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NITRATE-N LOADS TO SUBSURFACE DRAINS AS AFFECTED BY DRAINAGE INTENSITY AND AGRONOMIC MANAGEMENT PRACTICES

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ABSTRACT Few field studies have documented the impact of subsurface drainage intensity on nitrate loads in drainage waters. A long-term (23-yr) study has been conducted on a silt loam soil in southeastern Indiana, USA, to determine the impacts of drainage intensity (5-, 10-, and 20-m drain spacings) and changes in crop production system on nitrate loads to drainage water. Annual rainfall, drainflow, and drainage efficiency were higher in the 2000-2007 period compared to the 1985-99 time period. Average drainflow per unit area was 72% greater for the 5-m spacing compared with the 20-m spacing during the 1985-99 time period and 24% greater during the 2000-2007 period. The greater drainflow per unit area with the narrow spacing compared to wider spacings led to proportionately greater N loads to surface waters. The relative differences in drainflow among spacings has become smaller with time, possibly due to improved soil structure and permeability with time after drain installation or resulting from the no-till cropping system. No consistent differences in nitrate-N concentrations between corn and soybean years were evident except during the month or two following sidedress urea ammonium nitrate fertilizer application. Nitrate-N concentrations have generally remained below 10 mg/liter for most of the year during the past 12 years of the study. Nitrate loads were higher in 2000-2007 than in 1997-99, however, due to higher drainflow. Addition of a winter cover crop along with lower fertilizer N rates, have significantly reduced the nitrate concentrations and loads in drainflow over the experimental period.

Keywords: Nitrate, Cover crop, Fertilizer N, Drainage intensity, Permeability.

INTRODUCTION Subsurface drainage is an important agronomic and environmental water management practice, but it may also contribute substantial nitrate-N loads to surface waters. Few field studies have documented the impact of drainage intensity on nitrate-N loads in drainage waters, yet the desired drainage intensity is a critical factor in the design of drainage systems for crop production. An appropriate balance between increasing drainage intensity (narrower spacing) to improve drainage and crop yield, and decreasing drainage intensity to reduce nitrate-N losses, is site-specific and is challenging to determine. A long-term (23-yr) study has been conducted on a silt loam soil in southeastern Indiana, USA, to determine the impacts of drainage intensity and changes in crop production system on nitrate-N loads to drainage water. Three drainage intensities

(5-, 10-, and 20-m drain spacings) are compared for drainflow characteristics, nitrate-N concentrations, and nitrate-N loads. The objective of the current paper is to compare the recent eight years of data (2000-2007) to the previously published 15-yr data set (Kladivko et al., 2004). These types of long-term data sets are important for assessments of nitrate leaching into subsurface drains in the Mississippi River basin. Given that drainage intensity is continuing to increase in many agricultural areas, it becomes even more critical to more precisely manage the drainage and cropping system to prevent large increases in nitrate-N loads to drainage waters.

METHODS A subsurface drainage research facility was established in 1983 at the Southeastern Purdue Agricultural Center (SEPAC) in Jennings County, Indiana, USA. The site has been described in detail by Kladivko et al. (1991, 1999, 2004). The soil at the site is a Clermont silt loam (fine silty, mixed, mesic Typic Ochraqualf) and is typical of extensive areas of similar soils across southern parts of Ohio, Indiana, and Illinois. The soil was formed in 50 to 120 cm of loess over glacial till. The surface soil at the study site is light gray, low organic carbon (0.7%) silt loam containing 66% silt, 22% sand, and 12% clay. The soil is slowly permeable, and has a borderline fragipan at the 120 cm depth that severely restricts further downward drainage. Although subsurface tile drainage had not traditionally been used on these soils due to concerns of siltation in the tiles and the slow permeability of the soil, the past few decades have seen an increase in use of modern, perforated plastic drain tubing in these soils, with good success. The field experimental 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.

The center drains of the 5, 10, and 20 m plots discharge into observation wells at the bottom of the slope. Subsurface drainflow volumes are monitored continuously with tipping bucket flow gauges connected to a datalogger, and flow-proportional samples are collected with automatic water samplers during all time periods in which there is flow. Water samples are frozen until subsequent laboratory analysis. Nitrate-N mass losses were calculated as the product of water flow volumes and concentrations and were expressed on a per hectare basis, assuming that each drainline collects water from midplane to midplane with adjacent drains. A linear interpolation of concentrations was used to estimate concentrations on days between measurement points.

Corn (*Zea mays L.*) was planted each year from 1984 through 1993, using conventional tillage (chisel plow to a 20 to 25 cm depth in spring, followed by two passes with a disc or field cultivator). In 1994 a no-till, soybean (*Glycine max L.*) – corn rotation was begun, with the addition of a winter wheat (*Triticum aestivum L.*) 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 first 15 years, as new knowledge became available and fertilizer rate “philosophy” changed. Preplant fertilizer N rates were 285 kg N/ha for the first 5 years of monoculture corn, 228 kg N/ha for the last 5 years of monoculture corn (1989-1993), 200 kg N/ha in 1995, and 177 kg N/ha in 1997 and all succeeding corn years (odd-numbered years). The nitrogen was pre-plant applied as anhydrous ammonia up through 2001. The nitrification inhibitor nitrapyrin was used with the anhydrous ammonia applications through 1995. A small amount (8 to 28 kg N/ha) of “starter” fertilizer N was

also applied during the planting operation for corn. Fertilizer N application was changed from preplant anhydrous ammonia to sidedress urea ammonium nitrate (UAN) liquid in 2003. Table 1 summarizes field management practices over the 23-year period of study.

Table 1. Field management practices at SEPAC.

Year	**Crop**	**Tillage**	**Preplant or Sidedress Fertilizer N (kg/ha)**	**Winter "trap crop"?**
1984-88	Corn	chisel	285	no
1989-93	Corn	chisel	228	no
1994-95	Beans/Corn	no-till	200†	yes‡
1996-2007	Beans/Corn	no-till	177†	yes‡

†N applied to corn years only
‡winter wheat cover crop after corn only

RESULTS AND DISCUSSION

Hydrology Average annual precipitation over the 8-yr period of 2000-2007 was 124 cm, or 11% higher than the 112 cm of the previous 15-yr period (1985-99). The 30-yr "normal" (1971-2000) for this region is 113 cm. Drainflow volumes varied among years as a result of the differences in annual rainfall and the timing and intensity of the rainfall within each year. Average drainage efficiency (annual drainflow as a percent of annual rainfall) increased dramatically from the 1985-99 period to the 2000-07 period (Fig. 1). Drainflow per unit area was greater for the more intensive drainage systems (narrower spacings), as expected, and as had been found in the first 15 years. The increased drainage efficiencies for all spacings are largely due to the increased rainfall. Average annual rainfall was 12 cm higher in 2000-07 compared with 1985-99, and average drainflow was 12, 17, and 15 cm higher for the 5-, 10-, and 20-m spacings, respectively, during that same time period. Most of the drainage occurs during the fallow season when rainfall greatly exceeds potential evapotranspiration (PET), and so the additional rainfall was partitioned primarily to drainflow.

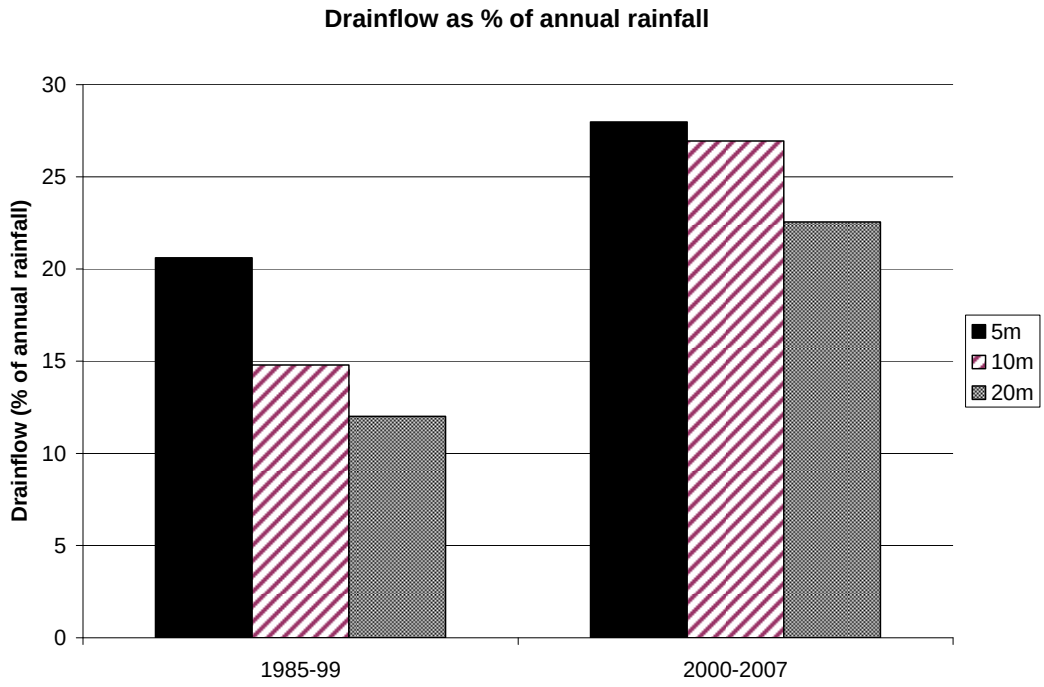

Figure 1. Annual drainflow as percent of annual rainfall, for the 1985-1999 period compared to the 2000-2007 period at SEPAC

The 10- and 20-m spacings showed a greater increase in drainflow between the two time periods than did the 5-m spacing. One potential explanation is the development of soil structure and alternate flow paths over time after drain installation, which would be expected to have a greater impact on the flow from further distances from the drain. Improved permeability and pore continuity developed during the long-term no-till on this site would be expected to affect all drain spacings, but it may have had relatively greater impact on the wider spacings.

Rainfall is fairly uniformly distributed throughout the year at this site, but drainflow is highly seasonal (Fig. 2). The drains typically flow very little during July through October and begin to flow in November or December after the soil profile has begun to rewet from autumn rains. The drains typically flow most of the winter and spring, although in some years they cease for short times during January or February. As has been found in other locations where the soil is not frozen the entire winter, the majority of the water flow (and nitrogen losses) occur in the autumn, winter, and early spring (Goss et al., 1993; Drury et al., 1996; Gilliam et al., 1999) when there are typically no crops growing and rainfall significantly exceeds PET.

Nitrate-N concentrations and loads Nitrate-N concentrations in drainflow had decreased from the 20-35 mg/L range in the 1985 to 1988 period, to the 7-10 mg/L range in the 1996 to 1999 period (Kladivko et al., 2004). Those concentration reductions were likely primarily due to a) lower fertilizer N rates, and b) growth of a winter cover crop as a “trap crop” for N after corn. During the 2000-2008 period, concentrations continued to

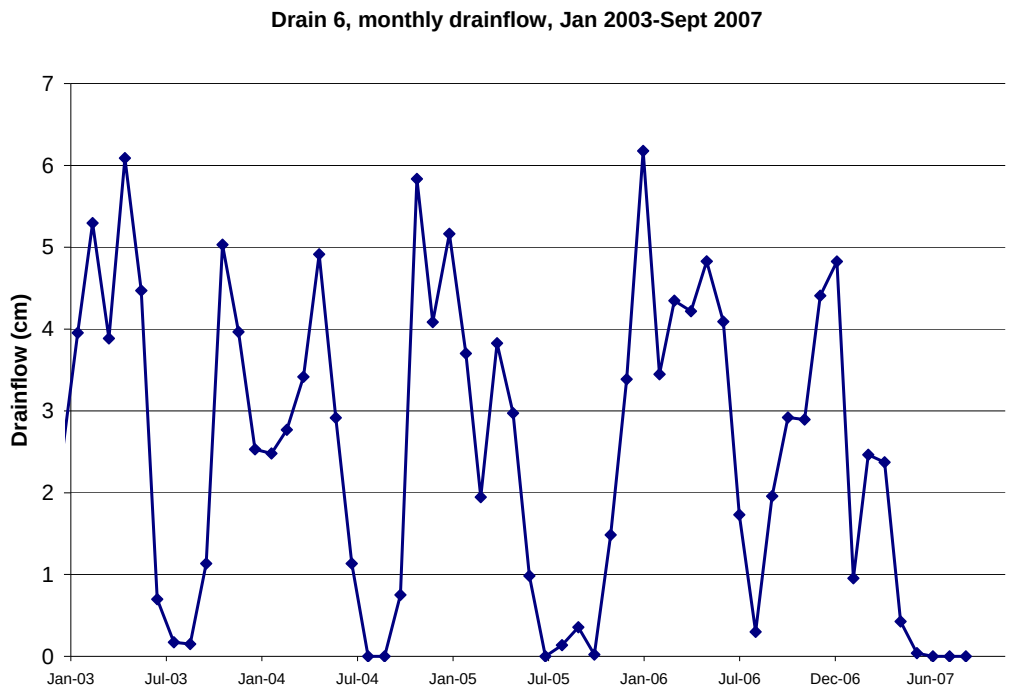

Figure 2. Monthly drainflow from the 20m spacing, west block, during 2003-2007 at SEPAC

remain below 10 mg/L during most time periods. However, as shown in the monthly flow-weighted mean concentrations for the 20-m west spacing, concentrations were sometimes in the 12-20 mg/L range during the first month or two after sidedress fertilizer N application (Fig. 3). This contrasts with results from the first 15 years of the study (Kladivko et al., 2004), when concentrations did not change after the preplant fertilizer N application. The anhydrous ammonia used during the earlier period had to first be nitrified in the soil, before it could be leached into tile drains. By the time this process had occurred, the crop was growing and there was also little drainflow, both of which would minimize any losses of nitrate. The urea ammonium nitrate (UAN), however, has a significant portion of the N that is immediately available to be leached, and thus a spike in nitrate-N concentrations can occur if there is any preferential flow after N application. Although nitrate-N concentrations spiked in June or July of the corn years (2003, 2005, 2007 in Fig. 3), the flow was usually very low during this time period, resulting in little impact of the high concentrations on loads.

Differences in nitrate-N concentrations between corn and soybean years were not clear, other than during the time periods shortly after fertilizer N application, as discussed above. There was a winter wheat cover crop sown after corn harvest, which would have taken up some of the residual soil nitrate. Although soybean residues are more readily degradable than cornstalks, there was not a discernible increase in nitrate-N concentrations after soybean harvest. During the earlier 1994-99 period, there had been even less difference between corn and soybean years because of the use of anhydrous ammonia rather then UAN. It appears that at this site, the cropping system of corn—winter cover crop—soybeans results in relatively consistent drainflow concentrations except for a few months after UAN application.

Annual nitrate-N loads had decreased from an average of 38 kg N/ha in the 1986 to 1988 period to an average of 15 kg N/ha in the 1997 to 1999 period (Kladivko et al., 2004). The large decrease in concentrations over that 15-yr period had resulted in the decreased loads. Although concentrations remained similar during the 2000-2007 period compared with the 1997-99 period, the overall flow was much greater, causing greater N loads (Fig. 4). There was still a tendency for the narrower spacing to have greater N loads due to the greater water flow compared to the wider spacing, but the differences were smaller than during the first few years of the study.

The results underscore the importance of continuing to search for better ways to optimize fertilizer N rates and grow winter cover crops to trap nitrate-N that would otherwise leach to drains during the normally fallow season. The nitrate-N loads were higher in 2000-2007 than in 1997-99, but the flow was much higher. If the current flow conditions had occurred while we had no cover crop and still had the fertilizer rates of the mid-1980s, the nitrate-N loads would have been very large. This can serve to remind us that progress has indeed been made in reducing nitrate losses from soils, but that there is still more innovation needed for the future. For example, cover crops are not typically grown in corn-soybean systems in much of the Midwest, due to increased cost and risk to the farmer and little economic gain. However, winter cover crops reduce nitrate concentrations and therefore loads by growing and taking up nitrogen during late autumn, winter, and early spring when most of the drainage occurs. New innovations are needed to better integrate cover crops and other "living cover" into cropping systems during the normally-fallow time of year, to reduce the risk of excessive nitrate leaching from intensive row-crop systems.

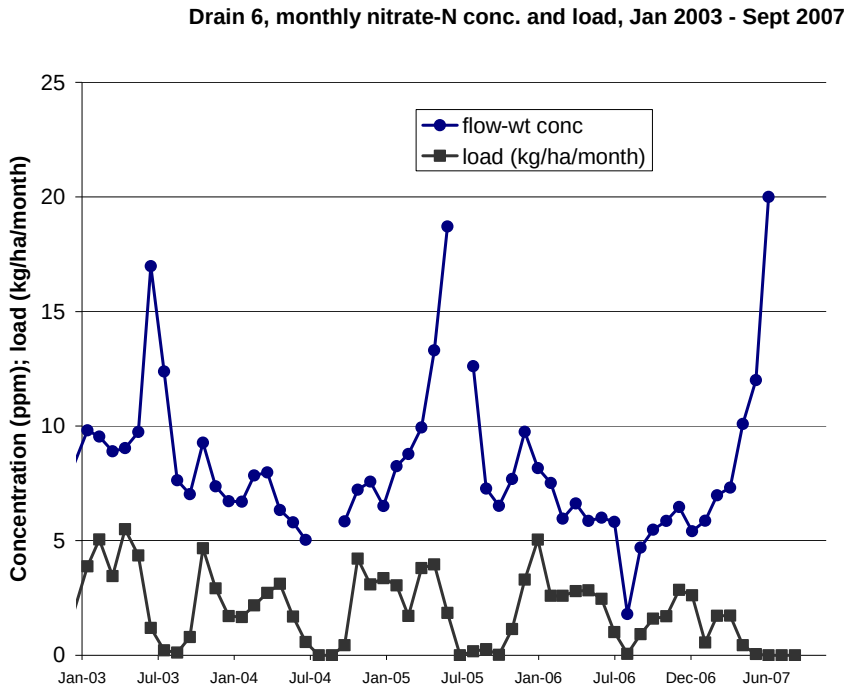

Figure 3. Monthly flow-weighted mean nitrate-N concentrations and nitrate-N load in drainflow from the 20m west spacing, during 2003--2007 at SEPAC

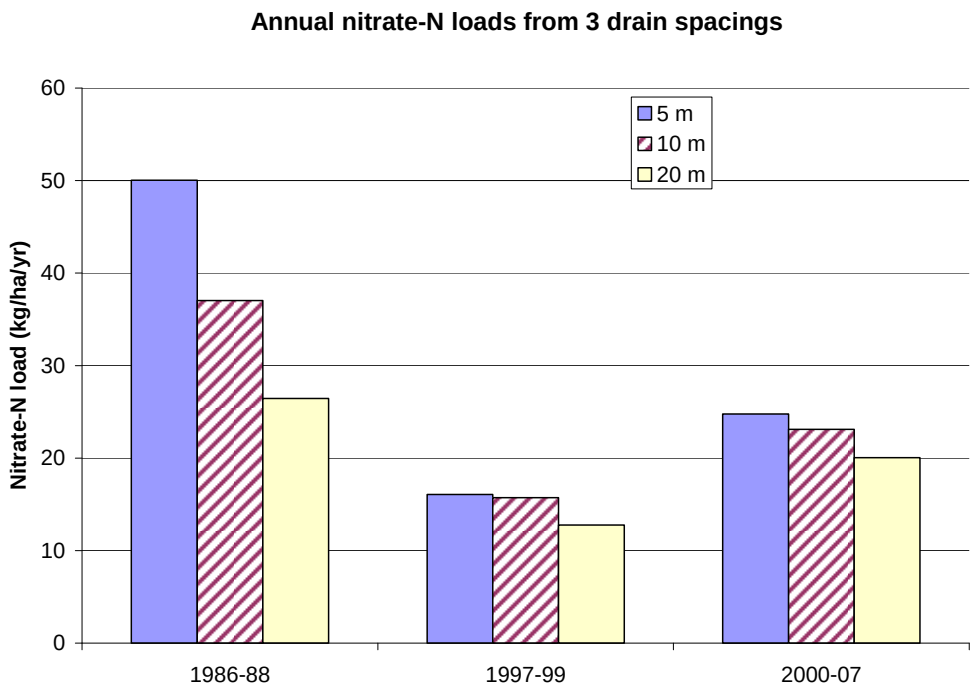

Figure 4. Average nitrate-N load in drainflow from 5, 10, and 20m spacings, during the 1986-88, 1997-99, and 2000-2007 time periods at SEPAC

CONCLUSIONS Subsurface drainage is a critical water management practice in humid regions of the world, but it also has potential negative effects of increased nitrate leaching through soils. Both drainflow volumes and nitrate loads to drainage waters are greater with more intensive drain spacing. When designing an "optimal drain spacing" for a given soil and climatic region, ideally both crop yield and drainage water quality should be considered. In the long-term study reported here, corn yields were only slightly higher with the narrowest spacing (5m) compared to the widest spacing (20m), but considering crop production alone would still result in narrower drain spacings than those desired for reducing nitrate-N loadings to surface waters.

Another way to look at this challenge is to consider that if we increase the intensity of one management practice, in this case drainage, then we also need to increase the management of some other practice(s) as well. So if more intensive drainage results in greater water flow through the soil as opposed to surface runoff, then we need to intensify management of the water and nutrients that move through the soil. Our current study has data related to winter cover crops, as one method to trap some of the nitrate before it leaves the root zone. Other possible management practices focus on reducing the drainflow itself, especially during the fallow season, by installing control structures for a drainage water management system. Other approaches include reducing concentrations in the water once it has left the field, with bioreactors or constructed wetlands. There are many possibilities for reducing concentrations or flow or both, and much more applied research is needed to help farmers and water management agencies choose and adapt an

appropriate set of practices for their system. This leaves many challenges for soil and water scientists and engineers for years to come!

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