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Soil Test Phosphorus as an Indicator of Nitrate–Nitrogen Leaching Risk in Tile Drainage Water

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Abstract A 2 year tile drainage study of 39 fields in Nova Scotia, Canada was conducted. Weekly nitrate–nitrogen (NO_3–N) concentrations were highest in spring and fall during high flow. Fields receiving poultry or swine manure had elevated drainage NO_3–N and soil test phosphorus. Water quality guidelines for NO_3–N (10 mg L^{-1}) were exceeded on 90% of rotations (corn-grass or corn-grain) and 13% of long-term cover fields. A significant correlation between NO_3–N and soil test P ($r^2 = 0.42$; $p < 0.001$) was found. The 10 mg L^{-1} guideline was exceeded at 100% of fields with soil test phosphorus >200 mg kg^{-1} and 60% overall.

Keywords Nitrate–nitrogen · Drainage · Soil phosphorus · Manure

Agronomic soil test phosphorus levels have been widely studied in relation to their source potential for phosphorous (P) migration to surface waters and likelihood to generate eutrophication (Sharpley and Tunney 2000). A threshold in the relationship between soil test P and P loss through drainage marks an abrupt increase in drainage P per unit of rising soil test P than below that reference point (Kleinman et al. 2000). A widely accepted threshold has not been precisely quantified. A guideline of 200 mg kg^{-1} of Mehlich III (M3) soil test P is commonly suggested while lower values have also been identified (Sharpley et al. 1996; Kleinman et al. 2000). Kinley et al. (2007) reported that soil test P in Nova Scotia fields is commonly >200 mg kg^{-1} and that they are at risk of producing drainage water P concentrations that exceed environmental guidelines.

In response to concerns of nitrate–nitrogen (NO_3–N) toxicity and groundwater contamination, the United Kingdom adopted World Health Organization (WHO) drinking water limits of 10 mg L^{-1} in the early 1970s (Heathwaite et al. 1996). The USEPA (1994) and the Canadian Council of the Ministers of the Environment (CCME 2004) have implemented the same maximum acceptable concentration (MAC). The CCME has also established a NO_3–N MAC of 2.94 mg L^{-1} for the protection of sensitive aquatic habitats. Transport of NO_3–N is to a greater extent determined by water flow while P accumulates and is more closely associated with the nutrient source. Manure is a source of both N and P, however it is commonly applied at rates based on crop N requirements with little consideration given to P resulting in excessive P fertilization. The P surplus in manures and long-term applications based on crop N requirements has the consequence of elevating soil test P in excess of crop requirements (Sharpley et al. 1996). The amount of N and P in manure types is variable but poultry manure and swine slurry have about 3× the concentrations of N, and approach 10× the concentration of P relative to dairy manure (Sharpley and Moyer 2000).

The Natural Resources Conservation Service (NRCS) of the United States Department of Agriculture (USDA) has

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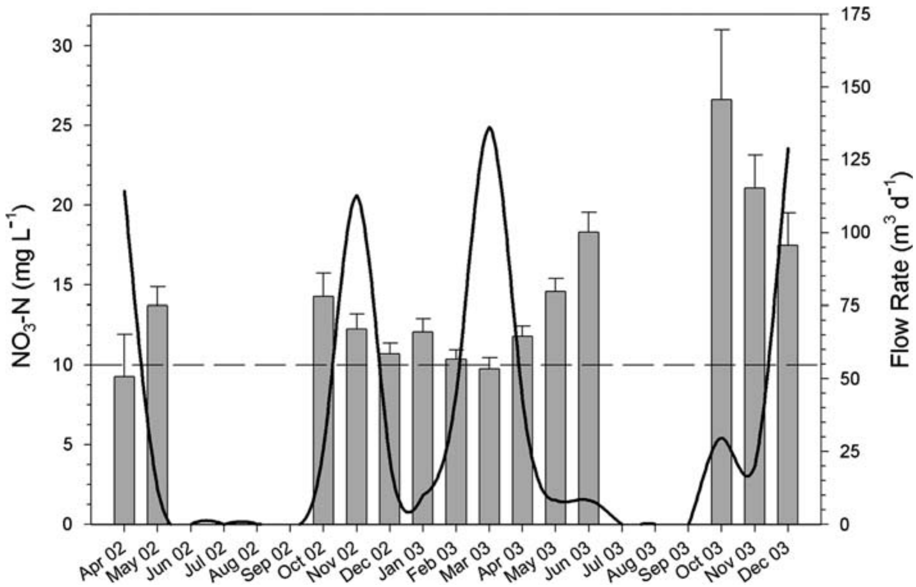

Fig. 1 Monthly (Apr 2002–Dec 2003) tile drainage water nitrate–nitrogen (NO_3–N) concentrations from 39 fields in Nova Scotia, Canada. *Vertical bars* represent average monthly NO_3–N concentration (mg L^{-1}) and the *continuous line* represents drainage discharge flow rates (m^3 day^{-1}) at the time samples were collected. The *dashed line* marks the CCME 10 mg L^{-1} drinking water MAC

implemented a policy for soil nutrient management planning (Sharpley et al. 2003). The original N-based planning standard has now been modified to consider P. The tools available for assessing site risk of P loss include: agronomic soil test P recommendations, environmental soil test P thresholds, or a P index that classifies a field based on a list of factors such as slope, soil permeability, current soil test P, cultivation practices (fertility/tillage), and proximity to surface water sources (Sharpley et al. 2003). As has been documented there is a link between soil test P and P leaching (Kinley et al. 2007) however, an association between soil test P and NO_3–N concentrations in drainage water may also exist. The combined application of P and N in manures and fertilizers may provide for conditions where retained soil P may be an indicator of NO_3–N leaching exceeding guidelines. Surface soil test P is a relatively stable quantity compared to NO_3–N (Heathwaite et al. 1996) and routine soil analysis in Nova Scotia includes soil test P but not soil N. The goal of this study was to assess the relationship between NO_3–N concentrations in tile drainage discharge and soil test P levels of agricultural fields in Nova Scotia.

Materials and Methods

Weekly tile-drainage samples were collected over 21 successive months (Apr 2002–Dec 2003) from 39 agricultural fields in northern and central Nova Scotia. The fields were distributed throughout Antigonish, Hants, Kings, and Pictou counties. Management activities were variable between the fields, which had M3 soil test P (Mehlich 1984) levels ranging from 30 to 470 mg P kg^{-1}. Fields varied in size and slope and were of grass (17), legume (7), and corn-grass or corn-grain rotations (15). The fields received combinations of dairy or swine manure, poultry litter, or inorganic fertilizer. Tile-drains, for all fields, were 10 cm in diameter at approximately 80 cm of depth and 20 m spacing.

A total of 1358 drainage water samples were collected from outlets in 250 mL polyethylene bottles and analyzed for NO_3–N concentrations. For each sample, drainage flow rate was also measured by determining the volume discharge of outflow ($n = 4$). Samples were stored at 4°C and for up to 4 months prior to analysis. Quality control monitoring confirmed that no significant change in NO_3–N concentrations occurred during storage. Nitrate–N was measured directly in the filtered (<0.45 μm) samples by ion exchange chromatography (Clesceri et al. 1998) with a detection limit of 0.04 mg L^{-1}.

In Oct 2003, 20 cm deep soil samples were collected at each field from approximately 50 subsamples per ha. The composite samples were air dried and ground to <2 mm. Soil test P was determined by inductively-coupled argon plasma (ICAP) analysis of M3 soil extracts (Mehlich 1984). Fields were classified by their respective soil test P into categories as follows: (L) Low for soils that were below the agronomic guideline for field crops (75 mg P kg^{-1}) as recommended by the Nova Scotia Department of Agriculture and Fisheries (Kinley et al. 2007); (M) Medium for soils between this agronomic guideline and an environmental threshold (200 mg P kg^{-1}) recommended by Sharpley et al. 1996; and (H) High soil test P were those exceeding this environmental threshold. Soil texture classification was based on sand, silt and clay percentages determined by the hydrometer method (Day 1965).

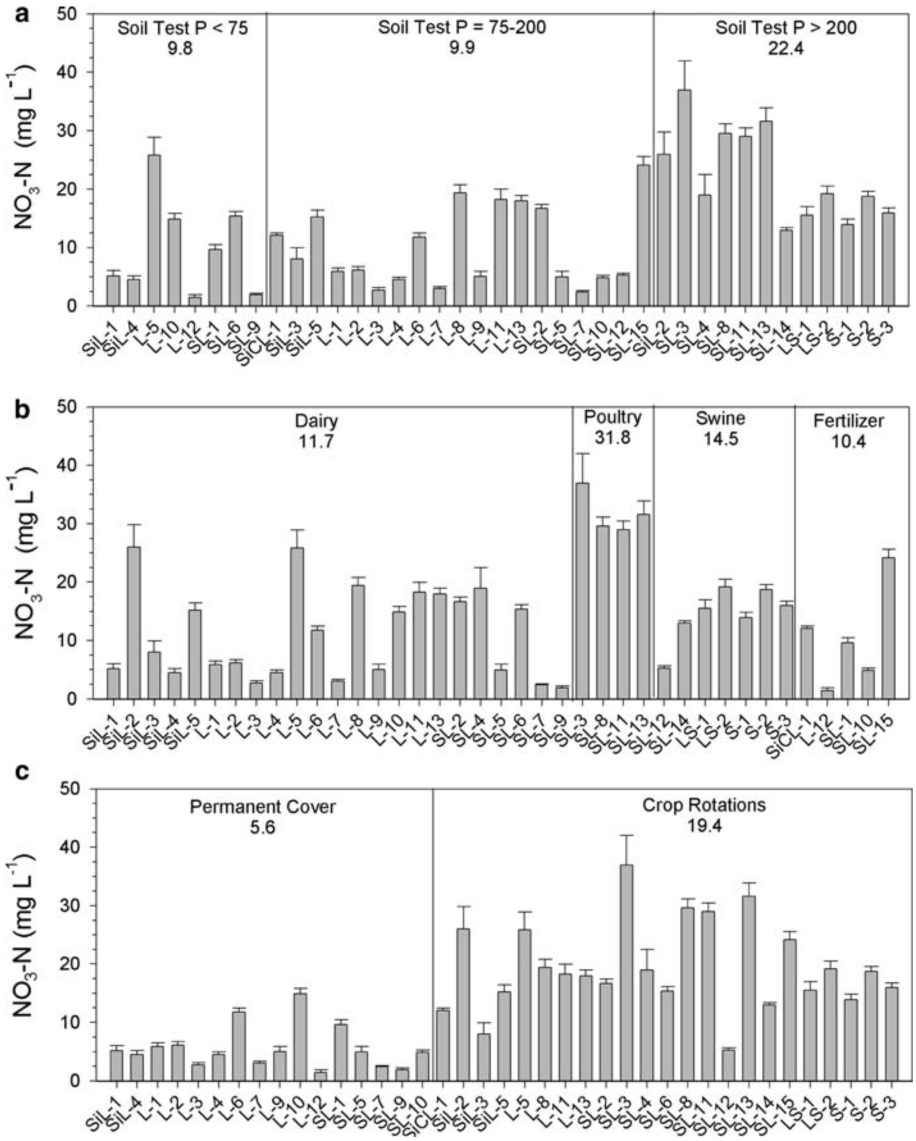

Fig. 2 Tile drainage NO_3–N concentrations (mg L^{-1}) as affected by: **a** soil test phosphorous (mg kg^{-1}), **b** manure type, and **c** crop type. Fields are shown within each subcategory in order of finest to coarsest soil texture based on % sand. Soil test P categories were chosen based on the agronomic guideline recommended as high for field crops (75 mg P kg^{-1}) by the Nova Scotia Department of Agriculture and Fisheries (Kinley et al. 2007), and an environmental threshold (200 mg P kg^{-1}) recommended by Sharpley et al. (1996). The data for individual *bars* represents the average of all weekly samples, and the within category means are given

Results and Discussion

The movement of NO_3–N through tile drainage systems had a seasonal pattern with concentrations increasing in response to spring and fall precipitation events. Randall and Vetsch (2005) from a 7 year study in Minnesota reported >70% of drainage flow and NO_3–N losses occurred from Apr through June with only 10% in the fall months. In contrast large discharge rates produced high NO_3–N concentrations from Oct through Dec in Nova Scotia (Fig. 1). Heavy fall precipitation after summer manure applications explains the large spikes in NO_3–N concentrations observed in the fall of 2003. In Fig. 1 the standard error bars indicate that there was variability in concentrations between weekly samples within fields as well as between fields.

Several factors were evaluated for contribution to variations in drainage NO_3–N concentrations. Included are relative proportions of sand and clay (texture), manure history, crop type and rotations (tillage), drainage flow intensity, and the seasonal nature (timing) of agriculture merges all these factors (Di and Cameron 2002). The largest NO_3–N concentrations were from fields with soil test P > 200 mg kg^{-1} (Fig. 2a). All fields with H soil test P (>200 mg kg^{-1}) exceeded the NO_3–N MAC. Some fields with L soil test P (<75 mg kg^{-1}) exceeded the NO_3–N MAC and also exceeded concentrations observed at some fields in the H range. Fig. 2b shows that with each manure type the soil texture has little impact on drainage NO_3–N concentrations, which is likely a reflection of high NO_3–N solubility and only one field (SiCL-1) had sufficient clay to be considered a clayey texture.

Figure 2c shows that NO_3–N was most elevated and variable under corn-grass corn-grain rotations. More than 90% of crop rotation fields had mean NO_3–N concentration >10 mg L^{-1} as opposed to the <13% from long term cover grass systems. The 16 long term cover fields were either in the L (6) or M (10) soil test P category and had histories of dairy manure or fertilizer applications. Conversely, poultry and swine manure were applied exclusively on crop rotations which dominated the H soil test P category. These produced generally higher drainage NO_3–N concentrations. Kinley et al. (2007) reported elevated TP concentrations with the same fields. They described field management practices of dairy manure spread over grassland, and poultry and swine on crop rotations as typical for Nova Scotia cropping systems.

Those agricultural systems in Nova Scotia, which were monitored, produced patterns shown in Fig. 2. Manure delivers both P and NO_3–N in various quantities depending on the source, and mobility is affected by the method of application, type and soil factors. With the factors in place a strong correlation is observed and soil test P accumulation is associated with high drainage water NO_3–N.

In spite of a lack of consensus on a soil test P threshold, generalizations related to soil test P are used to rate potential risks of P transport. Alternatively, data from the present study suggests that H class soil test P results may also be applicable in indicating the potential of NO_3–N leaching. Kinley et al. (2007) reported a significant correlation between TP and soil test P ($r^2 = 0.31$; $p < 0.001$) for these same fields. Figure 3 illustrates the significant correlation that was found between soil test P and NO_3–N concentrations ($r^2 = 0.42$; $p < 0.001$). There was lack of correlation within each soil class due to the erratic relationship encountered within small sections of the soil test P range. With increasing soil test P a greater proportion of fields within each class exceeded the CCME (2004) NO_3–N guidelines. The proportion of fields >10.0 mg L^{-1} was 30, 50, and 100% for each of the L, M, and H soil test P ranges, respectively. All but four fields produced NO_3–N concentrations in excess of the freshwater aquatic guideline (2.94 mg L^{-1}). All fields with an H soil test P level produced average tile drainage NO_3–N concentrations >10 mg L^{-1} (Fig. 3). Although the risk of elevated NO_3–N concentrations in tile-drainage was greater with H soil test P, there was still a risk of elevated concentrations with L and M soil test P.

Accordingly, as soil test P decreases the relationship becomes more tenuous due to their different source and transport relationships. Clearly NO_3–N does not need a P source to be elevated in drainage water however, at these sites when soil test P was >200 mg kg^{-1} the NO_3–N concentrations always exceeded the MAC. Using soil test P data to predict NO_3–N leaching risk is applicable under field management practices common to Nova Scotia, thus under high soil test P accumulation drainage water quality is at risk and direct evaluation of P and NO_3–N is recommended.

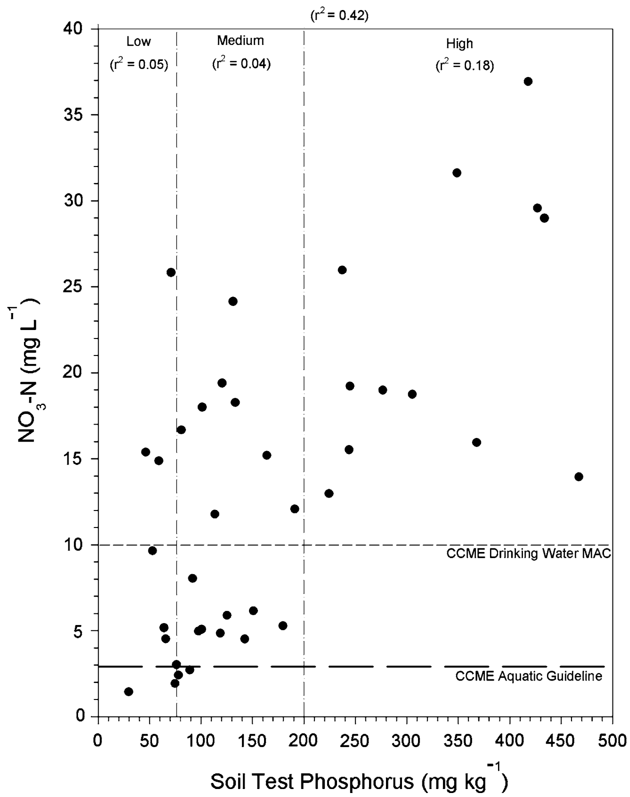

Fig. 3 Average tile drainage nitrate–nitrogen (NO_3–N) concentrations (mg L^{-1}) and soil test phosphorus (mg kg^{-1}) for 0–20 cm soil depth. Fields are separated into three soil test P classes (a) low (<75 mg kg^{-1}), (b) medium (75–200 mg kg^{-1}), and (c) high (>200 mg kg^{-1}). Correlations are given for overall and within each soil class

This adds further usefulness to the 200 mg P kg^{-1} threshold (Sharpley et al. 1996). It appears that high drainage NO_3–N was independent of soil test P, but with the described management practices high levels of soil test P are always in combination with high drainage NO_3–N concentrations. Results suggest that soil test P may be applicable as an indicator of NO_3–N leaching risks particularly at high soil test P. The likelihood of a field exceeding CCME MAC thresholds if soil test P levels exceed recommended environmental thresholds is high. Of the 39 fields monitored, 23 (60%) had tile drainage NO_3–N concentrations exceeding 10 mg L^{-1} of which 80% exceed an soil test P of only 100 mg kg^{-1}. In Nova Scotia soil test P approaching 200 mg kg^{-1} is applicable as an indicator of tile drainage NO_3–N exceeding health guidelines.

References

Canadian Council of the Ministers of the Environment (2004) Canadian water quality guidelines. http://www.ec.gc.ca/ceqgrcqe/English/ceqg/water. Accessed 26-02-2005

Clesceri LS, Greenberg AE, Eaton AD (eds) (1998) Standard methods for the examination of water and wastewater, 20th edn. American Public Health Assoc, American Water Works Assoc, Water Environ Fed APHA, Washington

Day PR (1965) Particle fractionation and particle-size analysis. In: Black CA (ed) Methods of soil analysis, part 1. American Society of Agronomy Inc, Madison, pp 545–567

Di HJ, Cameron KC (2002) Nitrate leaching in temperate agroecosystems: sources strategies and mitigating factors. Nutr Cycl Agroecosys 64:237–256

Heathwaite AL, Johnes PJ, Peters NE (1996) Trends in nutrients. Hydrol Proc 10:263–293

Kinley RD, Gordon RJ, Stratton GW, Patterson GT, Hoyle J (2007) Phosphorus losses through agricultural tile drainage in Nova Scotia, Canada. J Environ Qual 36:469–477

Kleinman PJA, Bryant RB, Reid WS, Sharpley AN, Pimentel D (2000) Using soil phosphorus behavior to identify environmental thresholds. Soil Sci 165:943–950

Mehlich A (1984) Mehlich 3 soil test extractant: a modification of Mehlich 2 extractant. Commun Soil Sci Plant Anal 15:1409–1416

Randall GW, Vetsch JA (2005) Nitrate losses in subsurface drainage from a corn-soybean rotation as affected by fall and spring application of nitrogen and nitrapyrin. J Environ Qual 34:590–597

Sharpley A, Moyer B (2000) Phosphorus forms in manure and compost and their release during simulated rainfall. J Environ Qual 29:1462–1469

Sharpley AN, Tunney H (2000) Phosphorus research strategies to meet agricultural and environmental challenges of the 21st century. J Environ Qual 29:176–181

Sharpley AN, Daniel TC, Sims JT, Pote DH (1996) Determining environmentally sound soil phosphorus levels. J Soil Water Conserv 51:160–166

Sharpley AN, Weld JL, Beegle DB, Kleinman PJA, Gburek WJ, Moore PA Jr, Mullins G (2003) Development of phosphorus indices for nutrient management planning strategies in the United States. J Soil Water Conserv 58:137–152

USEPA (United States Environmental Protection Agency) 1994 Water quality standards handbook, 2nd edn. EPA 823-B-94-005a. USEPA Office of Water. Washington