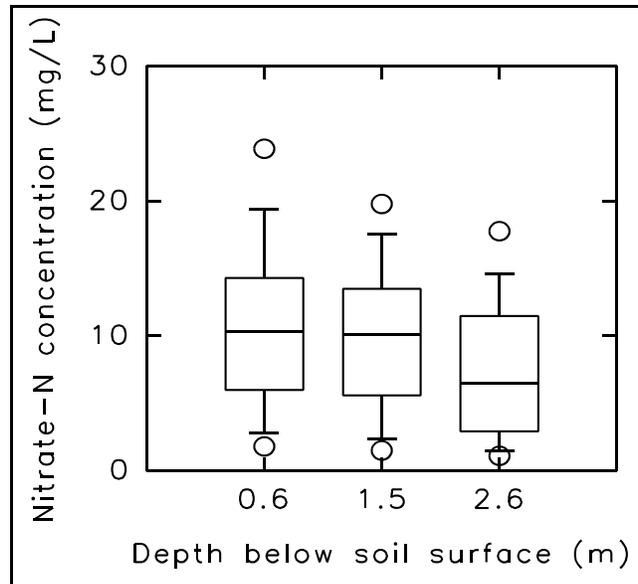


Figure 1. Box plot of nitrate-N concentrations measured at three depths below a corn/soybean field from 1991-1995.

denitrification naturally occurring in this zone.

Lastly, a significant part of the nitrate-N load to tile drainage systems is input between maturity of the main crop and emergence of the following crop. Increasing plant uptake of nitrate and water during fall, winter, and early spring should reduce water flow, nitrate-N load, and nitrate-N concentrations. Small grain cover crops, such as rye, planted in late summer and killed before planting of the next main crop should take up nitrate and water in the off-season between harvest and planting of main crops. Similarly, a permanent vegetative strip of a species such as eastern gamagrass planted over the drainage tile may accomplish the same purpose.

Research Methods

Measurements of nitrate in field studies are expressed as nitrate-N or $\text{NO}_3\text{-N}$. Nitrate-N refers to the elemental nitrogen portion of the nitrate molecule, which contains one N atom and three oxygen atoms. For example, a concentration of nitrate-N equal to 10 mg L^{-1} is equivalent to a concentration of nitrate equal to 44 mg L^{-1} because the nitrate molecule is approximately 4.4 times heavier than the nitrogen atom contained in a nitrate molecule. The unit of measure, mg L^{-1} will be used throughout the report and 1.0 mg L^{-1} is equal to 1.0 ppm.

The field site is located on poorly drained Webster and Canisteo soils at the Kelly Farm, which is part of the Agronomy and Agricultural Engineering Research Center of Iowa State University located west of Ames, IA. The randomized complete block design has 4 blocks (reps) of 6 treatments arranged in 6 tiers of 4 plots (Fig. 2), with each plot being 43-m (140 ft) long by 30-m (100 ft) wide with a drain tile draining the center. Plots were grouped into the four blocks based on their electrical conductivity, which has been shown to be highly correlated with soil properties such as clay content (Williams and Hoey, 1987), water content (Kachanoski et al., 1988), and soil organic matter content (Jaynes et al., 1995b). Apparent soil electrical conductivity (EC) was measured using an EM-38 electrical conductivity induction meter (Geonics, Ltd., Mississauga, ON, Canada; Jaynes et al., 1995a). All drainage is channeled to 3 large sumps where individual flow rates are measured and sampled.

The cropping system is a corn-soybean rotation with a high, but not unusual nitrogen fertilizer application rate for the area (spring urea-ammonium nitrate (UAN) application at 200 lbs of N $\text{acre}^{-1} = 224 \text{ kg ha}^{-1}$ prior to growing corn; 2000 and 2002). Phosphorus and potassium fertilizers were surface applied prior to corn planting at rates based on soil tests. Weed control was implemented using standard herbicides and practices for a no-till system. Plots were tilled in the fall 1999 and in spring 2000 and 2002 when tillage was needed to level the surface because of subsidence resulting from the tile installation. Plots were not tilled in 2001 before planting soybeans.

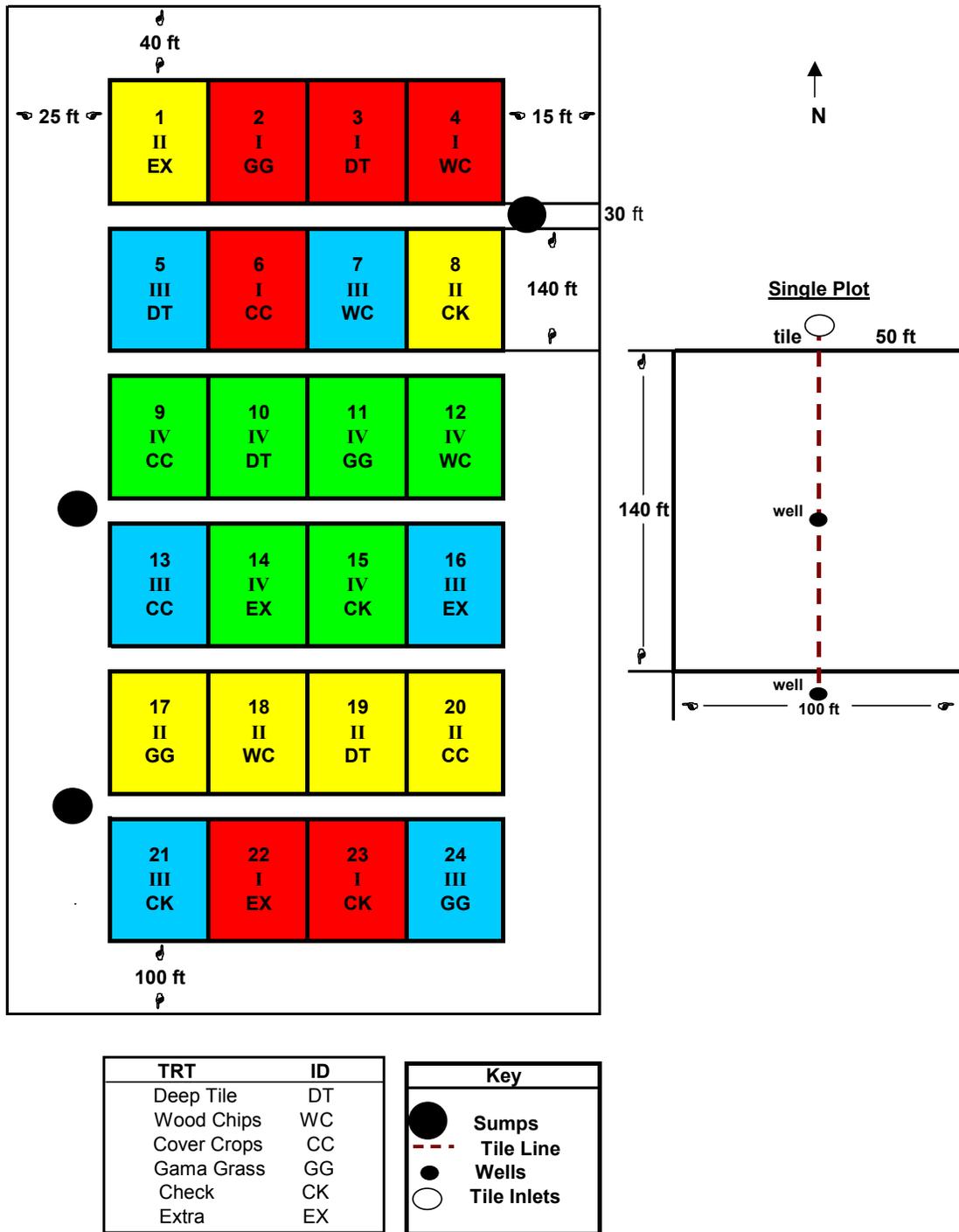


Fig. 2. Field plot layout for testing alternative tile drain designs and management.

Tile drainage systems for the field site were installed in August of 1999 using a private contractor and typical trenching and tile installation equipment (Fig. 3). Figure 2 shows the plot treatment assignment and a schematic of an individual plot. Drainage tiles in the plots are 100 ft from the tiles in the neighboring plots. The drainage tiles in each plot are connected by solid or closed tiles to one of the large collection sumps (eight plots per large sump) on the east and west sides of the field. The entire plot area is surrounded on all sides by a large drainage tile connected to the agricultural drainage system for this area. This tile carries away drainage water from the large sumps after measurement and sampling and also minimizes inflow of water from outside of the experimental area.



Fig. 3. Tile installation machinery.

Flow rates of individual plot tile drains were measured by diverting the drainage for each plot into a designated small sump chamber located within the large sumps (Fig. 2 & 4). Each of the three large sumps had eight small sump chambers to collect the drainage from eight individual plots. The small sump chambers were emptied with a sump pump (Bjorneberg et al., 1996) equipped with a paddle wheel type flow sensor connected to a Campbell Scientific CR10 datalogger. This arrangement allowed for accurate metering of flow rate over the entire range of drainage rates. Flow-weighted water samples were collected using a flow splitting device on the sump pump outflow line. Drain tile water samples were preserved, stored, and analyzed for nitrate following standard procedures.

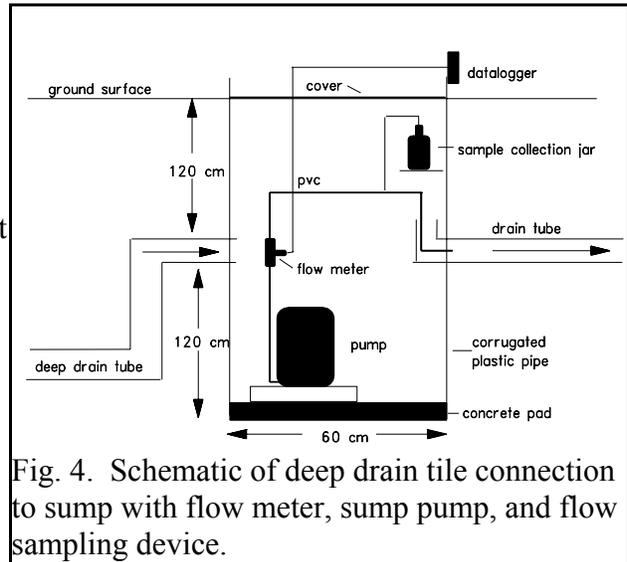


Fig. 4. Schematic of deep drain tile connection to sump with flow meter, sump pump, and flow sampling device.

Figure 5 is a schematic drawing of the five tile treatments. A conventional tile drainage system was installed at a depth of 1.2-m for use as a check treatment.

Alternative tile drain designs and management for reducing nitrate losses

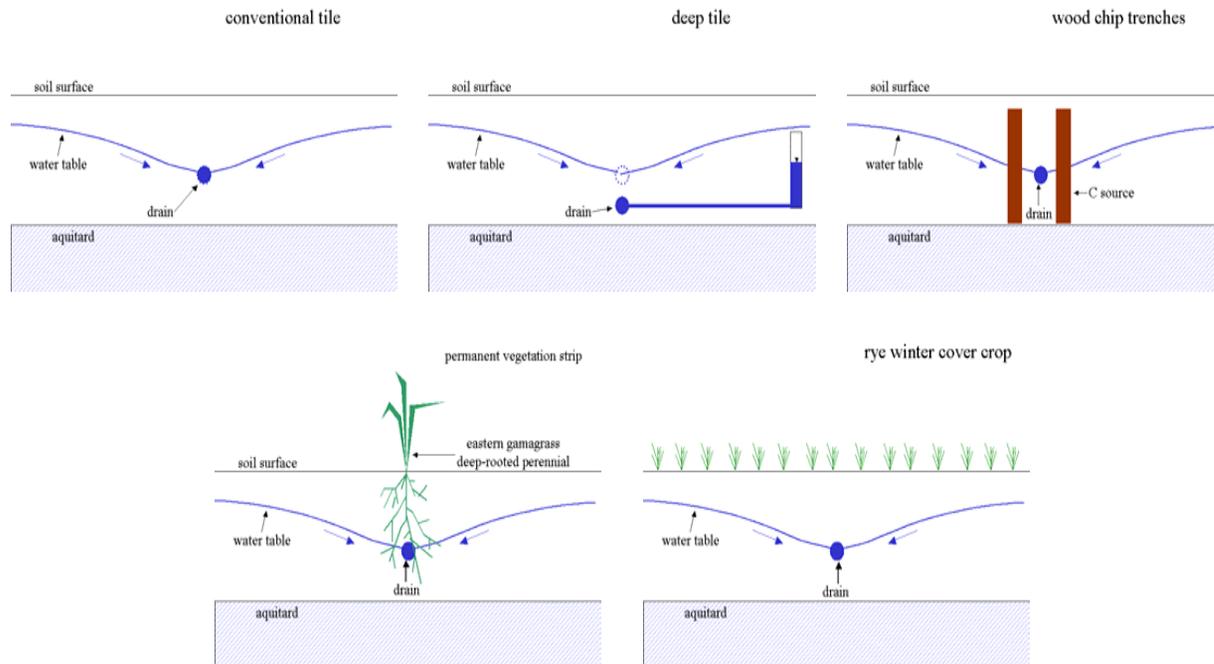


Fig. 5. Schematic of tile drain treatments.

- A wood chip trench biofilter (WC) treatment consisted of a conventional drain tile with a 0.6-m wide by 1.8-m deep denitrification trench filled with wood chips installed on each side (3.0 m away) of the drain tile (Fig. 6). The wood chips were obtained from a pallet recycling center, were primarily oak wood, and ranged in size from 1 to 10 cm long.
- The deep drain tile (DT) treatment was installed at a depth of 1.8 m, which is 0.6-m deeper than the conventional tile. The outlet of the deep tile, however, is at the same 1.2-m depth as the conventional tile system, so that the deep tile is under at least 0.6-m of water whenever water is draining.
- The permanent vegetation strip (GG) treatment consisted of a conventional drain tile system with a permanent 3-m wide strip of eastern gamagrass planted above the tile (Fig. 7 and also on cover). Eastern gamagrass was first planted in spring 2000 and supplemented with seedlings in fall 2000 and spring 2001. Plugs from established gamagrass plants were transplanted into gaps or open areas in the strips on several occasions.
- The cover crop (CC) treatment consisted of a conventional drainage tile with a rye cover crop overseeded into the standing soybean or corn crop in late summer or early fall each year and chemically killed before planting of the main crop the next spring (Fig. 8 and on cover).
- A sixth set of plots (EX) was established for use as extra control plots, for future use as treatment plots if the selected treatment plots had unusual drainage patterns, or as plots for a treatment to be added in the future.



Fig. 6. Installing wood chip trench.



Fig. 7. Gamagrass strip during the summer in corn.

Carbon degradation within the denitrification walls was measured using litter bags. Nylon bags (2 mm mesh) were packed with a known weight of the wood chips and buried during tile and wood chip trench installation with a plastic string leading to the surface. At approximately three and four years after burial some of the bags were retrieved. The wood chips in the bags were cleaned and weighed to determine loss. Additional bags will be dug up in 2004 and 2005.

Corn yields were measured by harvesting the entire plot, weighing the grain in a wagon instrumented with a load cell weighing system, measuring grain moisture with a capacitance grain moisture meter, and



Fig. 8. Rye cover crop in Nov. following soybean.

calculating corrected weight and yield on an area basis at a 0.155 kg kg⁻¹ (15.5%) grain water content. Corn grain yields of gamagrass plots were based on the total plot area minus the area of the gamagrass strip. Soybean yields are based on four 12.5 ft wide passes through each plot with a combine with a weigh tank mounted in the grain storage bin. Soybean yields were corrected to a 0.130 kg kg⁻¹ (13.0%) grain water content.

Treatment differences for all measurements were determined using an analysis of variance and the least significant difference test at the 10% significance level.

Results and Discussion

Although tile installation was completed in August 1999 and installation of pumps, sampling equipment, and dataloggers was completed in April 2000, very little drainage flow was collected in 2000 because of dry soil conditions and below normal precipitation between Sept. 1999 and May 2000. Because tile flow was sporadic and some tiles produced very little flow, the 2000 data will not be discussed. Complete data sets for 2001 and 2002 will be presented. Data for 2003 continues to be collected and will be presented in scientific reports, but will not be presented in this report. After 2001, plot assignments for two cover crop plots were changed to two of the plots designated as extra control plots because of unusually high tile flow rates in the originally assigned plots.

Tile Drainage Sample Nitrate-N Concentration

The tile drainage sample nitrate-N concentration is the nitrate-N concentration of the samples taken during flow events in the field. The frequency of sample collection was determined by the rate of flow. In 2001, the nitrate-N concentrations of samples taken from the wood chip treatment were much lower than the other four treatments (Fig. 9). The nitrate-N concentration of the wood chip treatment started off in March slightly above 10 mg L⁻¹, but decreased to less than 10 mg L⁻¹ by late April and stayed there until drainage ceased in late July. There were no major differences among the other treatments. The gamagrass treatment, however, tended to have a slightly higher concentration than the other treatments early in the growing season and then declining concentrations after mid June. We can think of no reason why the gamagrass treatment would have higher concentrations early in the

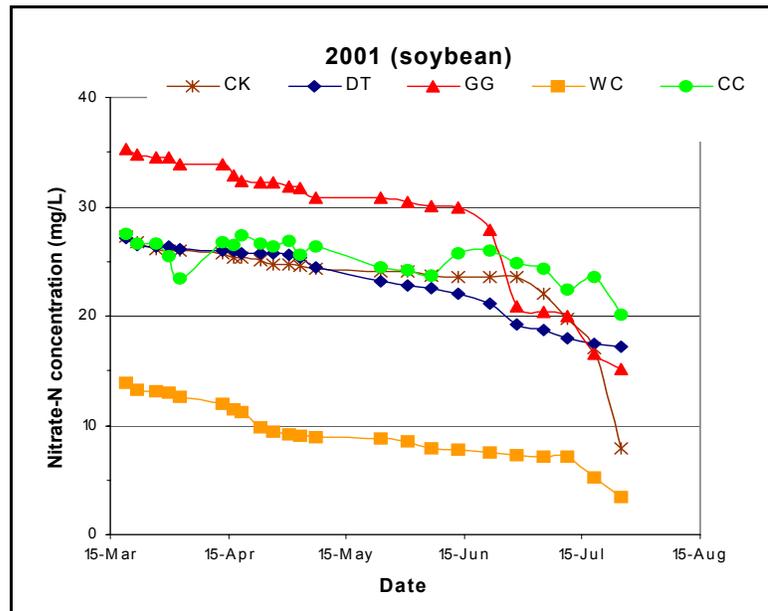


Fig. 9. Tile drainage nitrate concentration in 2001 for five tile treatments.

growing season. The decline later in the growing season may have been due to renewed growth of this warm season grass. Also of note, is the relatively high nitrate-N concentrations of the check in 2001 considering that soybean was the main crop that year and no nitrogen fertilizer was applied. In spite of this, the nitrate-N concentrations of the check only dropped below 10 mg L⁻¹ at the last sampling date in late July. In 2002, both the wood chip treatment and the rye cover crop treatment had concentrations that consistently were below 10 mg L⁻¹ and were less than the check and other treatments (Fig. 10). The better performance of the cover crop treatment can be attributed to the better establishment and growth of the cover crop in fall 2001 and spring 2002. Conditions in fall 2000 were dry at the time of cover crop seeding and as a result establishment was poor. As in 2001, nitrate-N concentrations of the gamagrass treatment started out high and declined sharply after mid June.

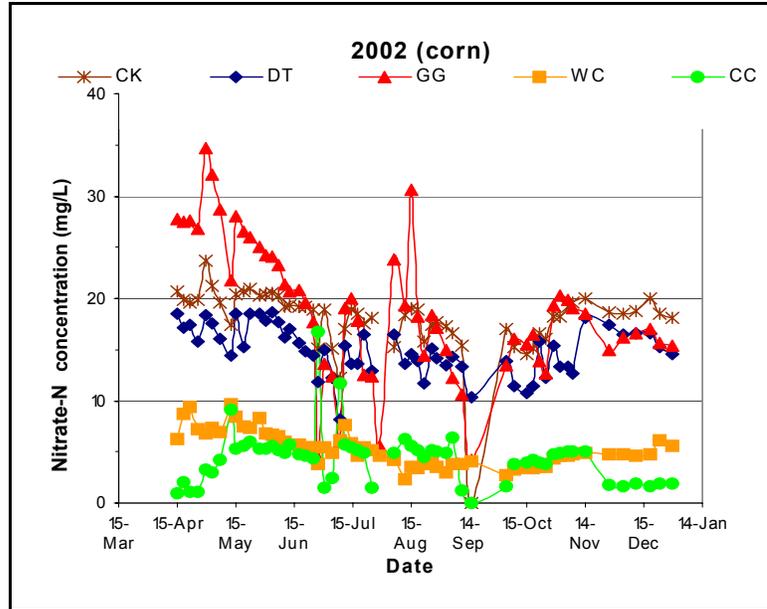


Fig. 10. Tile drainage nitrate concentration in 2002 for five tile treatments.

Cumulative tile flow

Cumulative tile flow is the total water that flowed through the tile installed in each plot in a calendar year. There were no significant differences in average cumulative tile flow in either 2001 or 2002 between any of the treatments (Fig. 11). Two minor trends in the data are the slightly higher flow in the deep tile treatment and the slightly lower flow in the gamagrass treatment. Although not significant statistically, these trends are consistent with pre-experiment hypotheses concerning these treatments. The deep tile treatment may have slightly higher flow because the placement

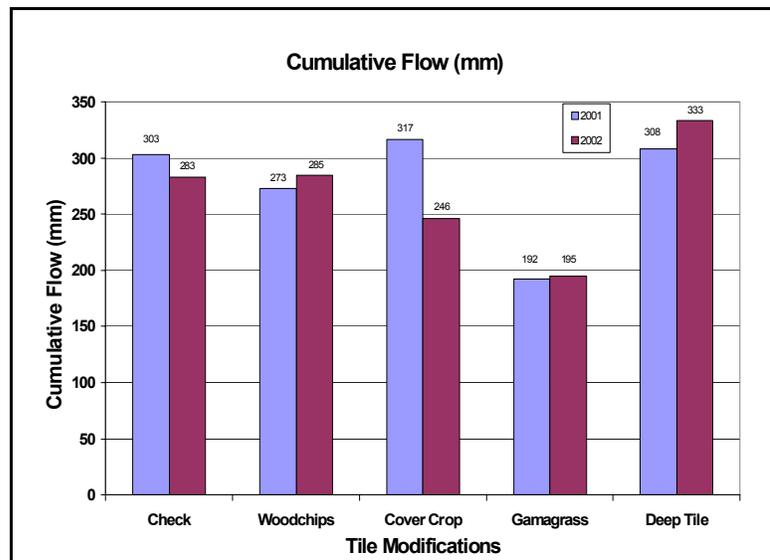


Fig. 11. Cumulative tile drainage flow in 2001 and 2002 for five tile treatments.

of the tile below the water table would cause it to be completely full when water is flowing and thus, have a greater capacity. The gamagrass treatment might be expected to have slightly lower flow rates because the permanent vegetation strip above the tile is using more water than the standard main crops. The gamagrass strip, however, was not fully established in 2001 and should not have affected cumulative flow in 2001 as it did in 2002. Cumulative flow was nearly the same in both 2001 and 2002 for all the treatments except the cover crop treatment. There are several reasons for the lower flow for the cover crop treatment in 2002. First, two of the plots that were originally assigned to this treatment had abnormally high flow rates and were reassigned in 2002. Second, the rye cover crop had much better growth in fall 2001 and spring 2002 than the previous year and most likely used more water.

Flow Weighted Nitrate-N Concentration

Flow-weighted concentration is the amount of nitrate-N lost in tile drainage divided by the total flow during the time period measured. Thus, annual flow-weighted concentrations would indicate the average nitrate-N concentration of the drainage water coming from the plots during the entire year. Obviously, nitrate-N concentrations of the drainage water would be above or below the average flow-weighted concentration at different times in the year (Figs. 9 and 10).

Only two treatments, wood chips and cover crops, significantly reduced flow-weighted nitrate-N concentrations (Fig. 12). The wood chip treatment had a flow-weighted nitrate-N concentration that was below the MCL of 10 mg L⁻¹ in both 2001 and 2002. The rye cover crop treatment had a flow weighted concentration of 5.69 mg L⁻¹ in 2002 and a much higher concentration in 2001. As mentioned previously, rye growth in fall 2001 and spring 2002 was much greater than the previous year and as a result the rye was more effective at reducing nitrate-N concentrations. Based on the results of laboratory studies we assume that the effectiveness of the wood chip trench treatment in reducing nitrate-N concentrations is the result of increased denitrification. The cover crop treatment, however, probably reduced nitrate-N concentrations in the drainage water by removing nitrate from the soil through plant uptake and by immobilization of nitrate during rye residue decomposition.

Cumulative Nitrate-N Load

Nitrate-N load to the tile drainage water is calculated by multiplying the nitrate-N concentration of drainage water during a sampling period by the flow during that same period. Cumulative nitrate-N load is calculated by adding up the calculated nitrate-N load from

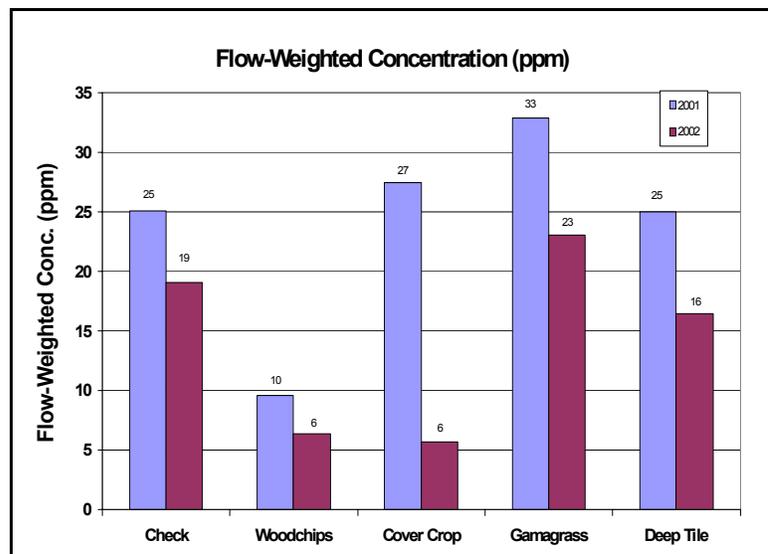


Fig. 12. Flow-weighted nitrate-N concentration of tile drainage in 2001 and 2002 for five tile treatments.

all the sampling periods. In 2001, only the wood chip treatment significantly reduced the nitrate-N load to tile drainage (Fig. 13). There were no significant differences among the other treatments (at the 10% significance level) although the cover crop and deep tile treatments tended to be slightly higher than the check. In 2002, both the cover crop and the wood chip treatments significantly reduced the amount of nitrate-N leaving the field in the tile drainage water. Figure 14 shows nitrate-N load as a percentage of the check treatment. In both 2001 and 2002, the wood chip treatment reduced nitrate-N loads by at least 65%.

The cover crop treatment reduced nitrate-N loads by 74% in a year when good cover crop establishment and growth occurred. When the data is presented this way it also seems that there is a small trend for a 16% decrease in nitrate-N load in drainage water by the gamagrass treatment. Because we know that this treatment did not reduce the flow-weighted concentration we can assume that the decrease, if real, is the result of the reduced flow caused by water uptake by the permanent vegetative strip above the tile.

Percentage of Wood Chip Dry Matter Remaining

One of the questions that needs to be addressed regarding the wood chip trenches is how long will they be effective in removing nitrate for the tile drainage water. The longevity of their effectiveness will be determined in part by how rapidly the wood chips decompose. To begin to answer this question, preweighed mesh bags of wood chips that had been buried in wood chip trenches were dug up three and four years after burial. After three years 60% of the wood chips remained at 90 cm below the surface and 89 % at

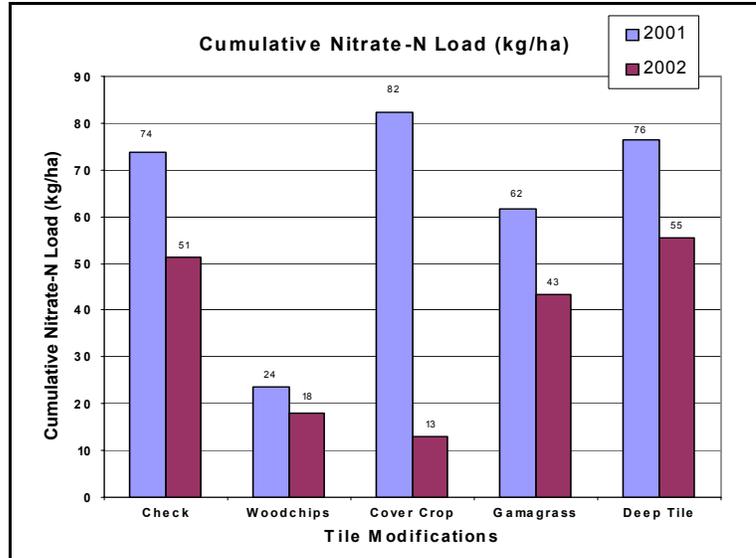


Fig. 13. Cumulative nitrate-N load to tile drainage in 2001 and 2002 for five tile treatments.

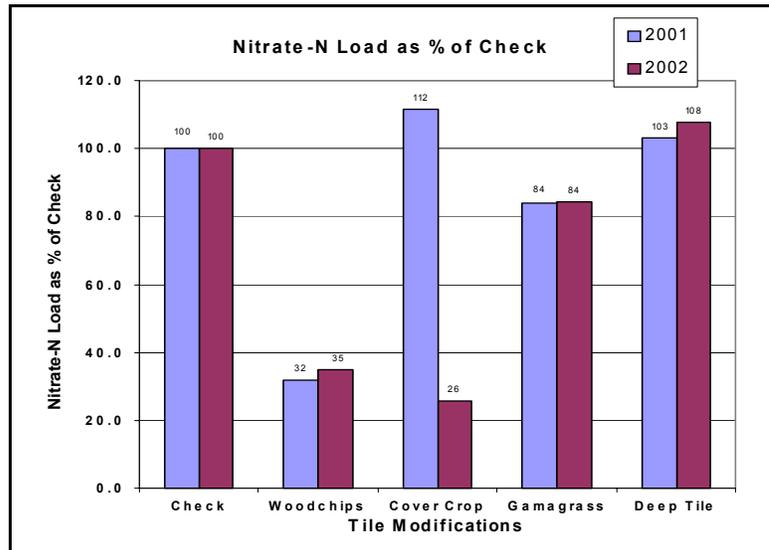


Fig. 14. Cumulative nitrate-N load to tile drainage as percentage of check in 2001 and 2002 for five tile treatments.

155 cm (Table 1). The 90 cm depth is above the drainage tile and is often above the water table. As a result, wood chips at this depth are better aerated and subject to more rapid decomposition.

Table 1. Percentage of wood chip dry matter remaining after three or four years in wood chip biofilter trench.

| Depth | % of Wood Chip Dry Matter Remaining | |
|--------|-------------------------------------|------------------|
| | After three years | After four years |
| 90 cm | 60 (17) [†] | 46 (7) |
| 155 cm | 89 (1.0) | 89 (1.4) |

[†] Mean of four replications with standard error in parentheses.

After four years the wood chips at the 90 cm depth had decreased to 46 % of their original weight and the wood chips at 155 cm had not changed. The lack of change between the third and fourth year at the 155 cm depth may indicate that the rate of decomposition is slowing somewhat and based on our laboratory studies this is what we would expect. At the 90 cm depth the wood chips continued to decompose at about the same rate as in the first three years. The decomposition rate will continue to be monitored and hopefully this will give us some idea of effective lifetime of the wood chip treatment.

Corn and Soybean Grain Yields

Corn grain yields in 2000 did not differ among the treatments (Table 2). In 2000, both corn and

Table 2. Corn and soybean grain yields for 2000-2002.

| Tile Treatments | Corn Yield 2000 | Soybean Yield 2001 | Corn Yield 2002 |
|-----------------|-----------------------------------|--------------------|-----------------|
| | ----- bu acre ⁻¹ ----- | | |
| Check | 164 a [†] | 46 a | 198 a |
| Wood Chips | 163 a | 45 ab | 189 abc |
| Cover Crop | 164 a | 44 ab | 176 d |
| Gamagrass | 170 a | 44 ab | 194 ab |
| Deep Tile | 165 a | 43 b | 187 bc |

[†] Mean of four replications. Means within a column with the same letter following it are not different at 0.10 level of significance.

gamagrass were planted above the tile lines and corn yield of the entire plot was not affected. Soybean yields in 2001 were obtained from harvesting one fourth of the plot area and thus, were not affected by the permanent gamagrass strip. The yield of the deep tile plots were 3 bu acre⁻¹

less than the check in 2001. All the other treatments were not significantly different from the check. In 2002, both the cover crop treatment and the deep tile treatment showed a yield decrease relative to the check although yields of both treatments were greater than 176 bu acre⁻¹. The yields of the gamagrass plots were adjusted to reflect only the plot area planted to corn. There is no apparent reason for the lower yields of the deep tile treatment plots in either 2001 or 2002. It is possible that the by installing the tiles deeper more subsoil was brought to the surface. If this were the cause, however, the same yield reduction would have occurred in the wood chip treatment plots, which had much greater soil disturbance. The lower yields of the cover crop treatment are also difficult to understand. As mentioned previously, the rye cover crop grew well between the fall 2001 and spring 2002. The rye cover crop, however, did not limit water availability to the corn crop and the amount of fertilizer nitrogen applied should have been adequate for the corn crop. The rye cover crop did delay early growth and maturity of the corn. Additionally, a severe wind storm in July 2002 knocked over much of the corn in the research plots, especially those plots on the west side, which included three of the cover crop plots. This may have affected the corn plants in the cover crop plots more severely than the plants in other treatments because the cover crop plants were behind in development. Two of the deep tile treatment plots were also in the part of the research area affected by the wind storm and the yields of this treatment were also reduced relative to the control. Other studies in Iowa, however, have also shown a yield reduction in corn yield following a rye cover crop, but the cause is unknown. In some ways, the effect of the rye cover crop on early corn growth and yield is similar to that of corn following corn. Obviously, a well-established rye cover crop has tremendous potential for reducing nitrate-N losses in tile drainage, for protecting the soil from erosion, and for increasing soil organic matter, but corn yield losses would limit its usefulness. Research with different cultivars of rye, winter wheat, and winter triticale is being conducted to find cover crop cultivars that don't affect corn yields. Additionally, new cover crop management practices are also being investigated to eliminate any detrimental effects on corn growth.

Summary

In 2001 and 2002, the woodchip trench treatment consistently reduced nitrate-N concentrations below 10 mg L⁻¹ and also reduced cumulative nitrate-N load to drainage water. In 2002, the rye cover crop treatment also reduced nitrate-N concentrations below 10 mg L⁻¹ and reduced nitrate-N loads. In 2001, the rye cover crop had no effect on nitrate-N concentrations and load because of poor establishment and growth of the cover crop due to dry fall conditions. The other tile treatments had no significant effects on nitrate-N concentrations or loads. There was some evidence that the gamagrass treatment may have reduced nitrate-N loads because of a small reduction in cumulative water flow. Monitoring of the site and data collection will continue through 2003 and 2004. Based on initial results it seems that wood chip trenches and rye winter cover crops have the potential to reduce nitrate-N concentrations and loads in tile drainage water in a corn-soybean rotation.

Another aspect of these tile modifications or managements that needs to be considered is their cost. Although the researchers involved in this project do not have expertise in cost estimation,

we would guess that the costs of the treatments relative to normal tile installation would be as follows:

- wood chips 4 X normal tile
- deep tile 1.5 X normal tile
- gamagrass 1.5 X normal tile + long term cost of land out of production
- cover crops \$10 - 20/acre

Part of the high estimated cost of the wood chip treatment is the use of two trenches on either side of the tile. This two-trench design was necessitated by the design of the tile trenching machine used by our contractor. We had originally intended to place the tile and wood chips in the same trench with wood chips above and below the tile. The contractor felt that if we tried to put wood chips below the tile, he could not guarantee that the tile would be laid on a uniform grade. The contractor felt that this could be accomplished in the future with a redesign or an attachment for his equipment. Of course we do not know for sure whether putting the wood chips in the same trench as the tile would be more or less effective at removing nitrate from the drainage water.

As mentioned earlier we are continuing to study the management of winter cover crops. There are many other cultivars of small grains or other species of plants that may work better than the rye cultivar that we used. This is especially true in regards to the potential for yield reduction of the following corn crop, which must also be included in the cost of the cover crop treatment. Additionally, it may not be necessary to plant the winter cover crop over the entire field to reduce the nitrate concentrations in the tile drainage water. To reduce nitrate concentrations in drainage water planting cover crops on the footslopes, lowlands, drainage ways, and above the tiles may be sufficient. These issues will need to be resolved with further research.

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Publications and Presentations Resulting from this Research

Popular Press Articles

"Wood Chips Cut Nitrate in Runoff" by Darrell Smith on AgWeb.com 25 June 2003

The Des Moines Register, "Chips of wood clean up nitrates in water", by Perry Beeman, p 1A, 29 April 2002.

Iowa Farmer Today, "Researchers say wood chips could stop nitrate runoff", 11 May 2002

Farm News, "In the chips: Study designed to slow nitrate runoffs", 17 May 2002.

Iowa Farm Bureau Spokesman, "Wood chips remove nitrates; practicality unknown", by Dale Johnson, p 12, 1 June 2002.

"Testing Tile Filters" by Karen McManhon in Farm Industry News, vol. 33, no. 9, p.20, July-Aug. 2000.

Public Presentations

Reducing Nitrate Levels in Subsurface Drain Water with Organic Matter Incorporation, Iowa Corn Promotion Board Research Committee Meeting, Aug. 15, 2000, West Des Moines, IA.

"Biofilter Concept for Tile Lines", presentation at Watershed Heroes Conference, Little Amana, IA June 8, 1999; (conference attendance 200)

"Biofilters for Tile Lines", presentation at Watershed Heroes Conference, Little Amana, IA June 5-7, 2000; (conference attendance 200)

"Biofilters for N in Tile Lines", presentation at Watershed Heroes Conference, St. Peter, MN June 19, 2003 (60 at presentation farmers, students, and Ag. Consultants).

"Overview of Ongoing Research", presentation by Dan Jaynes at Third Annual Minnesota-Iowa Drainage Research Forum, Farimont, MN, Aug. 13, 2002.

Scientific Presentations

Denitrification-Based removal of Nitrate from Subsurface Drainage Water, presented by Tom Moorman, American Water Resources Association, Agricultural Hydrology and Water Quality Conference, Spr. 2003, Kansas City, MO.

Subsurface Drain Modification to Reduce Nitrate Losses in Drainage. D.B. Jaynes, T.C. Kaspar, T.B. Moorman, and T.B. Parkin. Paper Number 022015. 2002 ASAE Annual International

Meeting/CIGR Xvth World Congress, Chicago, IL, 31 July 2002.

Variable Flow Rate Effects on Efficiency of Denitrification in Biofilters. C.M. Greenan, T.B. Moorman, T.B. Parkin, D.B. Jaynes, and T.C. Kaspar. ASA-CSSA-SSSA Annual Meetings - October 21 - 25, 2001 - Charlotte, NC *In* Annual Meetings Abstracts [CD-ROM]. ASA, CSSA, and SSSA, Madison, WI. 2001.

REFERENCES FOR LITERATURE REVIEW

- Baker, D.B. 1988. Sediment, nutrient, and pesticide transport in selected lower Great Lakes tributaries. U.S. EPA, Chicago, IL EPA-905/4-88-001.
- Baker, J.L. K.L. Campbell, H.P. Johnson, and J.J. Hanway. 1975. Nitrate, phosphorus, and sulfate in subsurface drainage water. *J. Environ. Qual.* 4:406-412.
- Baker, J.L. and H.P. Johnson. 1981. Nitrate-nitrogen in tile drainage as affected by fertilization. *J. Environ. Qual.* 10:519-522.
- Benoit, G.R. 1973. Effect of agricultural management of wet sloping soil on nitrate and phosphorus in surface and subsurface water. *Water Resour. Res.* 9:1296-1303.
- Bergström, L. 1987. Nitrate leaching and drainage from annual and perennial crops in tile-drained plots and lysimeters. *J. Environ. Qual.* 16:11-18.
- Brandi-Dohrn, F.M., R.P. Dick, M. Hess, S.M. Kaufmann, D.D. Hemphill, Jr., and J.S. Selker. 1997. Nitrate leaching under a cereal rye cover crop. *J. Environ. Qual.* 26:181-188.
- Bjorneberg, D.L., R.S. Kanwar, and S.W. Melvin. 1996. Seasonal changes in flow and nitrate-N loss from subsurface drains. *Trans. Am. Soc. Agric. Eng.* 39:961-976.
- Cambardella, C.A., T.B. Moorman, D.B. Jaynes, T.B. Parkin, and D.L. Karlen. 1999. Water quality in Walnut Creek watershed: Nitrate nitrogen in soils, subsurface drainage water and shallow groundwater. *J. Environ. Qual.* 28:25-34..
- Drury, C.F., C.S. Tan, J.D. Gaynor, T.O. Oloya, and T.W. Welacky. 1996. Influence of controlled drainage-subirrigation on surface and tile drainage nitrate loss. *J. Environ. Qual.* 25:317-324.
- Gast, R.G., W.W. Nelson, and G.W. Randall. 1978. Nitrate accumulation in soils and loss in tile drainage following nitrogen application to continuous corn. *J. Environ. Qual.* 7:258-262.
- Gilliam, J.W., R.W. Skaggs, and S.B. Weed. Drainage control to diminish nitrate loss from agricultural fields. *J. Environ. Qual.* 8:137-142.
- Goolsby, D.A. and W.A. Battaglin. 1993. Occurrence, distribution, and transport of agricultural chemicals in surface waters of the Midwestern United States. p.1-25. *In*: Goolsby, D.A., I.L. Boyer, and G.E. Mallard. (ed.), Selected papers on agricultural chemicals in water resources of the Midcontinental United States. U.S. Geological Survey, Open File Report 93-418. Dept. of Interior, Washington, DC.
- Hanway, J.J. and J.M. Laflen. 1974. Plant nutrient losses from tile outlet terraces. *J. Environ.*

Qual. 3:351-356.

Herbert, S.J., F.X. Mangan, G.Liu, J.Daliparthy, A.V.Barker, and L.J.Moffitt. 1995. Nitrate leaching in alternate cover crop systems. *Trans ASAE* 2:71-74.

Humenik, F.J., M.D. Smolen, and S.A. Dressing. 1987. Pollution from nonpoint sources. *Environ. Sci. Tech.* 21:737-742.

Hunter, W.J., R.F. Follett, and J.W. Cary. 1997. Use of vegetable oil to remove nitrate from flowing groundwater. *Trans. ASAE* 40:345-353.

Jaynes, D.B., T.S. Colvin, and J. Ambuel. 1995a. Yield mapping by electromagnetic induction. p.383-394. *In* P.C. Robert et al. (ed.) Site-specific management for agricultural systems. Proc. 2nd Int. Conf. Minneapolis, MN. 27-30 Mar. 1994. ASA, CSSA, and SSSA, Madison, WI.

Jaynes, D.B., T.S. Colvin, D.L. Karlen, C.A. Cambardella, and D.W. Meek. 2001. Nitrate loss in subsurface drainage as affected by nitrogen fertilizer rate. *J. Environ. Qual.* 30:1305-1314.

Jaynes, D.B., J.L. Hatfield, and D.W. Meek. 1999. Water quality in Walnut Creek watershed: Surface Water. *J. Environ. Qual.* 28:45-59.

Jaynes, D.B., J.M. Novak, T.B. Moorman, and C.A. Cambardella. 1995b. Estimating herbicide partition coefficients from electromagnetic induction measurements. *J. Environ. Qual.* 24:36-41.

Johnson, T.J., T.C. Kaspar, K.A. Kohler, S.J. Corak, and S.D. Logsdon. 1998. Oat and rye overseeded into soybean as fall cover crops in the upper Midwest. *J. Soil Water Conserv.* 53(3):276-279.

Kachanoski, R.G., E.G. Gregorich, and I.J. Van Wesenbeeck. 1988. Estimating spatial variations of soil water content using noncontacting electromagnetic inductive methods. *Can. J. Soil Sci.* 68:715-722.

Kanwar, R.S., J.L. Baker, and D.G. Baker. 1988. Tillage and split N-fertilization effects on subsurface drainage water quality and crop yields. *Trans. ASAE* 31:453-461.

Kapoor, A. and T. Viraraghavan. 1997. Nitrate removal from drinking water - review. *J. Environ. Eng.* 123:371-380.

Keeney, D.R. and T.H. DeLuca. 1993. Des Moines River nitrate in relation to watershed agricultural practices: 1945 versus 1980s. *J. Environ. Qual.* 22:267-272.

Logan, T.J., G.W. Randall, and D.R. Timmons. 1980. Nutrient content of tile drainage from cropland in the North Central Region. *Ohio Agric. Res. Dev. Ctr. Res. Bull.* 1119. Wooster.

McCracken, D.V., J.E.Box, W.L.Hargrove, M.L.Cabrera, J.W.Johnson, P.L.Raymer,

A.D.Johnson, and G.W.Harbers. 1995. Tillage and cover crop effects on nitrate leaching in the southern Piedmont. *Trans. ASAE* 2:135-138.

Meisinger, J.J., W.L. Hargrove, R.L. Mikkelsen, J.R. Williams, and V.W. Benson. 1991. Effects of cover crops on groundwater quality. p. 57-68. *In* W.L. Hargrove (ed.) *Cover crops for clean water*. Proc. of an international conf. April 9-11, 1991. Jackson, TN. Soil and Water Conservation Society, Ankeny, IA.

Miller, M.H. 1979. Contribution of nitrogen and phosphorus to subsurface drainage water from intensively cropped mineral and organic soils in Ontario. *J. Environ. Qual.* 8:42-48.

Rabalais, N.N, W.J. Wiseman, R.E. Turner, B.K. Sen Gupta, and Q. Dortch. 1996. Nutrient changes in the Mississippi River and system responses on the adjacent continental shelf. *Estuaries* 19:386-407.

Robertson, W.D. and J.A. Cherry. 1995. In situ denitrification of septic-system nitrate using reactive porous media barriers: Field trials. *Ground Water* 33:99-111.

Robins, C.W. and D.L. Carter. 1980. Nitrate-nitrogen leached below the root zone during and following alfalfa. *J. Environ. Qual.* 9:447-450.

Schipper, L., and M. Vojvodic-Vukovic. 1998. Nitrate removal from groundwater using a denitrification wall amended with sawdust: Field trial. *J. Environ. Qual.* 27:664-668.

Thurman, E.M., D.A. Goolsby, M.T. Meyer, and D.W. Koplin. 1992. A reconnaissance study of herbicides and their metabolites in surface water of the Midwestern United States using immunoassay and gas chromatography/mass spectrometry. *Environ. Sci. Technol.* 26:2440-2447.

USDA. 1987. *Farm drainage in the United States: History, status and prospects*. Misc. Pub. No. 1455. Washington, D.C.

U.S. EPA. 2000. *The national water quality inventory. The 2000 report to Congress*. U.S. EPA, Washington, DC.

Williams, B.G., and D. Hoey. 1987. The use of electromagnetic induction to detect the spatial variability of the salt and clay contents of soils. *Aust. J. Soil Res.* 25:21-27.