



Nitrate Leaching to Subsurface Drains as Affected by Drain Spacing and Changes in Crop Production System

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Subsurface drainage (often called “tile” drainage) is a common water management practice in agricultural regions with seasonally high water tables. It provides many agronomic and environmental benefits, including greater water infiltration, lower surface runoff and erosion, and improved crop growth and yield compared with similar agricultural soils without subsurface drainage. Subsurface drains have been found to reduce losses of sediment and phosphorus from agricultural fields but to increase losses of nitrate N through the enhanced leaching.

An appropriate balance between increasing drainage intensity (narrower spacing) to improve drainage and decreasing drainage intensity to reduce nitrate N losses needs to be found for different climatic and soil regions. Recent concerns about the hypoxic zone in the Gulf of Mexico and similar problems worldwide have caused a renewed interest in tile drain studies. Because tile drainflow contributes significant amounts of water and nitrate to ditches and streams during some months of the year, drainage studies provide valuable data for estimating nitrate loads in agricultural watersheds.

Nitrate concentrations and mass losses in subsurface tile drains vary with soil organic matter level, yearly weather variations, fertilizer N rates and timing, drain spacing, cover crop growth, cash crop yield and water table control practices. Noncontrollable factors such as precipitation and the mineralization of soil organic matter have a great impact on drainage volumes and nitrate loads. Our 15-year study provides an important data set for assessments of nitrate leaching in the Mississippi River basin. Our site is on a low organic matter, loess-derived silt loam soil in southeastern Indiana, which contrasts with the high organic matter soils of most of the drainage studies in Iowa, Minnesota and Illinois. By comparing results from different soils and climatic zones within the Midwest, sci-

entists and policymakers will hopefully gain greater understanding of the challenges to reducing nitrate loads to subsurface drains.

The objectives of our study were to (1) evaluate the effect of three different drain spacings on water flow and nitrate leaching into subsurface drains over a 15-year period and (2) measure changes in nitrate leaching that would result from first converting from conventional monoculture corn with high N fertilizer rates to the same cropping system with lower N rates, and then to a no-till corn-soybean rotation with lower fertilizer N rates and a winter “trap crop.”

MATERIALS AND METHODS

A subsurface drainage research facility was established in 1983 at the Southeastern Purdue Agricultural Center (SEPAC) in southeastern Indiana. The site has drains (10-cm diameter) installed at spacings of 5, 10 and 20 m at an average depth of 75 cm and a slope of 0.4%. Three drain lines (225-m length) were installed at each spacing, with the outside drain lines on each spacing acting as common drains between treatments. Each spacing was replicated in two blocks separated by a 40-m distance.

Corn was planted each year from 1984 through 1993, using conventional tillage. In 1994 a no-till, soybean-corn rotation was begun, with the addition of a winter wheat cover crop after corn as a “trap crop” for N in the soil profile. Fertilizer N rates were gradually reduced during the course of the experiment as fertilizer rate “philosophy” changed within the Purdue extension recommendations. Preplant fertilizer N rates were 285 kg N ha⁻¹ for the first 5 years of monoculture corn, 228 kg N ha⁻¹ for the last 5 years of monoculture corn, 200 kg N ha⁻¹ in 1995 and 177 kg N ha⁻¹ in 1997 and 1999, all preplant-applied as anhydrous ammonia. The nitrification inhibitor nitrapyrin was used at a rate of 0.56 kg a.i. ha⁻¹ with the anhydrous ammonia applications from 1984 through 1995. A small amount of “starter” fertilizer N was also applied during corn planting.

RESULTS AND DISCUSSION

Hydrology. Annual rainfall ranged from a low of 800 mm for 1987 to a high of 1,370 mm in 1995, with the average nearly equal to the 30-year “normal.” Drainflow per unit area decreased as drain spacing became wider, as expected. Drainflow varied from a low of 6.7 cm (8% of annual rainfall) for the 20-m spacing in 1987, the driest year, to a high of 32.5 cm (26% of annual rainfall) for the 5-m spacing in 1985.



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Drainflow as a percent of annual rainfall (“drainage efficiency”) was calculated for each year and each drain and averaged over the periods of interest. Averaged over the 15-year period, drainage efficiencies were 20.6%, 14.9% and 12.1% for the 5-, 10- and 20-m spacings, respectively. A comparison was then made between the two different cropping systems used in different time periods of the study, namely continuous corn with chisel tillage in 1985-1993 vs. the 1994-1999 soybean-corn rotation with no-till and a winter wheat cover crop after corn. Average annual drainage efficiencies were 20.4%, 13.7% and 11.2% for the 5-, 10- and 20-m spacings, respectively, for the 1985-1993 continuous corn years and 20.8%, 16.5% and 13.2%, respectively, during the 1994-1999 soybean-corn years. The data suggest drainage efficiency did not change over time for the 5-m spacing, but that the 10- and 20-m spacings showed an increased efficiency during the later time period. This increased efficiency for the wider spacings may reflect a maturation of the drainage system over time, with flow paths to the drains developing from greater distances over the years after drain tiles were installed. Because the 5-m spacing showed no evidence for a change in drainage efficiency with time, it suggests that the changes for the 10- and 20-m plots were not due to evapotranspiration differences resulting from the new cropping system. Within the six years of soybean-corn rotation, there were no apparent trends in drainflow or drainage efficiency between the corn years and the soybean years.

Nitrate Nitrogen Concentrations. Nitrate N concentrations in drainflow decreased considerably over the 15-year period. Concentrations were consistently in the 20 to 30 mg L⁻¹ range in the 1985 to 1988 period and in the 7 to 10 mg L⁻¹ range in the 1996 to 1999 period. Concentrations did not vary with block or drain spacing.

The 71% decrease in nitrate N concentrations from the 1986 to 1988 period to the 1997 to 1999 period is probably a result of a combination of the management practice effects along with yearly weather and crop yield variations. Reduction of fertilizer N rates and the growth of a winter “trap crop” after corn have both been shown to reduce nitrate N concentration in drainage and are probably the major factors in our study. A corn-soybean rotation compared with continuous corn or the soybean phase compared with the corn phase of a corn-soybean rotation have sometimes shown lower nitrate N concentrations and may also be a factor at our site. Conversion from spring chisel tillage to no-till probably had minor influence on nitrate leaching, since most of the annual drainage in the “tilled” years occurred before tillage was performed.

In addition to management practice changes, the weather and resulting crop yields had an impact on year-to-year variations in nitrate N concentrations (and load, as discussed later). During the first 5 years of the drainage study, preplant fertilizer N rates were 285 kg ha⁻¹, the recommended rate at that time for a yield goal of 12.5 Mg ha⁻¹. Several years of poor crop yields probably resulted in high residual soil N and contributed to the increasing trend in concentrations over the 1985 to 1989 period. Preplant fertilizer N rates were reduced from 285 to 228 kg N ha⁻¹ in the 5-year period from 1989 to 1993, and concentrations started to show a decrease in 1990, in the first “flow season” after the reduction in fertilizer application. A rise in con-

centrations in 1992 probably reflects the poor crop yield in 1991, but concentrations decreased again in 1993 following a high crop yield in 1992. The 1994 change to a soybean-corn rotation and lower fertilizer N rates for the corn did not result in an immediate decrease in concentration, but by 1996 the concentrations had declined again. The lower concentrations are probably a result of both the winter wheat “trap crop” after the corn and the lower fertilizer N rates.

The precise fertilizer N rate and crop management system needed for optimal crop growth and environmental quality is region specific and varies from year to year, and this remains a major challenge for agriculturalists worldwide. Results of all these types of studies underscore the necessity for long-term field experiments in different regions and on different soils, to understand the impacts of yearly weather variations, long-term climate, soils and management on nitrate N leaching.

Nitrate Nitrogen Load. Annual nitrate N loads to drainage water decreased significantly over the 15-year period, due to the large decrease in nitrate N concentrations over the same period. Annual nitrate N loads averaged 38 kg N ha⁻¹ in the 1986 to 1988 period and 15 kg N ha⁻¹ in the 1997 to 1999 period. This 60% reduction in load occurred even though drainflow was 29% greater in the 1997 to 1999 period than in the 1986 to 1988 period. The 71% decrease in concentrations resulted in a large decrease in loads even with a moderate increase in flow.

In addition to the long-term trends in nitrate N loads, year-to-year variations in loads occurred as a result of variation in weather and crop yields. Loads were particularly high in 1989 after the low corn yields in the 1988 drought year. The higher residual nitrate that was probably remaining in the soil profile in autumn 1988, coupled with high drainflow volumes in 1989, led to the highest nitrate N loads of the 15-year study. Other Midwest studies also found greater N losses to drains in years following a drought due to greater residual N in the soil profile.

Nitrate N mass loads per unit area varied similarly to drainflow volumes, with a tendency for greater losses from the narrower spacings. Annual nitrate N losses were 50, 37 and 27 kg ha⁻¹ for the 5-, 10- and 20-m spacings, respectively, in the 1986-1988 period and 16, 16 and 13 kg ha⁻¹ in the 1997-1999 period. Differences in loads between spacings were significant in some but not all years.

As can be expected, differences in loads were larger in years with overall higher loads, and statistically significant differences were more prevalent in those years. Significant differences occurred almost exclusively in the time period with continuous corn, higher N fertilizer rates and no winter cover crop (1985-1993), whereas both absolute loads and the differences in loads between drains were smaller in the period with the winter cover crop, lower fertilizer N rates and soybean-corn rotation (1994-1999). The total 15-year nitrate N load was 559, 298 and 232 kg ha⁻¹ for the 5-, 10- and 20-m east drains, respectively, and 675, 587 and 463 kg ha⁻¹ for the 5-, 10- and 20-m west drains. The greater total loads from the narrower spacings compared with the wider spacings are consistent with the annual differences in loads discussed previously.

Seasonal Effects on Drainflow, Loads and Concentrations. Loads to the drains exhibit a clear seasonal cycle related to the



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timing of drainflow in this system. The majority of drainflow and nitrate N loads occurs in the fallow season of November through March. Rainfall is relatively uniformly distributed throughout the year, but drainflow varies much more over the year, due to higher evapotranspiration in the growing season. Drains typically begin to flow in November or December at this site, after the soil profile has rewetted following the growing season. Drainflow at the site continues through the winter in most years, and flow usually ceases in May or early June. In climates where the soil does not freeze all winter, most of the drainage and nitrogen loss occurs in late fall, winter and early spring. Differences in seasonal distribution of flow must be considered when comparing studies from different regions and when designing and evaluating management strategies for decreasing nitrate loads to drainage water.

Visual observation of the data from individual drains did not reveal a strong seasonal pattern in monthly nitrate N concentrations for the 15-year period. The close correspondence of percent of annual flow and load in each month also indicates a relatively stable concentration throughout the year.

At our site, the tendency for slightly higher nitrate concentrations in May–June–July has minimal impact when considering total nitrate loads for the year. Nearly 80% of the annual drainflow and annual nitrate load occurs in the winter and early spring before fertilization for the next crop. These results underscore the potential importance of cropping systems that would use some of the nitrogen and water during late fall or early spring, such as winter cover crops or perennials that grow later in the fall and earlier in the spring than the typical corn-soybean rotation. Winter cover crops may be able to provide some of the benefits of perennials in the midst of an annual cropping system, if sufficient growth of the cover crop can be obtained under the cool conditions of the Midwest.

Concentrations vs. Flow Rates. Graphical analysis of concentration and flow data revealed some periods where concentration declined rapidly as the flow increased rapidly. This is opposite to the typical preferential flow behavior of pesticides or newly applied tracers, which tend to move with the water in the preferential flow paths and have higher concentrations as the hydrograph rises. Nitrate and other chemicals that are well distributed in the soil matrix tend to move more by matrix flow, however, and therefore drain concentrations are diluted by the relatively clean water flowing in the preferential pathways. This behavior does not occur consistently in our drains, and we do not know why it occurs sometimes but not always.

CONCLUSIONS

Subsurface drainage is an important water management practice in many humid regions of the world, but it also has potential negative effects of increased nitrate leaching through soils. Our 15-year study on a loess-derived soil in southeastern Indiana provides an important data set for assessments of nitrate leaching into tile drains in the Mississippi River basin. The primary findings from our site are:

- Nitrate N concentrations and mass losses were significantly decreased over the period of study by a combination of reductions in N fertilizer rates, change in rotation and tillage, and

growth of a winter cover crop as a “trap crop” after corn. Nitrate N concentrations and loads decreased from 28 mg L⁻¹ and 38 kg ha⁻¹ yr⁻¹, respectively, in the 1986-1988 period to 8 mg L⁻¹ and 15 kg ha⁻¹ yr⁻¹ in the 1997-1999 period, while drainflow was 29% higher in the latter period.

- Both drainflow volumes and nitrate N leaching losses were greater with more intensive drain spacing. Spacing affected drainflow throughout the study, but differences in nitrate N loads with spacing occurred primarily in years with continuous corn, high fertilizer N rates and no cover crop.
- The majority of the drainflow occurs in the fallow season. About 64% of the annual drainflow occurs in November through March, and 81% in November through April.
- The majority of the N loads occur in the fallow season. About 63% of the annual N load occurs in November through March, and 78% in November through April.
- Concentrations did not vary greatly by month within a year, but loads did vary due to seasonal drainflow distributions.

Concerns about hypoxia in the Gulf of Mexico have focused attention on nitrate N loads from tile-drained soils of the U.S. Midwest. As researchers and policymakers explore options for reducing the loads, studies from different Midwest locations should be carefully compared and contrasted. Some key points from our current study that should be kept in context when comparing results across the region are highlighted here:

- The relatively shallow (0.75 m) drain depth at our site may affect concentrations and drainflow volumes, compared with sites where drains are installed at deeper depths.
- The low organic matter content of this soil (approximately 1.3%) contrasts with the Mollisols of much of the upper Midwest. The nitrate N concentrations of less than 10 mg L⁻¹ achieved in the last four years of our soybean–corn rotation with winter cover crop after the corn may not be achievable on high organic matter soils growing the same rotation, due to higher mineralization rates.
- Drainage occurs all winter (usually) at our site. But at many Midwest drainage research sites (Minnesota, Iowa) drainflow ceases in January, February and part of March.
- Fertilizer N is applied as spring preplant anhydrous ammonia, in the second half of April. This contrasts with sites receiving fall N applications or nitrate-containing fertilizers.

Additional research comparing the low organic matter soils represented here and the high organic matter soils of much of the U.S. Midwest is essential for understanding the system and designing appropriate management practices for each region.

Editor's note: Content was adapted from the paper “Nitrate Leaching to Subsurface Drains as Affected by Drain Spacing and Changes in Crop Production System,” which was published in the *Journal of Environmental Quality*, Vol. 33, September-October 2004, and is courtesy of the authors E. J. Kladvik, J. R. Frankenberger, D. B. Jaynes, D. W. Meek, B. J. Jenkinson, and N. R. Fausey.



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Nitrate Leaching to Subsurface Drains as Affected by Drain Spacing and Changes in Crop Production System September Self-Study Examination

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1. Benefits of subsurface tile drainage include all of the following EXCEPT

- a. greater water infiltration.
- b. decreased losses of nitrate N.
- c. improved crop growth and yield.
- d. reduced surface runoff.

2. A management factor that can increase nitrate leaching losses is

- a. wider tile spacings.
- b. cover crops in the rotation.
- c. high crop yields.
- d. continuous corn.

3. A reason why researchers are interested in studying tile flow and nitrate nitrogen loads in tile drains is

- a. water turbidity caused by underground drains.
- b. hypoxia zones such as that in the Gulf of Mexico.
- c. new national standards dictating nitrate levels in soils.
- d. chemical contamination of fish in rivers and streams.

4. Drainage efficiency for tile drains can increase over time from

- a. the natural development of flow paths to tiles.
- b. normal degradation and deterioration of plastic tile.
- c. decreasing soil organic matter in cultivated soils.
- d. the settling of soil over drains.

5. Even in years with more tile flow, a significant decrease in annual nitrate N loads to drainage water could occur if

- a. tiles are closely spaced.
- b. conventional tillage is used.
- c. tile trenches are backfilled with gravel.
- d. the nitrate N concentration in drain water is lower.

6. Reasons why nitrate N concentrations in drainflow decreased during the 15-year test period included changes in

- a. crop management practices.
- b. forms of nitrogen used.
- c. hybrid genetics.
- d. soil texture that occurred as a result of drainage.

7. High nitrate loads in tile drains might be expected when

- a. following successive high-yielding crops.
- b. winter cover crops are used.
- c. a wet year follows a drought.
- d. applying animal manure during the winter.

8. One of the reasons for this research studying subsurface tile drainage and nutrient loads was to

- a. help determine the correct tile spacing to maximize drainage benefits while minimizing nitrate losses.
- b. measure the reductions in stream nitrate loads by reducing tile flow during certain times of the year.
- c. calculate crop yield improvements possible through subirrigation of crops.
- d. determine the effects on crop diseases in improving soil drainage.





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9. This study showed that the majority of drainflow and nitrate N loads occurs during

- a. November through March.
- b. April through June.
- c. July and August.
- d. September and October.

10. A reason why results from this Indiana site need to be interpreted before they are directly applied to other drainage sites includes the

- a. ceasing of tile flow in January, February and March.
- b. high organic matter content of the soils.
- c. relatively shallow drain depth as compared to other drainage sites.
- d. practice of applying fall nitrogen.



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