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NITRATE LEVELS IN SOIL, TILE DRAINAGE WATER AND SHALLOW GROUNDWATER UNDER A VARIETY OF FARM MANAGEMENT SYSTEMS

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ABSTRACT

Twenty farms in southwestern Ontario were monitored for three years, between 1995 and 1998 - tile water samples were collected weekly, groundwater samples were collected monthly. Also, soil samples were analyzed and crop inputs and outputs documented. The mean tile water nitrate-N, total P, and total K concentrations were 17.0, 0.48, and 3.8 mg/L, respectively. Differences in nitrate, P and K levels in water samples show the relative impacts of tillage practices, crops grown and livestock vs non-livestock operations.

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Nitrate levels in soil, tile drainage water and shallow groundwater under a variety of farm management systems

Ron Fleming, Malcolm MacAlpine, and Colleen Tiffin

Introduction

What happens on the land surface has an impact on the quality of drainage water and groundwater in the area. This is true of any area, whether the land use be residential, industrial, or agricultural. Farmers are constantly faced with decisions in the operation of their businesses. Many of these decisions can affect the potential for water quality impacts of the farm. Factors such as type of tillage, crop fertility program, livestock manure spreading, and type of crop grown all can affect water quality, either improving it or degrading it. However, many of these impacts are not well-documented.

Fleming (1990) reported on a study of tile drains in the Parkhill Creek watershed of southwestern Ontario. Nitrate-N concentrations averaged 10.6 mg/L and total P averaged 1.3 mg/L. The geometric mean density of fecal coliform bacteria was 78 per 100 mL. Bacteria numbers were associated with drains located around farmsteads and to a much lesser extent, with application of manure to fields. Insufficient cropping data was gathered to clearly identify the main practices contributing nitrates and phosphorus to tile water.

Objectives

This is a field study, set in southwestern Ontario, attempting to:

a) Measure tile water and shallow groundwater levels of nitrate-N, and other physical, chemical, and microbiological parameters under a variety of farm management practices to determine if a relationship exists.
b) Examine the relationship between soil test levels of N, P, and K and water test levels for the same field.
c) Identify those farm practices having the highest potential to contaminate groundwater with N, P, or K.

Procedure

A - Farm selection - A number of criteria were considered in selecting the 20 farms in the study. In an attempt to control some of the variables, yet remain representative of a large number of farms, farms were limited to those having soils in the clay loam to sandy loam range. Also, farms were selected in Kent and Essex Counties so the climate and cropping practices would be similar. Though some changes were made by the farmers during the study, the original goal was to have five farms where liquid swine manure was applied to the fields, five farms where tomatoes were in the crop rotation, five farms using a moldboard plow, five with some form of conservation tillage (e.g. no-till, ridge-till, reduced tillage). The farms were typical in that the most common crops were corn, soybeans, and wheat.

All farms needed to have a main drain exiting the field at a location that was convenient for water sampling. This outlet represented a drainage area completely contained within the farm, and preferably, with only one crop grown on the drained area. Farms where the drain system included tile drains near farm buildings (i.e. potential for surface water inlets or other connections) were avoided.

B - Piezometer installation - The groundwater sampling component of this study was not intended to be extensive. However, an attempt was made to install piezometers in an area that would represent shallow groundwater under the field in question. These piezometers also had to be out of the way of the farmers. Typically, they were located at the edge of the field or in the middle of the field near an obstacle (e.g. catch basin, hydro tower, group of trees) where they did not inconvenience the farmers.

The piezometers were constructed of 39 mm ID PVC pipe with a 300 mm length of screened PVC piezometer (slot size = 10, i.e. 0.01 inches) cemented to the end. The screened section and end cap were covered with a filter sock material. Holes were drilled with a tractor-mounted Giddings soil sampler. The piezometers were inserted into the holes. Silica sand was placed around the screened section, and the remaining backfilling was done with bentonite clay (Hole-Plug). In those cases where the direction of flow of groundwater was not obvious, three test holes were drilled, and the groundwater levels were surveyed. This established the flow direction and thus the best location for the piezometers.

During the installation, the groundwater level was observed (all were installed in September to November). The shallow piezometer was installed so that the top of the screened section approximately coincided with the water table at the time of installation. Piezometer #2 was installed so that the top of the screened section was 300 mm below the bottom of Piezometer #1 (or 600 mm from the bottom of P1 to the bottom of P2). The third installation was similarly installed below the second. The three installations were as close as possible together to minimize the inconvenience for the farmers - a typical separation distance between the piezometers was 0.5 m. The only exception to this pattern was on Farm 17, where the subsoil contained layers of hard-packed sand which were difficult to penetrate with the Giddings machine. One piezometer was installed in this manner. A second consisted of a drive-point piezometer (stainless steel - made by Solinst of Canada, installed with a jack-hammer) with a plastic tube extending to the surface to allow for water sampling. The third installation could not be made at this farm.

C - Water sampling - Tile drains were sampled weekly when the drains were running. Water samples were collected in a 250 mL bottle, then refrigerated and delivered to the lab where they were stored temporarily in a refrigerator until analysis. During the farm visit, the water temperature was recorded, and the tile flow rate was measured by timing the filling of a graduated container. No samples were collected when the drains were submerged or when they were covered by ice.

Groundwater samples were collected monthly. First, the water level was measured using an electronic water level tape. A peristaltic pump and clean tubing (rinsed with distilled water) were used to remove the water. In most cases, the piezometers were pumped dry, then allowed to recharge before a sample was removed. Alternatively, a volume of water equal to three times the standing volume was removed before a sample was collected. Again, the samples were refrigerated until testing.

D - Farm data - Information on tillage practices, crop planting dates, fertilizer application, and harvest yields was supplied by the individual farmers. Measurements of fields were made to establish the area of the drained lands. Soil samples were collected in the spring and occasionally also in the fall. For the swine farms, manure samples were collected occasionally.

E - Weather data - Many of the farmers recorded rainfall amounts. Otherwise, precipitation records for the nearest available site were used (usually less than 10 km away).

F - Lab analysis - All water sample analysis was performed at Ridgetown College. From the project start until March, 1997, the analysis was done by the Soil and Plant Analysis Lab at Ridgetown College (then a branch of the Ontario Ministry of Agriculture, Food and Rural Affairs). Measurements included pH, total salts, total P, total K, nitrate-N, and ammonium-N. This lab also performed the soil analysis. After March, 1997, this lab ceased to exist and the water testing was scaled back to include only nitrate-N, pH, and total salts - analyzed at Ridgetown College. Soil samples were sent to the University of Guelph, Guelph, Ontario.

Results and Discussion

Farm Selection - The 20 farms were selected from a much larger list of possibilities. The final group satisfied all of the selection criteria and also met the goal of involving farmers with an interest in the results of the study. The average drainage area was 15.9 ha (range 2.2 to 59.5 ha). All of the fields were systematically tile-drained with a typical spacing of tiles ranging from 8 to 12 m. The crops grown on these 20 farms included corn, wheat, soybeans, tomatoes, and seed corn. Tillage systems fell into one of the following: no-till, chisel plow, ridge tillage, moldboard plow and cultivation (with no primary tillage). Soil types on the study farms included Tuscola silt loam, Berrien sandy loam, Normandale very fine silt loam, Brookston silty clay loam and Toledo clay loam. No analysis was performed to determine if water quality differences were due to differences in soil type.

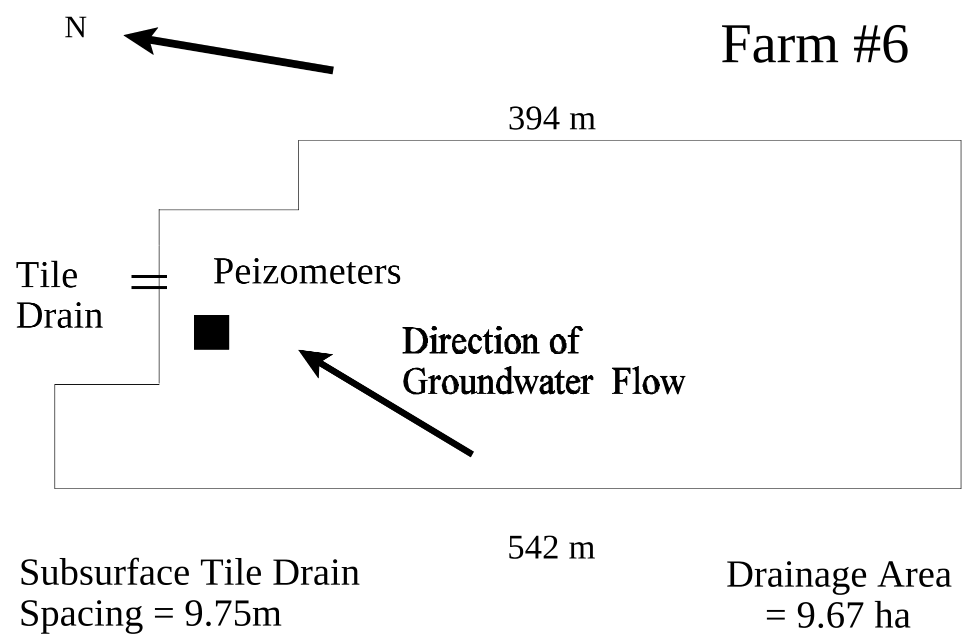


Figure 2 Typical farm drainage area layout

Figure 1 shows a field layout for Farm #6, which is representative of the farms in the study. It shows the piezometer location in an area downstream of the field - from a groundwater lateral flow point of view.

Water Sampling - Tile water sampling began in June, 1995, and several of the drains were already dried up by that time. Typically, the drains were dry for several months of the year, usually starting in June or July. Throughout the three years of the study, there was no flow for 34.0% of the time. Samples were collected from flowing drains 40.2% of the possible times. For the remainder of the time, samples were not collected for a variety of reasons: unable to visit the sites that week, tile outlet submerged or covered with ice or snow, flow too large or too small, etc.

Loadings - In order to help picture the overall water balance for these fields, total flows were estimated using the weekly data available. The average annual total volume of water exiting each tile was approximately equivalent to 736 m^3/ha. The average annual precipitation at the various sites was 790 mm. The water exiting the tile drains amounted to approximately 9.2% of all precipitation water falling on the fields. There was a considerable range from field to field, but the data needed to draw more detailed conclusions was not gathered in this study.

Using these numbers, annual loadings of N and P were estimated - i.e. mass of nutrients leaving the fields via the tile drains. They are as follows: 11.2 kg/ha of N; 0.13 kg/ha of P.

Water Table - As expected, the water table elevation fluctuated over the year. Typically, the water table was lowest during September and October of each year. The average distance below the ground level to the water table for all farms is shown in Figure 2. The average water table depth for all farms was 1.9 m below ground level (maximum was 5.8 m and minimum was 0.24 m).

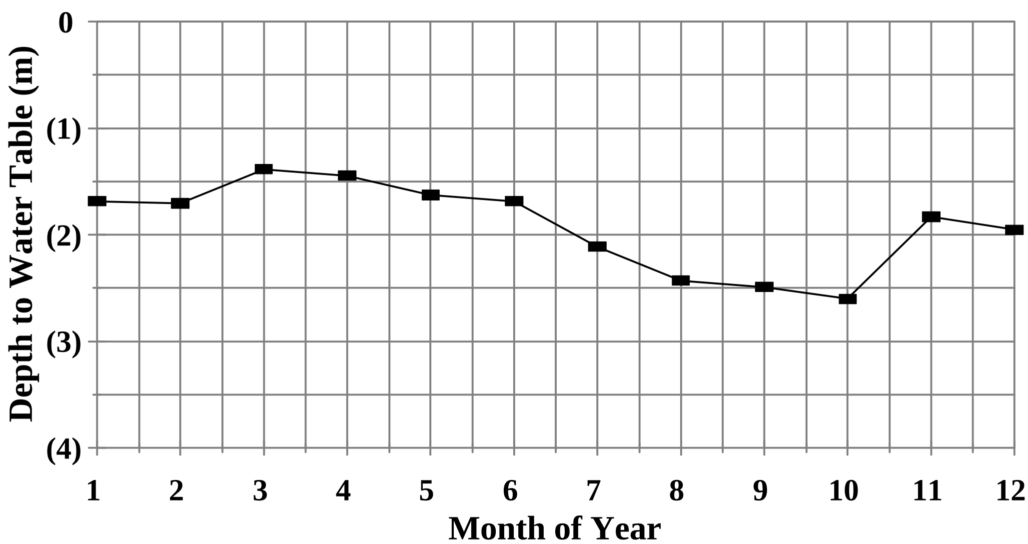


Figure 3 The average depth to water table of 20 farms (September 1995 to May 1998)

Water Quality - Table 1 contains average concentrations of chemical parameters measured in the tile drainage water during the study. It shows that the mean nitrate-N concentration of 17.0 is considerably higher than the existing drinking water standard on 10.0 mg/l. Also, the P concentration of 0.48 far exceeds the surface water target of 0.03 mg/L. As mentioned earlier, certain parameters were not measured for the duration of the project. Note that the total number of samples tested for P was 749, compared to 1295 samples for nitrate.

Table 1 - Average chemical parameters for all tile drains

	Average	Std. Dev.	Number
Nitrate-N (mg/L)	17	9.9	1295
pH	7.6	0.3	1296
P (mg/L)	0.48	3.3	749
K (mg/L)	3.8	7.4	749
ammonium-N (mg/L)	2.3	18.7	748

When using the drinking water standard of nitrate for comparison purposes, it seems more appropriate to examine the groundwater concentrations of nitrate. These values, for the three levels, are shown in Table 2. These numbers show a decrease in concentration with increasing depth below the water table. They also show that the mean values are lower than the drinking water standard. There were fewer samples analyzed for P1 (shallow) because of the fact that occasionally, the water table was below the bottom of the pipe and no sample could be collected. There was a statistically significant relationship between tile drain nitrate-N levels and concentrations found in the shallow piezometer ($P = .007$). However, for the linear model, $R^2 = 2.7\%$, indicating a relatively weak relationship.

Table 2 - Average concentrations (mg/L) of nitrate-N in piezometers for all farms

Piezometer	Average	Std. Dev.	Number
P1 - shallow groundwater	3.26	4.9	470
P2 - slightly deeper	1.57	3.6	498
P3 - slightly deeper	1.29	3.3	494

Tables 3 and 4 show the corresponding values for concentrations of P and K in the groundwater samples. There was no relationship between tile water P and groundwater P concentrations. It is interesting to note that mean groundwater P concentrations equal or exceed the surface water standard of 0.03 mg/L.

Table 3 - Average concentrations (mg/L) of Total P in piezometers for all farms

Piezometer	Average	Std. Dev.	Number
P1 - shallow groundwater	0.03	0.068	246
P2 - slightly deeper	0.055	0.311	259
P3 - slightly deeper	0.031	0.066	258

Table 4 - Average concentrations (mg/L) of Total K in piezometers for all farms

Piezometer	Average	Std. Dev.	Number
P1 - shallow groundwater	4.78	8.01	246
P2 - slightly deeper	3.77	4.16	259
P3 - slightly deeper	3.02	3.2	258

The mean pH values for the tile water, P1, P2, and P3 were 7.6, 7.5, 7.6, and 7.6, respectively. Similarly, mean concentrations of NH_4-N were 2.27, 0.086, 0.14, and 0.13 mg/L, respectively. The ammonium concentrations were quite variable (for tile water, SD = 18.7) and appeared to correspond to times of fertilizer application.

Manure Application - Swine Farms - The average nitrate concentrations for tile drains from land receiving manure (i.e the five swine farms) was significantly higher than for all other farms - the mean tile water concentration of nitrate-N for the manured lands was 26.5 mg/L (SD = 0.46). This compares to a concentration of 13.8 mg/L (SD = 0.26) for the 15 farms that did not receive manure. Groundwater nitrate levels were also significantly higher for the manured fields (for piezometer 1, $P < 0.001$). Nitrate-N in Piezometer #1 averaged 5.77 mg/L for manured fields and 2.46 for non-manured fields.

Total P in tile water was influenced by manure applications. Mean concentrations for tile water from the swine farms was 1.05 mg/L (count = 185), compared to 0.29 for all other farms (count = 564). This was significantly different ($P < 0.01$). The groundwater P concentrations were not significantly affected by manure application. A similar pattern emerged for K, where the tile water concentrations were significantly different but the groundwater concentrations were not.

These results suggest that the swine farms are subject to an over-application of nutrients - i.e. when all sources of nutrients are accounted for. Unfortunately, the component of this study dealing with nutrient application is not yet complete. If this turns out to be true, however, as many people believe, it would support the claim that "nutrient management planning" will have the greatest impact on the livestock farms.

Tillage - In some cases, the farmers in the study stayed with a particular method of tillage for the duration of the study. In other cases, tillage practices changed over the three year period. Water quality was deemed to be affected by one tillage method until the next method was used. For example, if a farmer has no-till for two years, but always moldboard plows before corn, all water samples from the date of plowing onward were considered to be associated with moldboard plowing. Tile water nitrate-N levels were significantly higher on those fields where chisel plowing was practiced (mean = 19.6 mg/L, count = 269). This is shown in Figure 3. Similarly, the nitrate concentration in P1 was significantly higher for the chisel plowed fields (mean = 7.5 mg/L, count = 79). In both cases, there was no difference in nitrate levels for the other tillage methods.

Levels of total P in tile drains and groundwater were not affected by tillage method. However, levels of K in tile drainage water were significantly higher for the fields that were chisel-plowed (mean = 6.7 mg/L, count = 204). The next highest levels were from the moldboard plowed fields, and these levels were significantly higher than the other three tillage methods (mean = 4.3 mg/L, count = 249).

Crop - The crops associated with the highest tile water nitrate-N levels were corn (mean concentration 18.4 mg/L, count = 333) and seed corn (17.9 mg/L, count = 95). Levels were significantly higher than those found with the other three crops - see Figure 4. Also, nitrate levels from the soybean land had significantly higher levels than for the tomato or wheat fields. For P1,

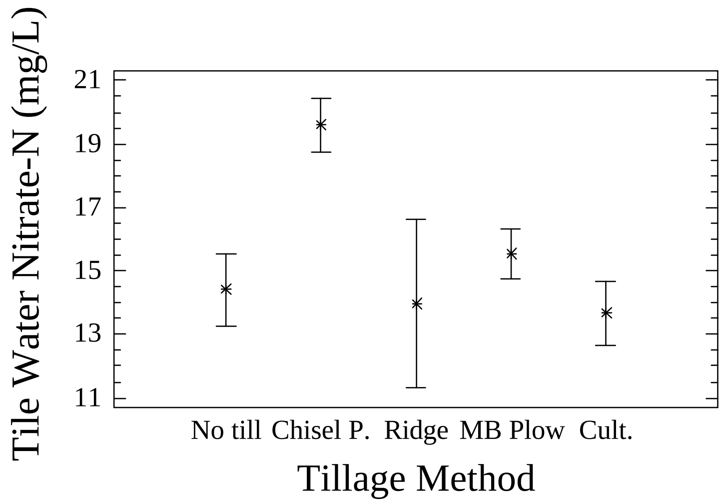
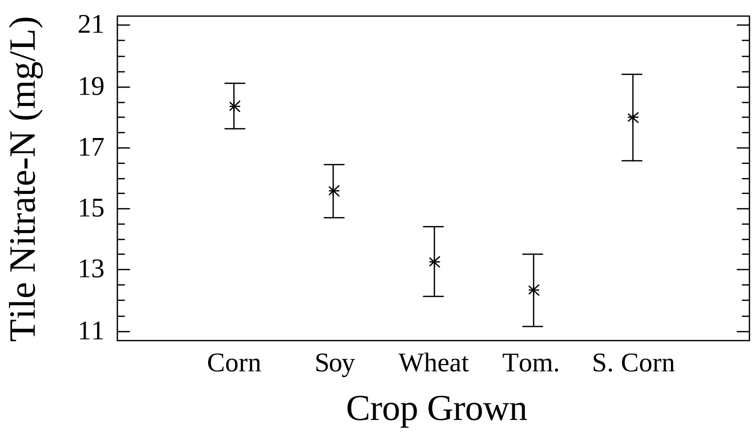


Figure 4 Mean levels of tile water nitrate-N (and 95% confidence limits) vs tillage method

corn and soybeans yielded significantly higher levels of nitrate than the other crops.



Corn and seed corn also yielded significantly higher concentrations of tile water total P than the other crops, with seed corn giving the highest at 1.6 mg/L. K levels in tile drains were significantly higher for seed corn than for other crops (mean 7.64 mg/L). Next highest levels were associated with corn, which were significantly higher than the remaining three crops. It is interesting to note the relatively low levels for tomatoes, even though this crop has such high inputs of K.

Soils, Fertilizer, Bacteria - Data were collected that, to date, have not been analyzed. These are in the areas of soil background nutrient levels, fertilizer inputs for the various crops, crop yields, and *E. coli* densities in selected tile water and groundwater samples.

Conclusions

1. The tile drains on these study farms were dry for about 1/3 of the year, on average.

2. The average water table depth for all farms was 1.9 m below ground level (maximum was 5.8 m and minimum was 0.24 m).

3. The mean tile water nitrate-N concentration was 17.0 mg/L. The mean P concentration was 0.48 mg/L.

4. Shallow groundwater levels of all nutrients were lower than those for the tile drains. Mean nitrate-N concentrations in the shallowest piezometer was 3.6 mg/L.

5. Farm practices leading to significantly higher levels of nitrate-N in tile water were: swine farming (and subsequent land application of manure), chisel plowing, and growing field corn or seed corn.

6. Farm practices leading to significantly higher levels of total P in tile water were: swine farming, and growing field corn or seed corn.

7. Practices leading to significantly higher levels of nitrate-N in shallow groundwater were: swine farming (and subsequent land application of manure), chisel plowing, and growing field corn or soybeans.

Acknowledgments

The authors would like to thank the farmers who co-operated in this study, allowing us access to their farms and providing us with detailed cropping information. They showed a genuine interest in learning all they could about possible water quality impacts of their farm practices.

Reference

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