

# Agronomy Guide

SOILS (TILLAGE)

## Interpreting Nitrate Concentration in Tile Drainage Water

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### Introduction

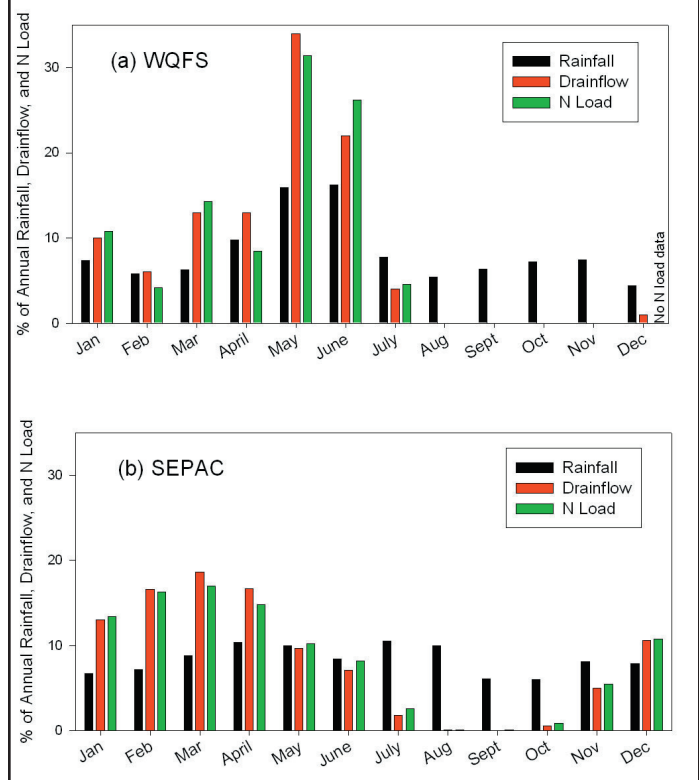
The combined objectives of maximum corn yields, efficient use of inputs (including fertilizer), and improved water quality in agricultural watersheds has led to both agricultural and regulatory interest in measuring nitrate nitrogen ( $\text{NO}_3\text{-N}$ ) concentrations in field drainage tile outlets. Crop, soil, and fertilizer management practices can have a strong influence on the amount of nitrogen (N) that is leached through soil and susceptible to loss in tile drainflow. However, other factors beyond a farmer's control can also strongly influence  $\text{NO}_3\text{-N}$  leaching and these need to be considered when attempting to evaluate the success of N management practices based on  $\text{NO}_3\text{-N}$  concentrations measured in tile drainflow.

The **purpose** of this publication is to (1) provide some general guidelines for interpreting measured  $\text{NO}_3\text{-N}$  concentrations in drainflow samples collected through monitoring programs, and (2) describe the most important factors influencing drainflow  $\text{NO}_3\text{-N}$  concentrations.

It is important to understand that some N loss is an inevitable outcome of improving the drainage and thus the agricultural productivity of naturally poorly drained soils. Nitrate is mobile in soils and is carried by water moving through soils. Subsurface drainage tiles create a direct pathway to carry  $\text{NO}_3\text{-N}$  from the bottom of the root zone to the adjacent surface water. Whenever tile lines flow,  $\text{NO}_3\text{-N}$  is lost from the field.

In Indiana, tile lines typically flow intermittently from late November to June. During this time, temperatures are cool and plants are either not present or are small and, as a result, combined water losses through evaporation and transpiration are minimal. In northern Indiana, tiles may cease flowing over long periods during the winter, causing the majority of the flow to occur between April and June. A six-year study at the Purdue University Water Quality Field Station (WQFS) in Tippecanoe County, for example, found that greater than 50 percent of the

**Figure 1.** Average monthly distribution of rainfall, drainflow, and N load at the (a) Water Quality Field Station (WQFS) and (b) Southeast Purdue Agricultural Center (SEPAC).

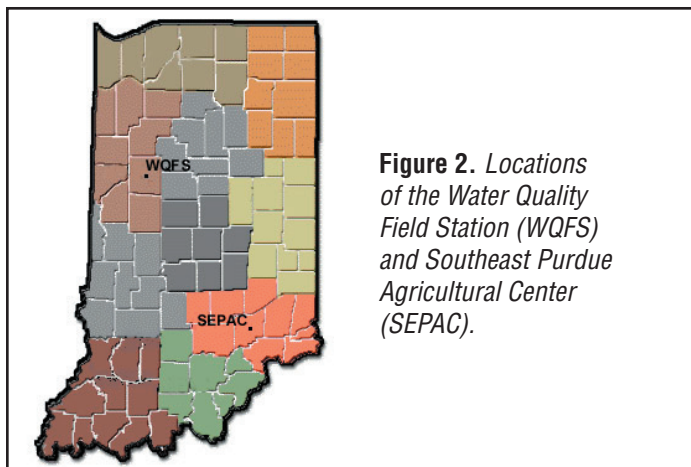


annual tile flow occurred in May and June (see Figure 1a). In contrast, in much of central and southern Indiana, tile lines flow all winter, and up to three-fourths of the annual drainflow and nitrate losses occur during the November to April period before field work and fertilization for the next crop begins. Results from a 15-year study at the Southeast Purdue Agricultural Center (SEPAC) in Jennings County illustrate this point (see Figure 1b) and underscore the potential importance of growing winter cover crops as “trap crops” for the N in the soil. The timing of drainflow during the year has important consequences for potential management of nitrate leaching to tiles.

### General Guidelines for Interpretation of NO<sub>3</sub>-N Concentrations in Tile Drains

Because of the importance of both tile drainage and nitrogen fertilizer to corn production in the Eastern Cornbelt, NO<sub>3</sub>-N concentrations in tile drainage water have been studied extensively by university researchers. Collectively, these studies suggest some common guidelines for interpreting the meaning of an individual concentration result from a water testing program. *However, caution should always be exercised in drawing conclusions from an individual sample, because concentrations may fluctuate over short time periods without a specific known cause.*

When corn productivity is not restricted by environmental conditions (e.g., saturated soils during stand establishment or drought during pollination), the optimal N fertilizer rate will usually result in NO<sub>3</sub>-N concentrations of <20 ppm in tile drainage water the following fall/spring (see Table 1). It should be noted that growing a row crop such as soybeans that fixes its own N from the atmosphere, does not drastically reduce NO<sub>3</sub>-N concentrations in drainage water. Crop residue decomposes after harvest, releasing a portion of the fixed N and making it available for use by a subsequent crop or for loss through leaching. Studies have consistently shown NO<sub>3</sub>-N values in spring drainage water following a soybean production year to be comparable to, or only slightly less than, values observed following an N-efficient



**Figure 2.** Locations of the Water Quality Field Station (WQFS) and Southeast Purdue Agricultural Center (SEPAC).

corn crop.

When a lack of N fertilizer limits yields in an otherwise optimal growing season, the NO<sub>3</sub>-N concentrations in tile drainflow the following spring may be less than 10 ppm. Cover crops may also reduce tile NO<sub>3</sub>-N concentrations if the crops grow sufficiently to trap significant quantities of residual N, then decompose at an appropriate time to release the trapped N to a growing crop. In the SEPAC study on a low organic matter soil, for example, nitrate-N concentrations averaged 8 ppm in a no-till corn-soybean rotation with a winter wheat cover crop grown after the corn. However, truly low drainflow NO<sub>3</sub>-N concentrations

**Table 1.** General guidelines for interpreting NO<sub>3</sub>-N concentrations in tile drainage water. The interpretation is derived from numerous studies conducted throughout the cornbelt and highlights land management strategies commonly found in association with a concentration measured in tile as the tile leaves the edge of the field.

NO <sub>3</sub> -N Concentration (ppm)	Interpretation
≤ 5	Native grassland, CRP land, alfalfa, managed pastures
5 – 10	Row crop production on a mineral soil without N fertilizer Row crop production with N applied at 45 lbs./acre below the economically optimum N rate† Row crop production with successful winter crop to “trap” N
10 - 20	Row crop production with N applied at optimum N rate Soybeans
≥ 20	Row crop production where: <ul style="list-style-type: none"> <li>• N applied exceeds crop need</li> <li>• N applied not synchronized with crop need</li> <li>• Environmental conditions limit crop production and N fertilizer use efficiency</li> <li>• Environmental conditions favor greater than normal mineralization of soil organic matter</li> </ul>

† Economically optimum N rate is the rate that maximizes the return on investment in N fertilizer and therefore may be slightly lower than the N rate that maximizes crop yield.

**Table 2.** Impact of N rate and rotation on NO<sub>3</sub>-N concentrations in tile drainage water measured the following spring. Yields were not responsive to N at rates higher than 150 lbs. per acre.

Rotation	N rate (lbs. per acre)	1997 yield (bu. per acre)	Spring 1998 tile NO <sub>3</sub> -N concentration (ppm)
Corn-corn	190	134	50.5
Corn-corn	170	151	30.5
Corn-corn	150	145	14.5
Corn-soybean	150	156	38.5

only consistently occur under grasslands, pastures receiving minimal inorganic N fertilizer, or land that has been taken out of production and put in the Conservation Reserve Program (CRP).

When spring NO<sub>3</sub>-N concentrations exceed 20 ppm, improper N management may be the cause. However, over-application of N is not the only factor that can result in high NO<sub>3</sub>-N concentration in drainage water. Therefore, it is important to understand the underlying cause of the water quality problem before implementing changes in N management strategies.

### Factors Resulting in High (>20 ppm) NO<sub>3</sub>-N Concentrations in Drainage Water

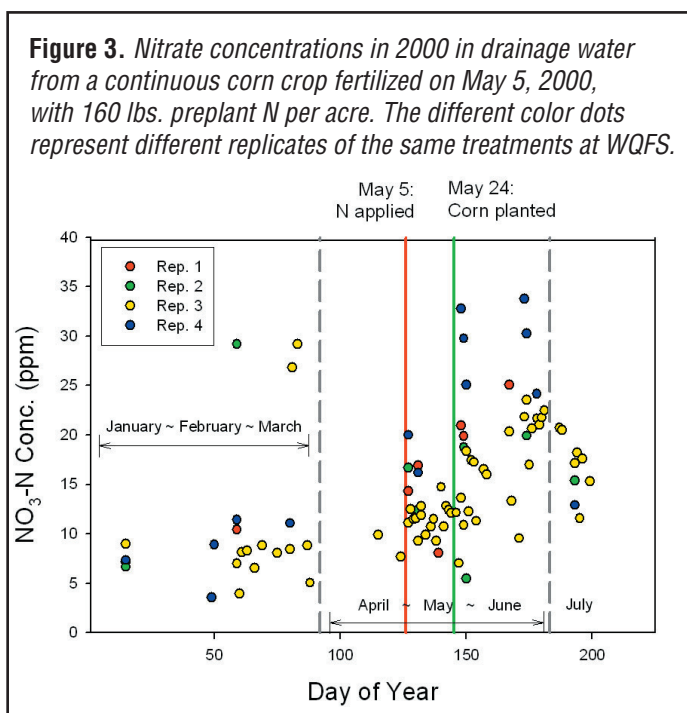
#### Management Factors

**N rate:** When the amount of N fertilizer applied exceeds the needs of the cropping system, the residual N remains in the soil after harvest. This N is already in the form of NO<sub>3</sub>-N and is readily lost when late fall or early spring rainfalls cause tile drains to flow. Studies conducted in Wisconsin have shown that N fertilizer rates that were 45 lbs. per acre more than the economic optimum consistently resulted in soil water NO<sub>3</sub>-N concentrations >20 ppm. Results from Purdue University's WQFS also illustrate this concept. In 1997, yields for continuous corn were maximized by fertilizer N rates of 150 lbs. per acre (see Table 2). N rates of 170 and 190 lbs. per acre did not significantly increase yields. However, the following spring, NO<sub>3</sub>-N concentrations in tile drainage water from plots receiving 150 lbs. N per acre averaged 14.5 ppm while those from 170 and 190 lbs. N per acre averaged 30.5 and 50.5 ppm, respectively.

**Improper Crediting of N from Organic Sources:** Many of the recommendations for N fertilizer management developed by land-grant universities, including the Tri-State Fertilizer Recommendations developed for Michigan, Indiana, and Ohio, assume continuous corn production as the baseline cropping system. They also assume that the only additional N added to the system will be in the form of inorganic N fertilizer. However, many farmers use production systems that add significant amounts of N to the system as organic N. Common organic N sources that have significant replacement value for inorganic fertilizer N include manure and soybean residue. Table 2 shows the impact of failing to take credit for the N in soybean residue on water quality at the WQFS. When the amount of N required to optimize yields

of continuous corn (150 lbs. per acre) is applied to corn grown in rotation with soybean, average NO<sub>3</sub>-N concentrations in tile drainage water increase from 14.5 ppm to 38.5 ppm.

**Timing of N Application:** The longer the period between the time of N fertilizer application and the time of crop N demand, the greater the opportunity for N to be leached through the soil and lost in tile drains. An example of what can happen during a rainy period after application of nitrate-containing fertilizers is shown in Figure 3. Preplant N fertilizer (28 percent urea-ammonium nitrate) was applied at the recommended rate on May 5, 2000, 19 days before planting. In this year, 5.25 and 8.1 inches of rain fell in May and June, respectively, 1 and 4.2 inches above the 30-year local average for these months. Some of the applied N immediately appeared in the drainage water, increasing NO<sub>3</sub>-N concentrations from below 10 ppm to values that ranged between 10 and 35 ppm. Had the N application been delayed until sidedressing, less N would have been leached and concentrations would have remained lower during May and into June. Had the N application occurred earlier (e.g., the first week of April), NO<sub>3</sub>-N concentrations in tile drainage water would have been elevated throughout April as well.



**Form of N Used:** In Figure 3, the N fertilizer used was 28 percent urea-ammonium nitrate and therefore contained a portion of the N already in the leachable  $\text{NO}_3\text{-N}$  form. Had a different N source such as anhydrous been applied, the impact of N fertilization on water quality would have been delayed and therefore reduced. This is because the application of anhydrous kills microbes in the zone of the band application. The conversion of  $\text{NH}_4\text{-N}$  to  $\text{NO}_3\text{-N}$  is delayed until the band is recolonized and biological activity can proceed. Leaching rainfalls occurring during this period of no or reduced biological activity will not result in much fertilizer N loss. In the SEPAC study, for example, where anhydrous was applied in late April throughout the study, there was no consistent increase in concentrations in drainflow after the fertilizer application (see Figure 4). Selecting the most suitable fertilizer product for soil conditions is a key component of developing an efficient N management strategy.

### Nonmanagement/Environmental Factors

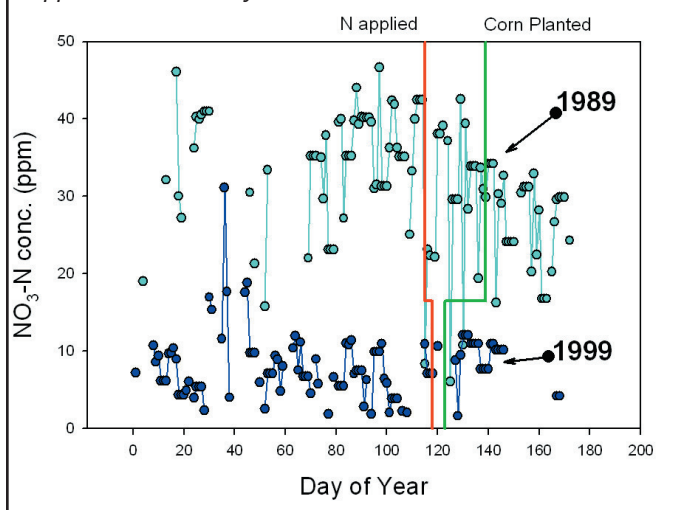
**Bad Weather, Crop Productivity and N Use:** Results from a six-year study at the WQFS illustrate the extent to which high  $\text{NO}_3\text{-N}$  concentrations in tile drainage water may be beyond a farmer's control. When yields fall significantly below the expected yield or goal due to reasons other than N deficiency, the crop may not use all the available N. The residual can be leached into drainage water the following spring. At the WQFS, a linear relationship was observed between yield and drainage water  $\text{NO}_3\text{-N}$  concentration (see Figure 5). For every 14 bu. per acre decrease in yield from a yield goal of 150 bu. per acre,  $\text{NO}_3\text{-N}$  concentration in drainage water increased 10 ppm. Throughout the Cornbelt other researchers have observed similar patterns. Unfavorable weather patterns, especially hot dry conditions during crop growth and development, can significantly raise drainage water  $\text{NO}_3\text{-N}$  concentrations the following spring.

**Good Weather and Mineralization of Soil Organic Matter:** Surprisingly, especially favorable weather resulting in good yields may also negatively affect water quality the following spring. In Figure 5, results from the 1997 growing season appear as an outlier. In this year, yields of approximately 160 bu. per acre were followed by spring  $\text{NO}_3\text{-N}$  concentrations above 20 ppm. The 1997 growing season was marked by less rain and saturated soil conditions during planting and early crop growth but relatively more rain during August when compared to other years (see Figure 6). This rainfall pattern was optimal for crop growth but also for soil biological processes. The amount of N released from soil organic matter was likely greater than in other years and some of this additional N was not used by the crop.

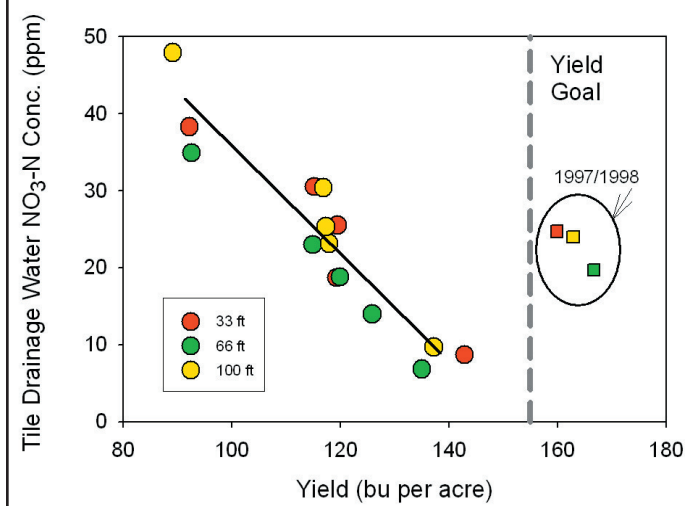
### Other System Factors to Consider

**Tile Flow Rate:** While the focus of N management and water quality discussions tends to be on the concentration of  $\text{NO}_3\text{-N}$  in drainage water, the real concern for both producers and environmentalists is the total amount of N lost. Concentration is certainly a key factor governing the amount lost, but should

**Figure 4.** Daily  $\text{NO}_3\text{-N}$  concentrations measured in tiles at SEPAC in 1989 and 1999 showing no influence of  $\text{NH}_3$  application in either year.



**Figure 5.** Relationship between yield and  $\text{NO}_3\text{-N}$  concentrations in drainage water measured in the following spring at the WQFS. Data are for continuous corn fertilized with 180 lbs. N per acre grown on three different tile spacings (33, 66, and 100 feet).



not be considered independently of the amount of water flowing from a tile drain. The amount of  $\text{NO}_3\text{-N}$  lost is the product of the volume of water lost and the concentration of  $\text{NO}_3\text{-N}$  in that water. The importance of this concept is illustrated by data from individual replicates of an N management treatment that uses fall swine manure as the only supplemental N source for a continuous corn system. The average  $\text{NO}_3\text{-N}$  concentrations measured in the drain from replicate 1 was 14 ppm, while other replicates had concentrations from 22 to 33 ppm (see Table 3). However, the volume of water drained from replicate 1 was several times higher than that drained from the other replicates, resulting in the greatest total amount of N loss in replicate 1. These data demonstrate both the need to understand the

**Table 3.** Differences among replicates of the fall swine manure treatment at the Water Quality Field Station. Mean tile drainage water NO<sub>3</sub>-N concentrations, drainflow volumes and estimated mass N loss are for January through early May 2000.

Replicate Number	Average NO <sub>3</sub> -N concentration (ppm)	Total tile drainflow volume (inches)	Estimated mass N loss (lbs. per acre)
1	14.1	3.92	12.5
2	22.1	0.92	4.6
3	28.1	1.42	9.0
4	32.6	0.75	5.5

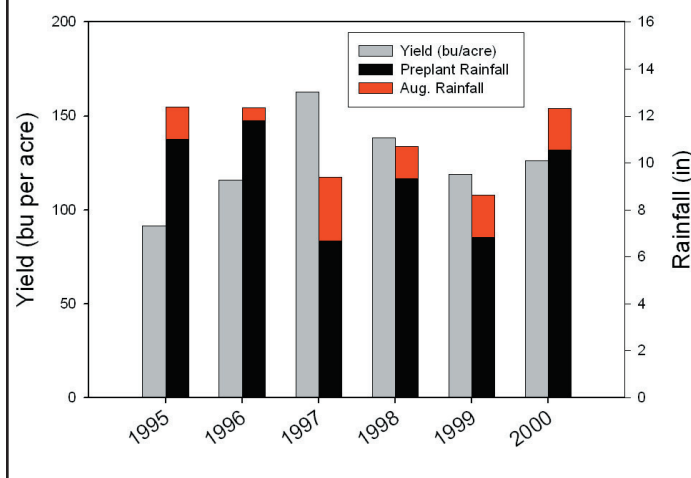
relationship between concentration and flow volume and the fact that identical management systems may have different water quality impacts due to differences in hydrology.

**Tile Spacing:** Since inter-tile spacing alters the rate of water movement through the soil, it should also affect water quality. A study at the WQFS compared the impact of the recommended tile spacing (66 feet) with a narrower spacing (33 feet) and a wider spacing (100 feet). The recommended spacing resulted in concentrations that averaged 4 to 5 ppm lower than the wider or narrower spacings (see Table 4). The recommended spacing optimized yields (see Figure 7) and N uptake in grain. The lower NO<sub>3</sub>-N concentration in tile drainflow reflects this relatively better crop N-use efficiency with 66-foot spacing. However, the total mass N loss was lowest with 100-foot spacing reflecting the lower volume of water removed by the tile drain.

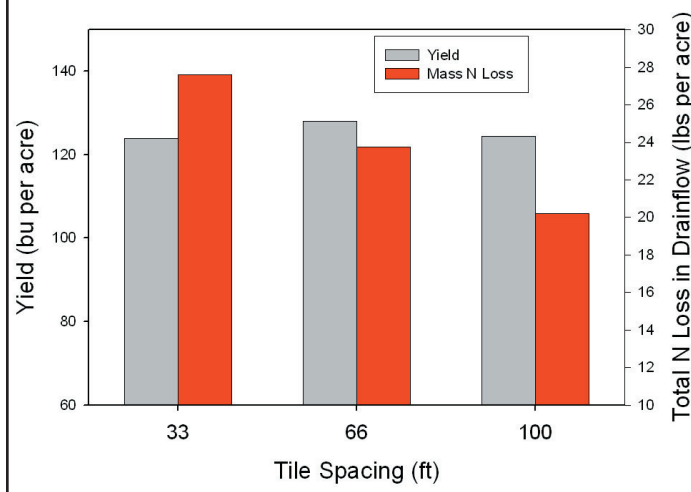
Somewhat different results were obtained on the low organic matter soil at the SEPAC study site. Tile spacings were 16, 33, and 66 feet, and there were no consistent differences in nitrate concentrations among spacings. However, the narrower spacings (more intensive drainage) had greater drainage than the wider spacings. Over the 15-year study, the amount of annual rainfall removed by the tile drains was, on average, 20.6 percent, 14.8 percent, and 12.0 percent for the 16-, 33-, and 66-foot spacings, respectively. Generally the nitrate-N losses were greater from the narrower spacings compared with the wider spacings, because the drainflow per acre was greater from the narrower spacings. This was especially true in years with high N fertilizer rates, continuous corn, and no cover crop (1986-88 period, see Figure 8) compared to the years with a corn-soybean rotation, lower fertilizer N rates, and a winter cover crop after corn (1997-99). The results suggest that wider drain spacings are preferable for reducing nitrate loads to surface waters, and that future drainage design should optimize drain spacing to reduce nitrate loads while providing adequate drainage for crop growth.

**Tillage:** Since tillage mixes the soil and can accelerate the breakdown of crop residue and mineralization of soil organic matter, it might be expected that conventional tillage would increase NO<sub>3</sub>-N loss in tile drainage water. In general, the studies that have been conducted have shown only small influences on drainflow NO<sub>3</sub>-N concentrations (with no-till being lower than conventional) and volumes (with no-till being higher than

**Figure 6.** Average continuous corn yields and corresponding rainfall pattern at the WQFS. The amount of preplant rainfall is the sum of rainfall occurring in the month before and the month during planting.



**Figure 7.** Influence of tile spacing on yield and total annual N lost as NO<sub>3</sub>-N in tile drainage water based on WQFS data, 1995-2000.



conventional) and these have not translated into differences in system total N loss.

**Table 4.** Selected statistics (annual average, minimum and maximum values, and the coefficient of variation) for NO<sub>3</sub>-N concentrations measured in 24-hour flow proportional composite samples of tile drainflow. Tile spacing (TS) treatments are 33 feet, 66 feet, and 100 feet (based on WQFS data).

TS Trt.	Univ. Stat		Year						Mean
			1995	1996	1997	1998	1999	2000	
<b>33</b>	<b>Ave.</b>	<b>mg L<sup>-1</sup></b>	<b>18.7b†</b>	<b>38.3b</b>	<b>30.5a</b>	<b>24.7a</b>	<b>8.7b</b>	<b>25.2a</b>	<b>22.2b</b>
	Min.	mg L <sup>-1</sup>	3.4	7.9	16.6	11.6	0.2	9.8	
	Max.	mg L <sup>-1</sup>	36.2	64.7	44.4	33.7	14.0	34.2	
	C.V.	%	43.4	47.5	22.6	18.9	34.4	29.3	
<b>66</b>	<b>Ave.</b>	<b>mg L<sup>-1</sup></b>	<b>14.0c</b>	<b>34.9b</b>	<b>23.0b</b>	<b>19.7b</b>	<b>6.8c</b>	<b>18.8b</b>	<b>17.7c</b>
	Min.	mg L <sup>-1</sup>	1.0	12.6	9.1	0.4	0.6	4.9	
	Max.	mg L <sup>-1</sup>	29.9	66.6	35.3	28.7	14.3	36.8	
	C.V.	%	42.9	30.8	33.4	31.5	35.5	41.1	
<b>100</b>	<b>Ave.</b>	<b>mg L<sup>-1</sup></b>	<b>23.1a</b>	<b>47.9a</b>	<b>30.4a</b>	<b>24.0a</b>	<b>9.7a</b>	<b>25.3a</b>	<b>24.3a</b>
	Min.	mg L <sup>-1</sup>	6.3	18.3	16.5	12.5	1.3	10.6	
	Max.	mg L <sup>-1</sup>	32.6	79.2	43.7	47.9	13.5	47.1	
	C.V.	%	22.3	27.8	21.1	27.4	23.9	27.8	
<b>Annual Ave.</b>		<b>mg L<sup>-1</sup></b>	<b>18.2</b>	<b>39.8</b>	<b>27.6</b>	<b>22.5</b>	<b>8.3</b>	<b>22.4</b>	<b>21.0</b>

†Average values within columns followed by the same letter are not significantly different (P = 0.05 level).

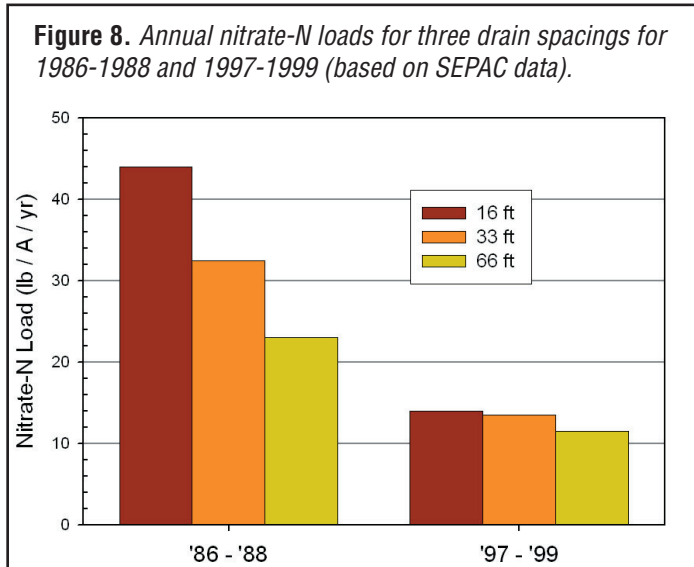
**Table 5.** Percent probability that the NO<sub>3</sub>-N concentration measured in one sample collected weekly, monthly, or quarterly will be within 5 percent, 15 percent or 25 percent of the average annual value for that time period.

Sampling frequency	Percent probability of result within		
	5%	15%	25%
Weekly	52	89	99
Monthly	31	74	93
Quarterly	20	57	79

**Sampling Protocol Factors to Consider**

**Effect of Sampling Frequency:** Finally, both the timing and the number of samples collected can affect the sample value itself. The data from the WQFS illustrate the critical point that concentrations may vary widely on a day-to-day basis. For example, in 2000, 66-foot tile spacing resulted in average NO<sub>3</sub>-N concentrations of 18.8 ppm, but individual values ranged from 5 ppm to 37 ppm (see Table 4). There is a certain amount of error associated with any given value that can only be reduced by collecting numerous samples in time (for a given tile line) or space (multiple tile lines for the same system).

For a given tile line, Table 5 shows the probable accuracy of sampling on a weekly, monthly, or quarterly (once every 3 months) basis, rather than daily. These results show the likelihood that the average concentration of daily composite samples taken periodically during a year will fall within a given

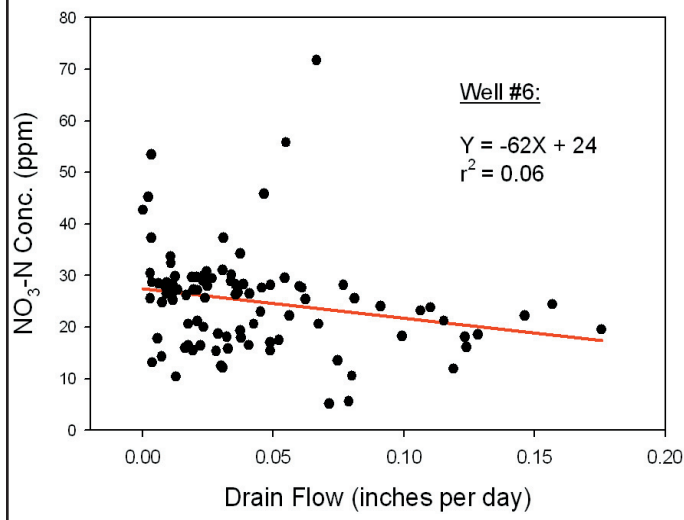


percentage of the true average concentration (which was assumed to be the average of the daily concentrations). Results are based on a three-year analysis of three drains at SEPAC, using composited daily samples (flow-proportional samples over a 24-hour period). For example, if the true average concentration of water in a certain tile was 20 ppm, there is a 52 percent chance that the average of samples taken on one day every week would be between 19 ppm and 21 ppm (i.e., within 5 percent), and a 99 percent chance that the weekly average would be between 15 ppm and 25 ppm (i.e., within 25 percent). Monthly sampling only has a 93 percent probability of accuracy within 25 percent, and quarterly sampling only a 79 percent probability. Sampling less than quarterly is less likely to result in a reliable estimate of average nitrate concentration.

Using flow-proportional sampling of drainage water to collect a sample every day would be the most accurate way to assess the average concentration; however, this is usually not feasible except in research studies. The accuracy of typical “grab samples” will be less than the values given in Table 5, but we don’t know how much less. Best approaches to sample collection to derive meaningful information at a minimum cost are the subject of several ongoing research initiatives.

**Effect of Drainflow Volume:** People often ask if they should consider the rate of flow in the tile drain when sampling drainage water to monitor  $\text{NO}_3\text{-N}$  concentrations. Results from both the WQFS and SEPAC research sites have shown that  $\text{NO}_3\text{-N}$

**Figure 9.** Relationship between rate of drain flow and  $\text{NO}_3\text{-N}$  measured in one drain at SEPAC in 2000.



concentrations in tile drains are not typically strongly influenced by drain flow. Over the 15-year study period at SEPAC, there was a weak negative correlation of concentration with flow rate, meaning there was only a slight tendency for higher flow rates to have lower concentrations. An example of the correlation for one year and one drain at SEPAC is shown in Figure 9. It is probably advisable to avoid sampling on days of extreme high or low flows, but “typical” high flows during spring should not pose a problem.