

Quantifying soil nitrogen supply to reduce nitrate loading to groundwater from high intensity agricultural production areas in Nova Scotia

Project Report
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Introduction

The potential for nitrate contamination of groundwater in Nova Scotia is real and must be a consideration in framing nitrogen management decisions in agriculture. The Agri-Environmental indicator series, developed by Agriculture and Agri-Food Canada, assess the potential for environmental impacts as a result of agricultural activities (AAFC, 2013; Fig. 1). The Indicator of the Risk of Water Contamination by Nitrogen (IROWC-N) has gone from low to moderate based on agricultural activities practiced in 1981 (Fig 1A), high to very high in 2006 (Fig. 1B), and to a more moderate condition in 2011 (Fig. 1C). This indicator is generated using modelling of water quality impacts based on agricultural activities reported in the Agricultural Census (Statistics Canada, 2017).

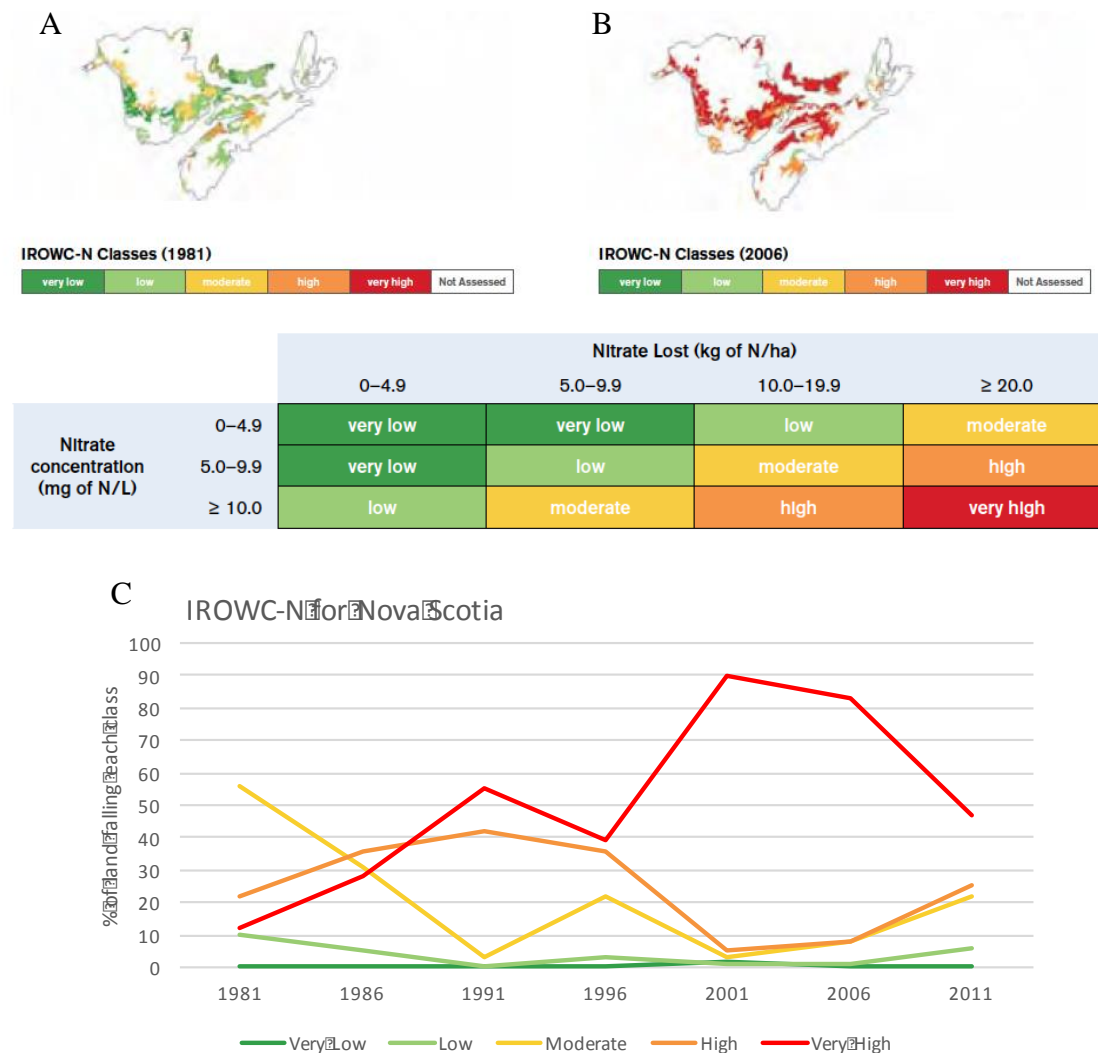


Figure 1: The risk of water contamination by nitrogen from farmland in the Atlantic Provinces under A) 1981 farm-management practices and B) 2006 farm-management practices. The classification system is based on the predictions of the concentration of N in the water and the total amount of nitrate-N lost during the over-winter period (non-growing season). C) The percentage of total farm-land in Nova Scotia falling into each of the five IROWC-N classes in 5-year intervals since 1981 based on the Census of Agriculture.

Changes in IROWC-N are attributed to changes in Residual Soil Nitrogen (RSN) estimates (Fig. 2). Increased N inputs from 2001 to 2006 did not result in increased N outputs, resulting in an increase in residual soil nitrogen (Fig. 2A&B) and IROWC-N (Fig. 1C). In the 2011 census there was both a decrease in N inputs and an increase in N output resulting in decreased RSN (Fig 2C) and a corresponding decrease in IROWC-N (Fig. 1C).

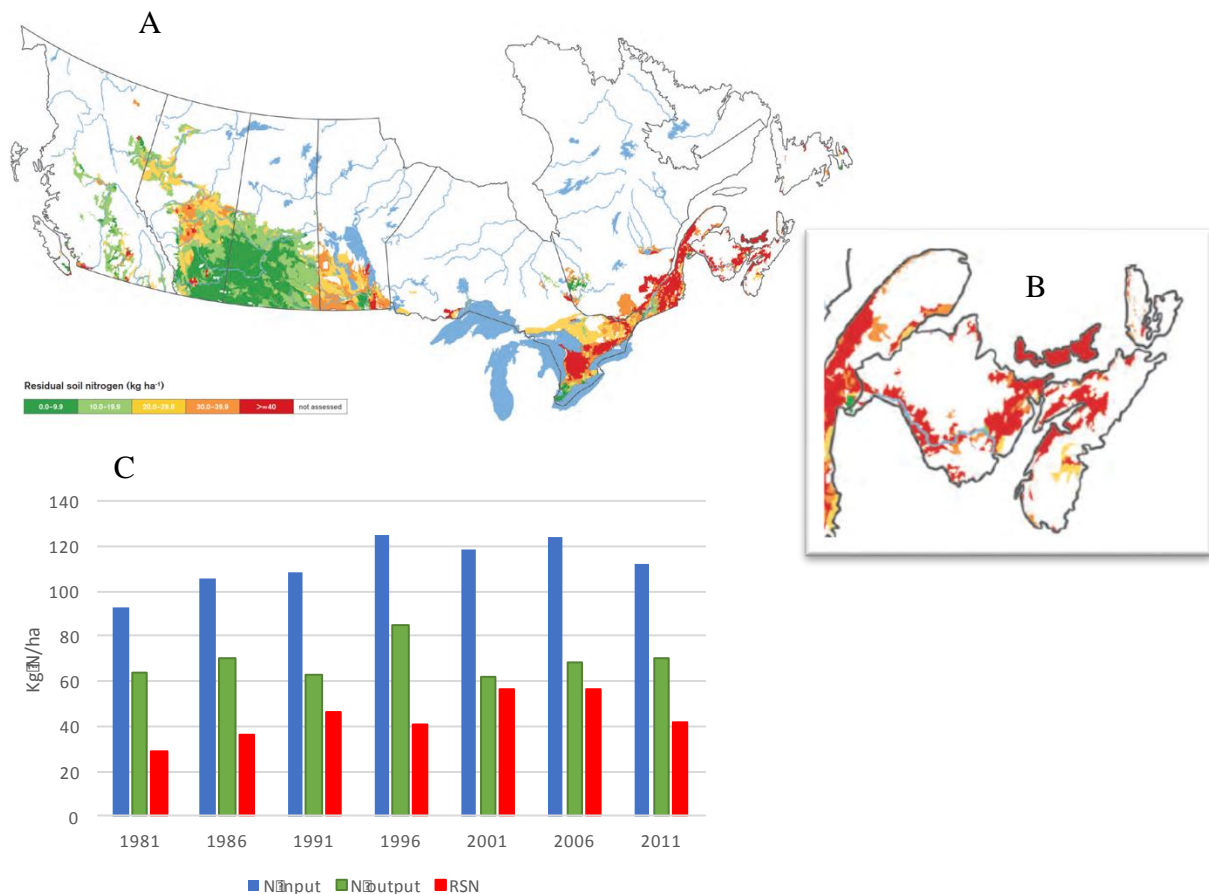


Figure 2: The estimated amount of residual soil nitrogen(RSN) remaining in the soil in the fall in A) Canadian farm-land, B) the maritime provinces. Residual soil N is calculated as the difference between estimated N inputs and N outputs (C) as determined using

These indicators are not based on measured soil or ground water nitrogen contents but are estimated risks based on models driven by agricultural census data. As a result, their primary value is to indicate areas of concern and are not direct evidence of impact. They do indicate that nitrogen impacts on groundwater sources associated with agricultural activities is of concern in Nova Scotia.

There are other lines of evidence that can inform our assessment of the potential for the impact of agricultural activities on ground water N content. Nova Scotia Environment has

been monitoring well water nitrate concentration of 150 drinking water wells in Kings County, Nova Scotia for over two decades (NSE, 2012; Fig. 3). An increasing trend in mean nitrate concentration of drinking water wells was observed between 2000 and 2004 and following a decline in 2005, and an increasing trend from 2005 to 2011. In 2011, 23% of the wells surveyed exceeded the drinking water guideline of 10 mg NO₃⁻N/L. Like the results of the Agri-Environmental Indicator Report, these results point to concerns about the potential for agricultural impact on groundwater in Nova Scotia.

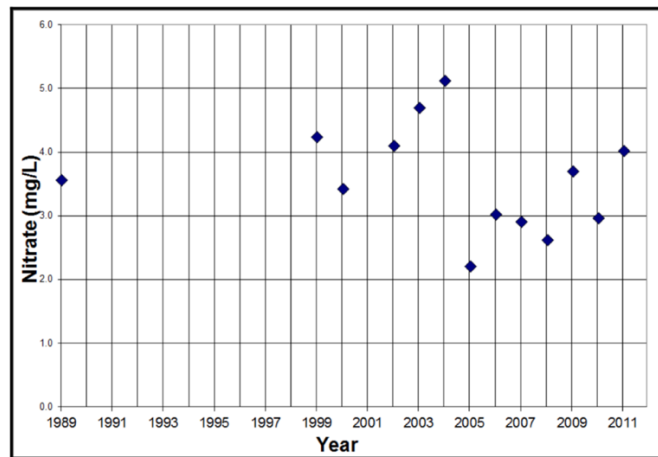


Figure 3: Annual median concentration in well water in Kings County, NS from 1989-2011 (NS Environment)

Two questions need to be addressed in assessing the validity of the trends predicted by these indicators:

1. Do the models used to translate soil N status into groundwater nitrate loading accurately reflect Nova Scotia conditions?
2. Are the impacts of agricultural activities on soil N status accurately represented?

Beyond assessing whether indicators of the potential for water quality impacts are accurate, we need to also assess whether our fertilizer nitrogen practices are adequate to meet production and environmental objectives. Are we providing producers with the tools necessary to make informed nitrogen management decisions? In particular the lack of a quantitative tool to measure the soil nitrogen supply capacity of the soil is problematic.

In other jurisdictions, agricultural management of nitrogen fertilizer application rate is often based on measures of soil nitrogen content or supplying capacity of the soil based on soil testing. In Atlantic Canada, routine soil nitrogen testing is not undertaken and crop nitrogen recommendations are typically based on assumptions of plant N requirements, which are independent of climate, soil type, and land management history. Provincial guidelines recommend a single recommended rate of supplemental N application for a particular crop for the entire province. As a result, it is unlikely that the recommended N fertilizer application rates achieve optimal economic returns and raises significant concerns regarding groundwater protection. Since N deficiency is more visually apparent to the producer than N excess, there is good reason to suspect that N rates are more likely to be in excess of optimal N requirements than to be sub-optimal.

Over the past decade, we have been developing a framework for assessing soil nitrogen supply for Atlantic Canada (Fig. 4) that provides a suite of tools to measure and predict the magnitude of soil N supply and inform a producer's N management decisions. This information could be used as a means of adjusting generalized crop-based N recommendations to reflect site-specific conditions. For this tool to gain the confidence of producers, such that it will be used, and to be of value as a management tool, it is important to determine the range of values present in agricultural soils in Nova Scotia. The information gained can be used to develop the scoring functions that will form the basis of site-specific adjustments to N fertilizer recommendations.

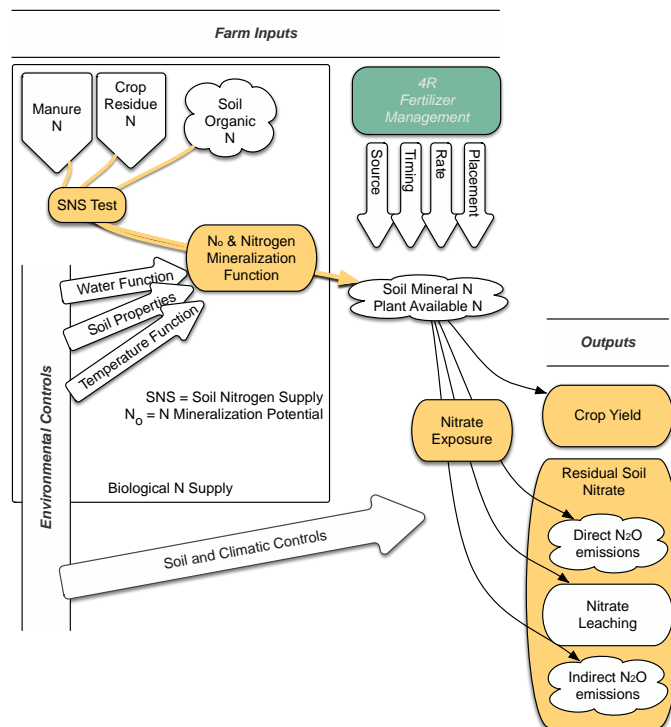


Figure 4: Conceptual framework for integrated N management in Nova Scotia.

Here we survey the soil nitrogen supplying (SNS) capacity of Nova Scotia soils and assess whether there is sufficient variation in the soil nitrogen supply to make this measure of value in recommending economically and environmentally optimum rates of nitrogen fertilizer application.

The project involved the replicated sampling of 80 agricultural fields across Nova Scotia in the fall of 2016 (and an additional 62 in the fall of 2017 but not reported on here) encompassing a range of climatic regions, soil types, cropping systems and fertility management systems. Sites were selected in consultation with Perennia crop specialists.

In addition to assess the ability to model the leaching of nitrate from agricultural production systems in Nova Scotia, the HYDRUS 1D model was parameterized to describe solute flow for the BEEC Organic Amendment Lysimeters. A ¹⁵N tracer experiment was conducted to determine the timing and magnitude of the contribution of N mineralization to NO₃⁻ leaching (results not reported here).

Modelling Nitrate Leaching under Nova Scotia Conditions

Introduction

A study was conducted at the Bio-Environmental Engineering Centre (BEEC), Bible Hill, Nova Scotia using field lysimeter plots to evaluate seasonal nitrogen mineralization and transport of inorganic nitrogen into subsurface water after the application of soil amendments. The lysimeter cells had previously been established in 2010 to aid in developing fate and transport modeling of nutrients and contaminants from the application of alkaline treated biosolids to soils. The lysimeter plots are connected to subsurface drains tied to calibrated tipping buckets and auto-sampling systems to measure water flow and collect water samples for chemical analysis. The lysimeter plots were established using a sandy loam textured soil with a bulk density representative of local agricultural fields in the area.

The Root Zone Water Quality Model (RZWQM) is a comprehensive one-dimensional, numerical agricultural systems model used to predict the effects of agricultural management on crop production and environmental quality (Ma et al. 2001). The model is designed to simulate conditions on a unit-area basis, through the vertical profile, with the crop root zone as the primary zone of focus but can be extended to deeper vadose zone. The model can respond to agricultural management practices, such as planting, harvesting, tillage, pesticide applications, manure and chemical nutrient applications, and irrigation events. A major component in the RZWQM that governs the organic matter/nitrogen cycling is the OMNI sub-model (Fig. 5). The OMNI links with the other sub-models in the RZWQM, such as the soil chemistry, plant growth, and solute transport models, to simulate all the major pathways in soil carbon-nitrogen cycling (Ahuja et al. 2000). This report will focus on the simulation of nitrogen mineralization and nitrification in a field study under Nova Scotia conditions.

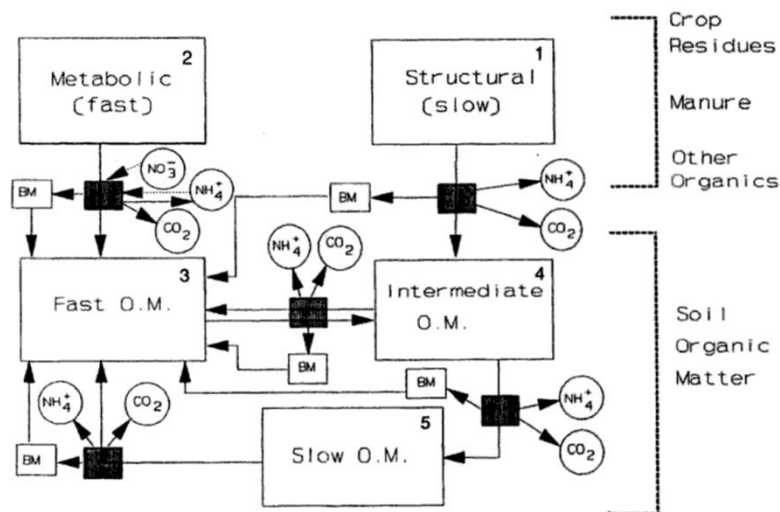


Figure 5: OMNI submodel for describing organic matter turnover in the Root Zone Water Quality Model (From Schaffer et al. 2000).

The objectives of this study were to i) evaluate the concentrations of mineralized nitrogen from soils amended with different rates of alkaline treated biosolids and ii) model transport of nitrates into subsurface water using the RZWQM.

Material and Methods

Lysimeter cells

Lysimeter plots were amended with different rates of alkaline treated biosolids (ATB) in the spring 2017. These plots have a history of annual ATB amendments. In 2016, the lysimeter plots received three treatments, including a 7 Mg ATB ha⁻¹, a 28 Mg ATB ha⁻¹, and a 0 Mg ATB ha⁻¹ (control) on a wet basis. In 2017, a larger loading, non-agronomic rate, of ATB was applied to the plots to ensure a nitrate response was exhibited for model calibration purposes. The rates of application, on a wet basis, was 17.5 Mg ATB ha⁻¹ and 70 Mg ATB ha⁻¹. The treatments were applied on June 28, 2016 and May 11, 2017 and tilled in using a small push rototiller. The plots were planted to fall ryegrass in July 2016 and planted to corn on May 31, 2017 (replanted bare spots on August 1, 2017). The treatments were replicated three times for a total of nine lysimeter cells. Total nitrogen content of the ATB was measured at 0.97% (dry basis) with a total solids content of 61.5%. Total nitrogen addition from ATB rates in 2017 was calculated to be 104 kg and 416.6 kg N for the 17.5 Mg ATB ha⁻¹ and 70 Mg ATB ha⁻¹ treatments, respectively. The control plots were not fertilized in 2017 but had received a labelled ¹⁵N tracer, as ammonium nitrate, in 2016.

Water sample collection

The lysimeter plots were each linked to an individual drain line attached to a calibrated tipping bucket system and a 6712 portable Isco automated water sampler (Teledyne Isco, Lincoln, NE, US). Water flow for each lysimeter plot was individually logged using a Campbell Scientific CRX-100 datalogger. Water samples were collected in 24 x 500mL vessels activated by each flow event beginning in February 2017 and ending in November 2017. Water samples were collected from the Isco water samplers after each precipitation event, when the autosampler vessels were full, sterilized with mercuric chloride to reduce biological activity and stored in freezers until analysis. Samples were analyzed for ammonium and nitrate using a colorimetric method measured with a Bran and Luebbe Autoanalyzer 3 system. Ammonium concentrations in all the samples were typically <2 mg L⁻¹ and were not included in the modeling.

Modelling approach

Minimum data required to run the RZWQM are shown in Table 1. The sources of data inputs required to run the model in this study include data from lysimeter cells, model default values, and values from the literature. The period of daily meteorology data used for the simulation ranged from January 1st, 2017 to December 7th, 2017, while the simulation period was from May 1st, 2017 to October 31st, 2017. Water flow through the soil profile (measured seepage) was continuously logged for each lysimeter cell throughout the year, and over the entire study period, on an hourly basis. Soil characteristics, including soil hydraulics, particle and bulk density, and soil fraction, were characterized for each lysimeter cell. Other measurements, such as rainwater chemistry and soil chemistry state, were also determined for the lysimeter site. Alkaline treated biosolids were input into the model at rates of 0, 17.5 and 70 Mg ha⁻¹, respectively. A total of 11 scalar variables and 2 vector variables were selected as outputs from RZWQM. The scalar variable of 'Water flux into GW (simulated seepage)' was used to determine the model performance based on a value of R² (≥ 0.7), NSE (≥ 0.7), and

PBIAS (± 0.15), by comparing with the measured seepage data. Model calibration was conducted by carefully changing the input data in the model, such as soil physical properties, soil horizons, bulk density, fraction sand, silt and clay, and saturated hydraulic conductivity. With the properly calibrated model, the model simulation was then conducted for the change of nitrate concentrations and nitrate mass in the system.

Table 1: Minimum data requirements to run RZWQM (Modified from Malone et al. 2004)

Data file	Minimum data requirement
Breakpoint rainfall	Two pairs of rainfall amounts and times (e.g. 0 cm rainfall at 100 min; 1cm rainfall at 200 min)
Daily meteorology	Minimum air temperature Maximum air temperature Wind run Solar radiation Relative humidity
Site description	Soil horizon delineation by depth Soil horizon physical properties: bulk density, particle size fractions for each horizon (optional soil properties, if available, include: 330 or 100 cm suction water content and saturated hydraulic conductivity for each horizon) Estimate of dry mass and age of residue on the surface General pesticide data such as common name, half-life, partition coefficient, dissipation pathway Specifying a crop from supplied database with regional parameters
Initial state	Initial soil moisture contents Management details (e.g. tillage type and timing, chemical application and timing) Initial soil temperatures Initial soil pH, CEC values Initial nutrient model inputs (soil residue, humus, microbial populations, mineral $\text{NO}_3\text{-N}$, $\text{NH}_4\text{-N}$, may use incorporated RZWQM98 wizard to determine values)

Results

Model simulation of seepage through lysimeter plots

The seepage, or volume of water, flowing through the 17.5 Mg ATB ha^{-1} and 70 Mg ATB ha^{-1} treatment lysimeter plots are shown in Figure 6A and B. The water flow simulations for the 17.5 Mg ATB ha^{-1} and 70 Mg ATB ha^{-1} treatments, shown in Fig. 6A and B, were able to be fully representative of the actual flow volumes measured and the timing of the flow events. The simulation was based on soil hydrology parameters measured in 2013/14 and meteorological data from 2017. Some flow events were well predicted by the model simulation in both treatments but some disparities between measured and simulated suggest that better model calibration is required. Despite the differences between actual and simulated flow through the lysimeter plots the response by the model is suggestive of good potential to achieve better results. The RZWQ model has been used extensively through the United States, and in parts of Canada, to simulate fate and

transport of nutrients and /or contaminants in agricultural soils. Linking soil characteristics, such as texture and hydraulic parameters, with historical meteorological data, crop management systems, and types of soil amendments holds significant promise as a decision support system to evaluate outputs from agricultural practices.

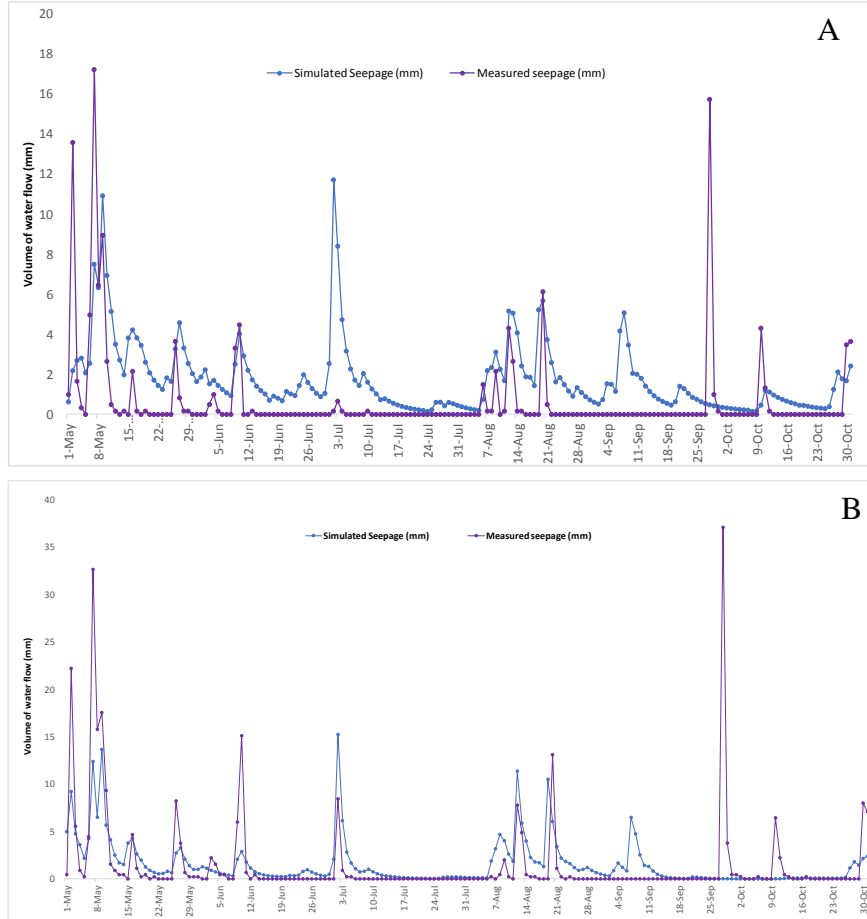


Figure 6: Seasonal water flow volumes in the 17.5 Mg ATB ha⁻¹ and 70 Mg ATB ha⁻¹ treated lysimeter plots at the Bio-Environmental Engineering Centre, Nova Scotia

Transport modeling of nitrate concentrations in lysimeter plots

The guidelines for Canadian drinking water quality establishes the maximum concentration for nitrates at 45 mg L⁻¹ or 10 mg L⁻¹ as nitrate nitrogen (Health Canada, 2013). Nitrate concentration in water samples collected from the field research lysimeter plots at the BEEC in Nova Scotia over 2017 are shown in Figure 7. The control plots, received no fertilizer and were planted to corn, leached nitrate throughout the growing season, ranging from 10 to 25 mg L⁻¹. In contrast, soils receiving the ATB treatments mineralized greater quantities of nitrogen, relative to the control, and consequently had higher nitrate concentrations in water samples collected over 2017. Beginning in mid-June to late June nitrate concentrations in ATB amended soils increased from approximately 15 mg L⁻¹ to 45 mg L⁻¹ by late July. Nitrate concentrations peaked in mid-to late August to 65 mg L⁻¹ and 85 mg L⁻¹ in the 17.5 Mg ATB ha⁻¹ and 70 Mg ATB ha⁻¹,

respectively. Nitrate concentrations remained high through the late summer and early fall in the ATB treated plots and declined to background levels, i.e. control plot, only in the 17.5 Mg ATB ha⁻¹. A number of factors may have contributed to higher nitrate concentrations measured in the ATB treated soils, including accumulation of organic matter from previous years' applications that also are mineralizing N, poor crop germination and growth resulting in reduced plant N uptake, and rapid degradation of ATB after application to soils (Gillis and Price, 2011).

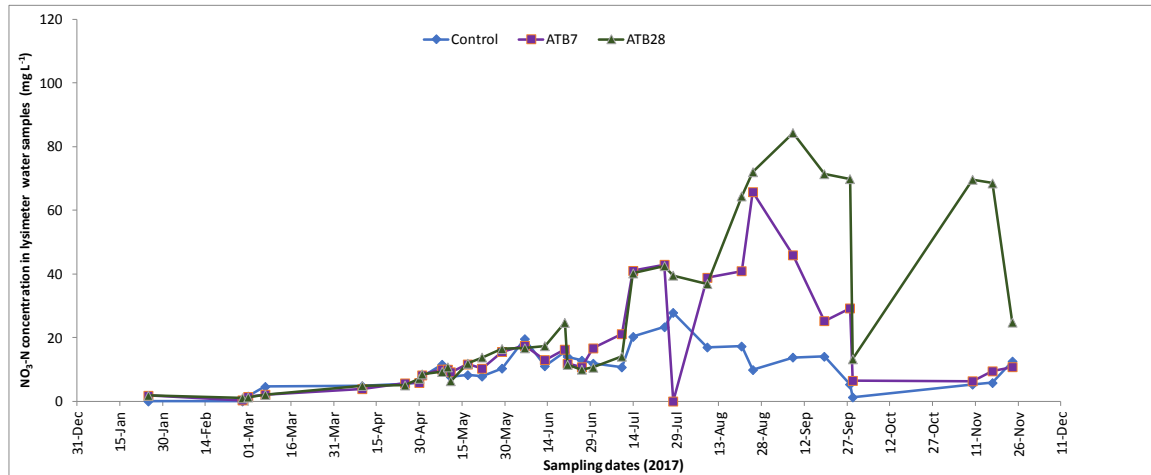


Figure 7: Seasonal nitrate concentrations (mg L⁻¹) in water samples collected in Nova Scotia from lysimeter plots amended with alkaline treated biosolids at rates of 0, 17.5 Mg ATB ha⁻¹, and 70 Mg ATB ha⁻¹.

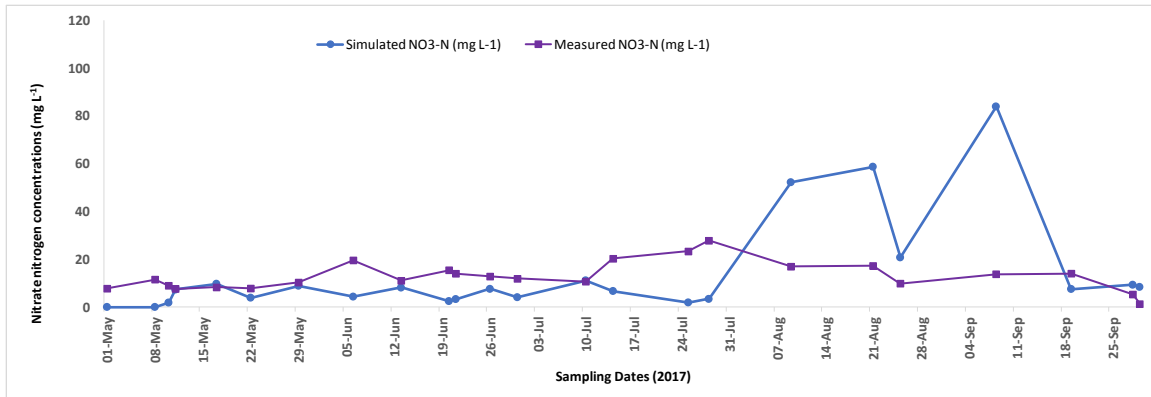
The model simulation output for nitrate concentrations from each treatment are shown in Figure 8. The RZWQ model simulation of nitrate concentrations in soils amended with ATB was generally very close to measured data, with the exception of two to three event periods (Fig. 8B & 8C). Model simulations of nitrate concentrations for the 17.5 Mg ATB ha⁻¹ and 70 Mg ATB ha⁻¹ treatments was better than the control (Fig. 8A), which overestimated nitrate in the late summer and early fall period. Simulation responses are affected by the amount and type of data input into the model. In this study, the meteorological data used was only for 2017 whereas an extended historical dataset can provide a warm up period for the simulation. Moreover, soil characteristics and soil hydrological data play a significant role in calibrating the model. Site characteristics were originally developed for the lysimeter plots in 2014 and updated characterization would help improve the model parameterization.

Seasonal cumulative nitrate

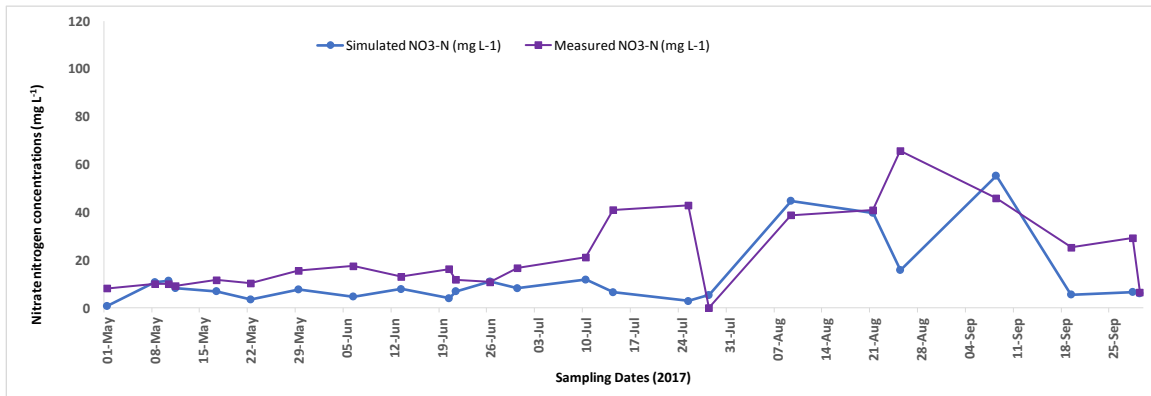
The nitrate concentrations for each sampling period were converted into a flow adjusted nitrate mass (mg). These nitrate masses were transformed into cumulative nitrate masses over the entire season and are shown in Figure 9. The model simulation for the cumulative nitrate masses in the control plots was very good for the control and 70 Mg ATB ha⁻¹ treatments (Fig. 9A and 9C) but underestimated cumulative nitrate mass in the 17.5 Mg ATB ha⁻¹ treatment from mid-August onwards. This underestimate appears early in August in the model simulation and the error compounds over time. However, while the simulation does not capture the correct magnitude of nitrate mass over the season, the trend in accumulated nitrate is well simulated by the model. Additional sampling data, as

well as a longer historical meteorological dataset, may help resolve this issue in the model.

A



B



C

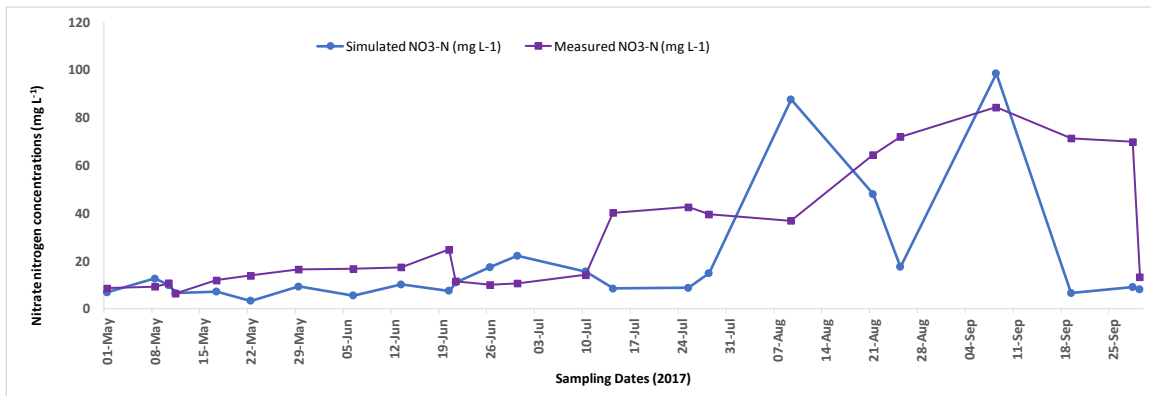
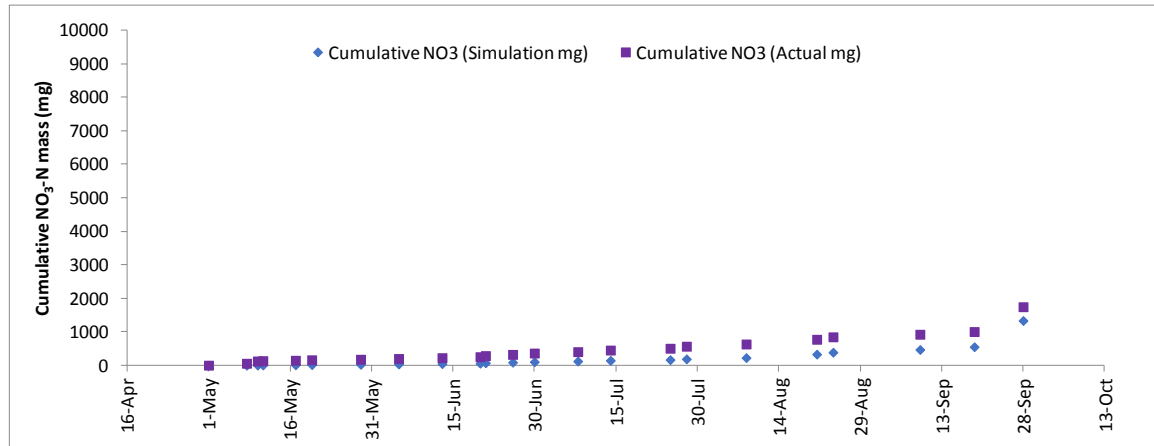
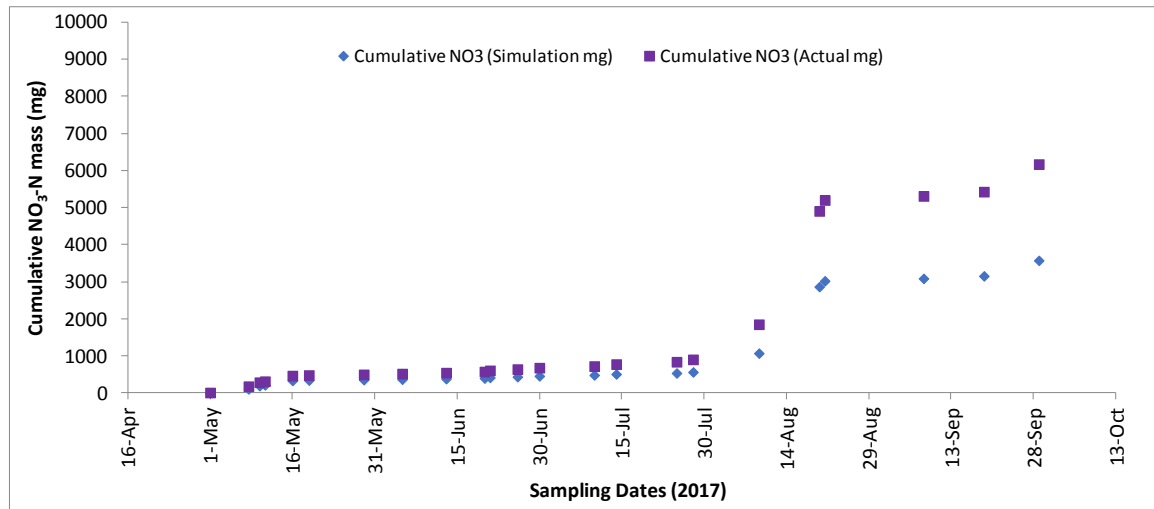


Figure 8: Model simulation (RZWQM) vs actual measures of seasonal nitrate concentrations (mg L^{-1}) in water samples collected in Nova Scotia from lysimeter plots amended with alkaline treated biosolids at rates of (A) 0, (B) 17.5 Mg ATB ha^{-1} , and (C) 70 Mg ATB ha^{-1}

A



B



C

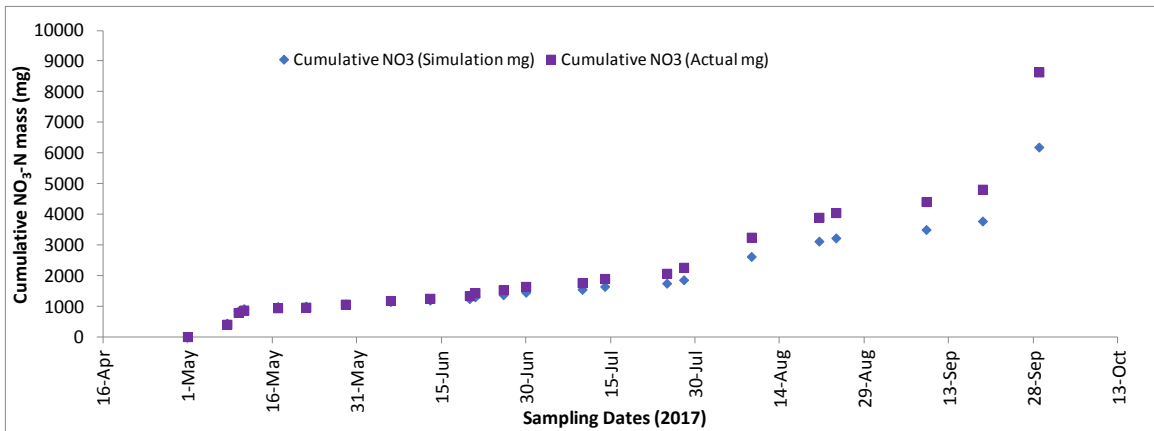


Figure 9: Seasonal cumulative nitrate mass (mg) in water collected from lysimeter plots in a sandy loam soil amended with alkaline treated biosolids in Nova Scotia. Figures represent the modeled (simulated) and actual measured cumulative nitrate masses from: (A)

Evaluation of the responsiveness of the RZWQ model to simulate nitrate in soils, amended with the ATB and without any amendments, was within acceptable limits. In particular, the cumulative nitrate datasets had a higher degree of acceptability based on

the evaluation parameters used. Several measures were identified to help determine the usefulness of the simulation results from the model, including PBIAS, RMSE, NSE, and R^2 . The measure of average tendency of simulated data to be larger or smaller than observed counterparts is the percent bias (PBIAS). Other values used to determine how appropriate the model simulation is included the root mean square error (RMSE) and the Nash-Sutcliffe efficiency. The NSE is a normalized statistic that indicates how well the plot of the observed versus simulated data fits the 1:1 line. The values in Table 2 suggests that the model simulation, based on soil, hydrological, and meteorological data collected for the lysimeter plots, were well related to the measured cumulative nitrate data. In contrast, simulation values measured for nitrate concentrations on an event basis were not well related suggesting that additional calibration time periods are required to better calibrate the model.

Table 2: The model evaluation statistics for the control and ATB amended lysimeter plot simulations of cumulative nitrate mass in collected water samples, including the root mean square error (RMSE), the Nash-Sutcliffe efficiency (NSE), percent bias (PBIAS), and coefficient of determination (R^2).

Treatments	RMSE	NSE(>=0.7)	R^2 (>=0.7)	PBIAS (0.15)
Control	292.36	0.87	0.84	32.42
17.5 Mg ATB ha ⁻¹	525.97	0.80	0.98	44.28
70 Mg ATB ha ⁻¹	477.35	0.89	0.98	30.99

Conclusions

Modelling the transport of nitrate from the soil solution into the subsurface is dependent on a wide range of biotic and abiotic factors that vary widely, and rapidly, over time. The Root Zone Water Quality model is a well-established process based model developed by the U.S. Agricultural Research Service (USDA, 2017) that can respond to an array of different conditions in the soil. The outcomes from this study suggest that the RZWQ model has significant capacity to simulate nitrate concentrations and seasonal cumulative nitrate in soil and water, from amended and unamended soils in Nova Scotia. When larger historical external datasets, i.e. meteorological data, are available, they can greatly improve the reliability of the simulation. In our study, two to three outlier weather events over the sampling period and the use of a shorter meteorological window in the model resulted in lower reliability of the simulation of nitrate concentrations. However, when the nitrate data was evaluated as a cumulative mass over the sampling period the simulation fell within more acceptable statistical limits. Overall, factors affecting model performance include soil chemical and hydraulic characterization, historical meteorological datasets, crop management history, and organic amendment characteristics. Many of these variables are typically available from farm records, public data sources, and the scientific literature making the use of agricultural process-based models, such as the RZWQ model, a highly accessible tool for nitrogen management in soils.

Assessing the Soil Nitrogen Supplying Capacity of Agricultural Soils in Nova Scotia

Introduction

This survey was conducted in collaboration with a larger project entitled “Assessing the cropping systems of Nova Scotia and Prince Edward Island for soil health, carbon storage capacity, and soil nitrogen supply as a basis for site-specific greenhouse gas mitigation planning”. This report will focus on the nitrogen supplying capacity of agricultural soils in Nova Scotia.

The object of the soil N supply survey was to i) measure the amount of mineral N remaining in the soil in the fall following crop harvest, ii) measure the magnitude of the biological N flush, and iii) estimate the amount of soil N mineralization based on the biological N flush and total N content of the soil. The survey identified the range of values present in Nova Scotia, the average value and values associated with particular cropping systems. The intent was to assess the potential for these measurements to inform N management decisions in Nova Scotia. As part of that assessment we wished to determine whether there was significant variation in soil N supply and whether that variation was influenced by cropping system.

Materials and Methods

Site Selection

In the fall of 2016 a total of 80 farm fields were sampled in Nova Scotia (Fig. 10), an additional 62 farm field were sampled in the fall of 2017 but will not be reported on in this report. Fields were selected in consultation with Perennia cropping specialists. They were selected to represent the major cropping systems in Nova Scotia (Fig. 11). The majority of the sites were in Kings County as that is where there is greatest concern for groundwater nitrate impacts. All sites were geo-referenced. Producers were surveyed to capture agronomic activities on the field for the past five seasons (2010-2014).

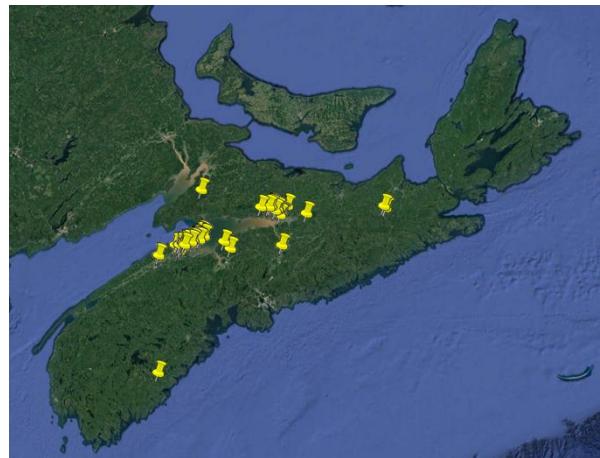


Figure 10: Location of soil nitrogen supply sampling sites in 2016.

For each field, soil samples were collected from four locations within the field. At each location within the field a composite of three soil cores collected to depth of 15 cm with a Dutch Auger. Samples were collected in the fall of 2016 and the fall of 2017.

Approximately 1 kg of soil was sampled from the 0-15 cm depth, air-dried and passed through a 2-mm sieve.

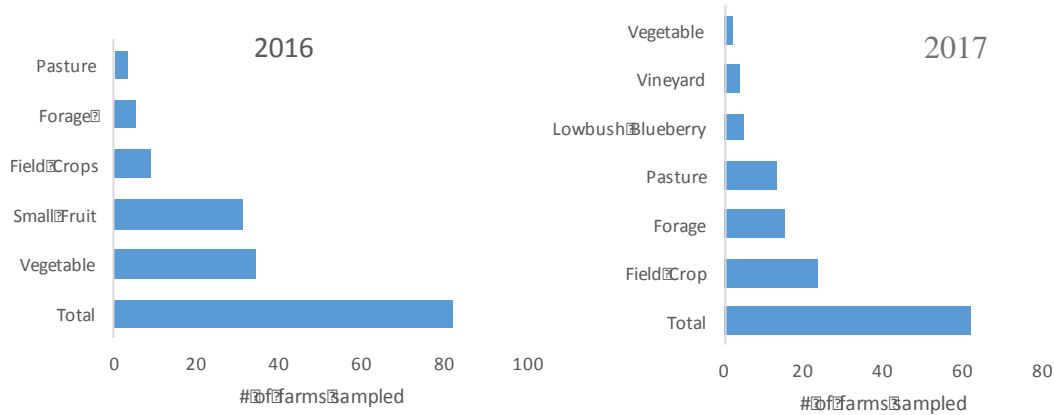


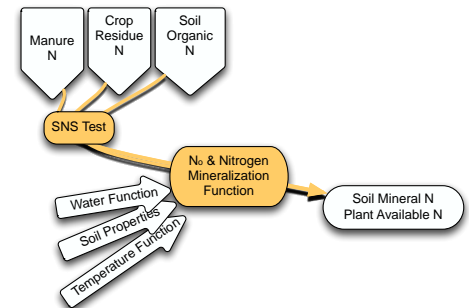
Figure 11: Distribution of farms sampled in 2016 and 2017 in terms of farm type

Soil Analysis

A complete assessment of each sample was undertaken using the Cornell Soil Health Assessment framework. Here we report on the more detailed assessment of soil N processes was undertaken to provide more information on the potential for N impacts on groundwater.

An integrated assessment of soil nitrogen supply (SNS) was undertaken measuring mineral N (NH_4^+ , $\text{NO}_2^- + \text{NO}_3^-$) followed by an assessment of N mineralization potential (N flush) based on a two-week aerobic incubation (Sharifi et al., 2007). The SNS test was performed by combining 30 g of soil with 30 g of washed Ottawa sand, placing in a Buchner funnel fitted with a 55 mm GF/A microfiber filter paper (Fisher# 90-874-16) and leached under vacuum with 200 mL of 0.01 M CaCl_2 . This was used as a measure of residual soil nitrogen (RSN). Following the first leaching the soil was incubated in the funnel covered with parafilm at 25 °C for 2 weeks. Following incubation, the soils were leached a second time with 200 mL of 0.01 M CaCl_2 . Leachates were analyzed using a Technicon AutoAnalyzer II system for NH_4^+ using the phenate method (Technicon Industrial Method #98-70W), $\text{NO}_2^- + \text{NO}_3^-$ using Cd reduction (Technicon Industrial Method #100-70W). Soil total organic carbon and total N were measured on samples that were ground for 24 hours using a roller mill and 0.5 g samples were measured using and Elementar analyzer.

Nitrogen mineralization potential (N_0) was also estimated from soil total N, and N flush (Dessureault-Romppe et al., 2011b; Dessureault-Romppe et al., 2012) and used to estimate N mineralization over a 130-day growing season using the revised biophysical water function:



$$f(x) = \lambda \frac{(1 - e^{-bx})}{(1 - e^{-b})} + 2(1 - \lambda) \times \frac{(e^g - e^{-g(x-1)})}{(e^g - 1)(1 + e^{-g(x-1)})}$$

where $f(x)$ is the scaled N net mineralization rate with $\lambda = 0.82$; $b = 3.80$; and $g = 8.00$ (Dessureault-Romppe et al., 2011a; Georgallas et al., 2012).

Conversion of mg N/kg soil to kg N/ha was made using the sampling depth of 15 cm and a bulk density of 1.3 Mg m^{-3} resulting in mass of 1,950 Mg soil/ha.

Results

Soil Mineral Nitrogen

The soil mineral N values averaged 5.7 mg N/kg soil with maximum values as high as 111 mg N/kg soil (Fig. 12). A non-normal distribution in data was observed with a few very high observations skewing the distribution. This is of particular concern with respect to N management as these few very high values represent the greatest risk of nitrogen loading to groundwater.

This parameter is a measure of how much mineral N (NH_4^+ and NO_3^-) remains in the soil following crop growth. The very high values identify opportunities to significantly reduce the risk of nitrate contamination by improving N management on these fields rather requiring a broad-based reduction in N fertilizer use. The question is how do you identify these fields in advance of the growing season rather than at its conclusion.

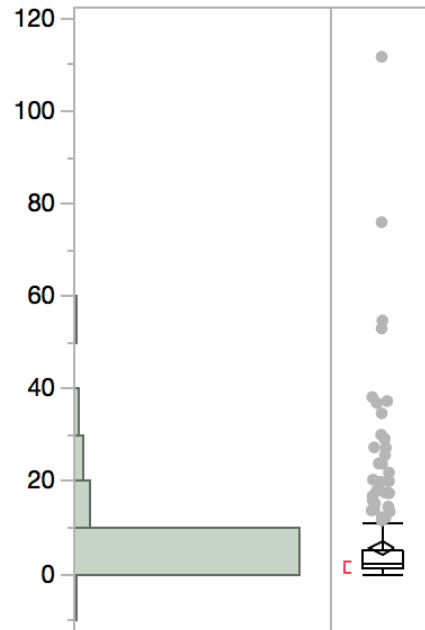


Figure 12: Distribution of mineral soil N (0-15 cm) in the fall 2016 sampling.

The residual soil nitrogen indicator in agri-environmental indicator series is expressed as kg N/ha in the soil profile. Normally the carry-over of nitrogen in the soil profile is measured to a depth of 60 cm. If the soil mineral N in the top 15 cm was expressed over a 60 cm depth and corrected for bulk density the average residual soil nitrogen value would be 44.3 kg N/ha, falling into the >40 kg N/ha class assigned in the RSN indicator (Fig. 2). Only 25% of the sites measured had values that were equivalent to the >40 kg N/ha RSN indicator this is somewhat less than the 47% value predicted based on the 2011 Agricultural Census.

Biological N Flush

The biological N flush is defined as the amount of soil mineral N produced during a 2-week aerobic incubation and is a measure of the potential of the soil to supply nitrogen to a crop. This is an important measure in Nova Scotia as much (~50%) of the N taken up by the crop is a result of N mineralization during the growing season. The average value of the biological N flush was 41.7 mg N/kg soil with a maximum value of 268 mg N/kg soil (Fig.13). This observation documents a considerable potential for soils in Nova Scotia to supply N. The variation in this value emphasizes the opportunity to include a measure of soil N supply in N management decisions and thereby provide site-specific N optimization and minimize potential groundwater impacts.

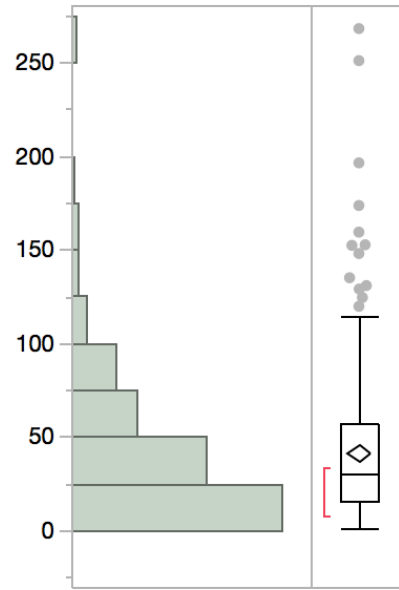


Figure 13: Distribution of biological N flush in the fall 2016 sampling.

The measurement of biological N flush provides a means of identifying fields with a high potential to supply N. There was a significant correlation between biological N flush and soil mineral N (Fig. 14). This relationship only explained 3% of the variation in soil mineral N. It would appear that there are three distinct relationships (a, b, c) between biological N flush and soil mineral N. The “a” group is dominated by field crop and vegetable production systems where the high mineral N is unrelated to N mineralization, the “b” group by field crop and small fruit systems and the “c” group by forage, pasture and cover crop systems where despite high N mineralization, mineral N does not accumulate. It is important to note that this pattern is based on the analysis of the fall 2016 sampling only. Analyses of the 2017 and future sampling events will provide more definitive data on whether this trend is real.

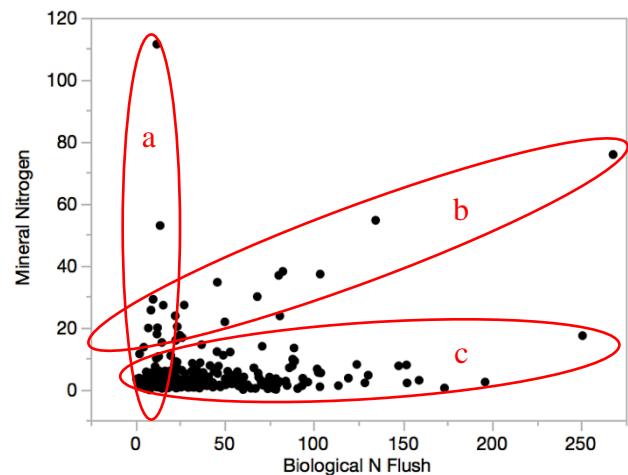


Figure 14: Relationship between biological N flush and soil mineral N.

Estimated N Mineralization over 130 days

The N supplying capacity of the soil interacts with climate to determine the amount of N that will be mineralized during the growing season. An estimate of the amount of N that would be mineralized by the soil over a 130-day growing period was undertaken using an estimate of nitrogen mineralization potential (N_o) based on soil total N, and the biological N flush (Dessureault-Romp   et al. 2011a & 2012) and the revised biophysical water function (Dessureault-Romp   et al. 2011b; (Georgallas et al., 2012) and expressed as kg N/ha.

The average estimated N mineralization over the growing season was 172 kg N/ha with values as high as 877 kg N/ha (Fig. 15). The average value underscores the important role that soil N supply plays in supplying N to crops in Nova Scotia. The farms where these values are extremely high (>500 kg N/ha) are indicators of production systems that have extremely high N fertility and a high risk of N losses. The sites with the highest estimated soil mineralization potential were also the sites with the highest mineral N in the soil in the fall. Again, this underscores the importance of explicit measurement and consideration of soil N supply in N management decisions.

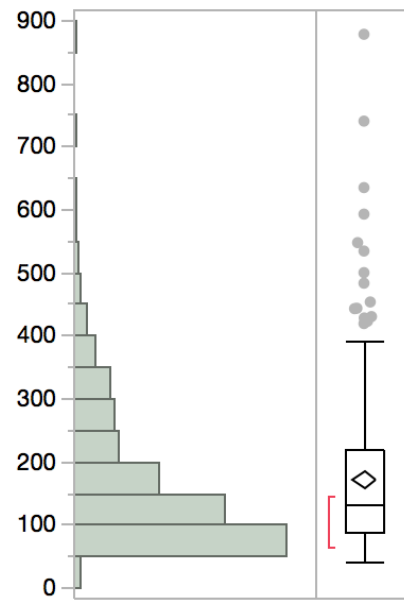


Figure 15: Distribution of estimated soil N mineralization potential based on a 130-day growing period.

Influence of Cropping System

Are the magnitudes of the various measures of soil N status influenced by cropping system?

To answer this question, we categorized the 82 farms sampled in the first year of the study broadly into 12 cropping systems. The distribution of each parameter in each of the 12 cropping systems is illustrated in Figure 16. Cropping system had no significant impact on soil mineral N remaining in the fall, but did significantly influence soil total N, biological N flush and estimated N mineralization over the growing season (Table 3). A few trends are apparent. Pasture and forage systems, both systems that typically have low N inputs with continuous plant cover and limited soil disturbance, resulted in greater soil N, biological N flush and estimated N mineralization. They also had the lowest fall soil mineral N values (this corresponds to group “c” in Fig. 14). Annual cropping systems with larger inputs and high degrees of soil disturbance such as vegetable production systems had lower values for the three measures of soil N mineralization, but had the highest values for fall mineral N. This suggests that low input systems with perennial cover and low disturbance result in more efficient internal cycling of N than do systems with higher inputs and great degree of disturbance and/or annual cropping systems. While

not a surprising observation, this does support the use of these parameters as measures of soil N cycling processes.

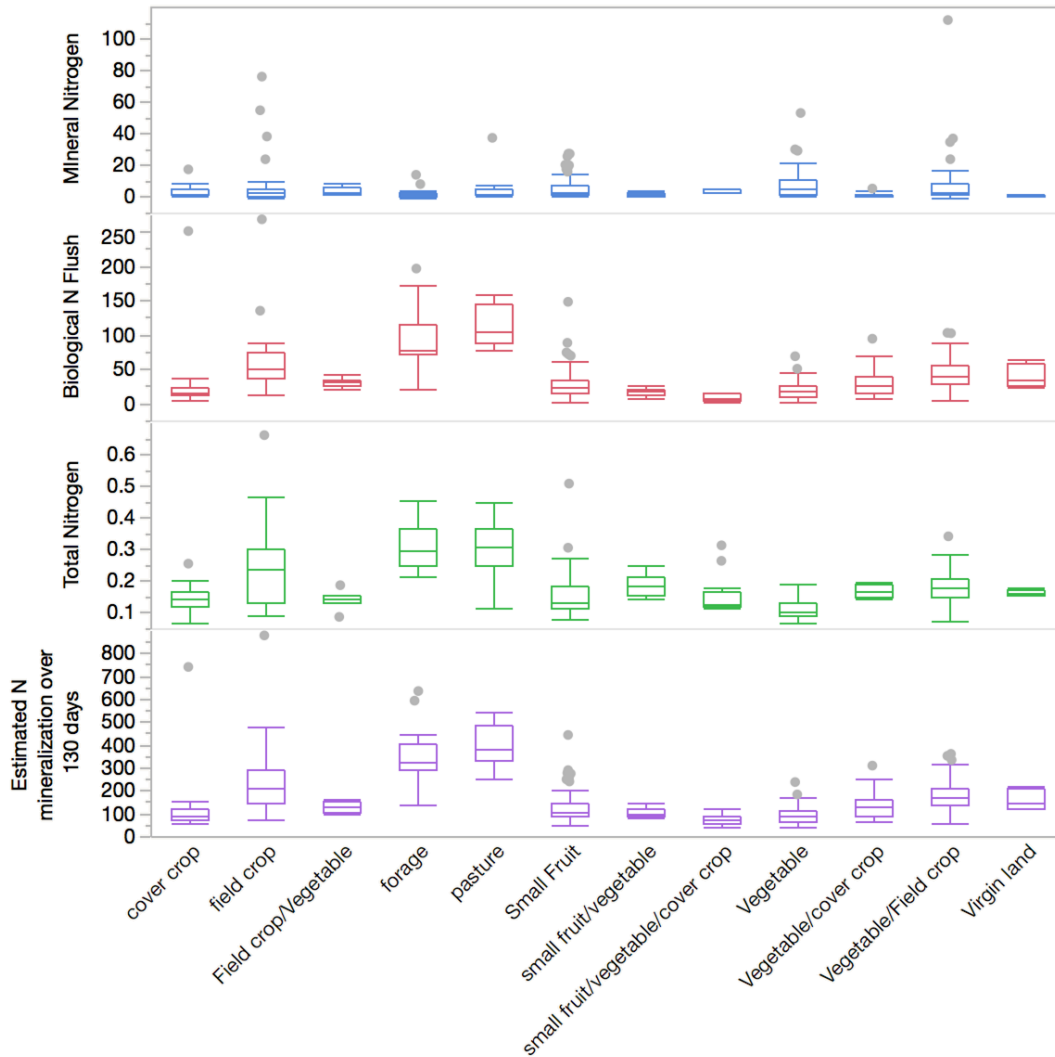


Figure 16: The influence of cropping system on A) soil mineral N in the fall, B) biological N flush, c) soil total N, and d) estimated soil N mineralization over 130-day period.

The development of a soil N test for Nova Scotia

Soil testing plays a crucial role in informing nutrient management decisions. It provides site-specific information on nutrient availability and forms the basis of the decision to add supplemental nutrients. In Nova Scotia, there is not currently a recommended soil test for nitrogen. Fall nitrogen tests, used in more arid regions like the Canadian Prairies, are not appropriate in regions where over-winter leaching results in the transport of fall nitrate to groundwater. The analytical infrastructure needs and the unreliability of early season nitrate testing has also not allowed for its adoption in Nova Scotia. These results point to the urgent need to develop the capacity to provide site-specific information on the soil N supplying capacity of soil to inform nitrogen management decisions and to mitigate potential losses to the environment.

Table 3: Mean values for measure soil N parameters as influenced by cropping system. Values with a measure followed by different letters are different at $p \leq 0.05$.

Level	Mineral Nitrogen (mg N/kg)	Total Soil N (%)	Biological N Flush (mg N/kg soil)	Estimated N Mineralization over 130 days (kg N/ha)
Cover Crop	3.5	0.15de	27de	120cd
Field crop	7.8	0.24bc	59c	238b
Field crop/Vegetable	3.9	0.14de	31cde	129bcd
Forage	2.3	0.31a	92ab	348a
Pasture	5.6	0.30ab	112a	401a
Small Fruit	5.7	0.16de	30de	131cd
Small fruit/Vegetable	1.8	0.19cde	17de	105cd
Small fruit/Vegetable /Cover crop	3.7	0.16de	9e	73d
Vegetable	9.2	0.11e	22de	94d
Vegetable/Cover crop	1.7	0.17cde	33cde	143bcd
Vegetable/Field crop	8.4	0.18d	45cd	180bc
Virgin land	1.0	0.16cde	40bcde	160bcd
Survey Average	5.7	0.19	41.7	172

How much N is enough? How do we determine how much supplemental N to add?

Traditionally N rate recommendations are based on information that has been gathered by conducting N response trials within the region using current varieties and production practices. In these trials, the increase in yield as a result of fertilizer N addition is measured and the economically optimum yield (the point at which a dollar's worth of fertilizer produces a dollar's worth of yield) is determined. These trials are conducted at different sites, over a number of years and soil testing is used to assess the differences in site years. The result is a soil test tool that can quantify the expectation of a yield response to additional fertilizer. Critical to the success of these approaches is a soil testing method that reflects the supply of the nutrient in question as influenced by current management practices.

In the absence of current yield response data, the construction of a partial N budget can provide insight whether the magnitude of nutrient addition is justified in terms of crop N demand and removal. Utilizing available data on corn and winter wheat production in response to N fertilization (Perennia 2015 & 2016), a partial N budgets can be constructed (Table 4). This analysis suggests that based on observed yields and estimated plant N uptake, the fertilization rate used assumed a soil N supply of 87 and 135 kg N/ha

over the growing period for corn and winter wheat respectively. Both values are well below the average 172 kg N/ha that was predicted from the survey of soil N supply.

Table 4: Partial N budget for corn and winter wheat production in Nova Scotia based on N response trials conducted by the Atlantic Grains Council in 2015 and 2016 (atlanticgrainscouncil.ca).

	Corn	Winter Wheat
Recorded Yield (t/ha)	8.3	5.7
Plant N Uptake[†] (kg N/t)	13.2	21.0
Assumed NUE (%)	50%	50%
Crop N Requirement (kg N/ha)	218	236
Fertilizer N (kg N/ha)	131	101
Assumed Soil N Supply[§] (kg N/ha)	87	135
N Removal in Grain (kg N/ha)	85	85
Residual Fertilizer N (kg N/ha)	46	16
Apparent Fertilizer Use Efficiency (%)	65	84
Actual NUE (%)	39%	36%

[†] Plant N uptake based on Atlantic Canada numbers from IPNI

[§] Assumed soil N supply calculated as difference between crop N requirement and fertilizer N addition

Here we are proposing a fall-based soil N testing approach for practicality reasons. It is based on the biological N supplying capacity of the soil and interprets this capacity in terms of local climatic conditions to estimate N mineralization over the growing season. At this stage, this is a theoretical approach, but the ability of this approach to detect differences in N status provides promise that this approach could be an important input into nitrogen management decisions. The magnitude of the estimates of soil N supply require further variation and field validation. To validate this approach and to produce a tool that can be relied upon by producers there is need to conduct field-based N response trials.

Towards an Measurement-based Approach to Improved Nitrogen Management in Nova Scotia

To provide effective nitrogen management in cropping systems in Nova Scotia we propose a series of tools to provide producers with the information necessary to adjust supplemental N rates and to track the success of their N management (Fig 4). The system is comprised of five basic elements:

1. Soil Nitrogen Supply Test – This is the measurement of Biological N Flush discussed earlier in the report. Measured in the fall of the year, this test provides a site-specific measure of the influence of management on the nitrogen status of the soil. Measured over time it can be useful in assessing whether management is improving or degrading the N status of the soil. It is also used in estimating growing season N mineralization.
2. Estimation of N mineralization – Based on a measure of total soil N, biological N flush and local climate (precipitation and air temperature) an estimate of N mineralization over 130 days can be made, providing producers with an estimate of how much N their soils are supplying to the crop.
3. Nitrate Exposure (NE) – is a time-integrated measure of the amount of nitrate in the soil. As an exposure measurement, it is effective in measuring the N available to the crop and predicting the potential for loss as N₂O emissions or NO₃⁻ leaching. It requires multiple measures of NO₃⁻ concentration in soil and therefore may not be practical in all situations. There are commercial tools available to facilitate the integrated measure of soil nitrate in agricultural fields.
4. Residual soil N – Residual soil nitrogen is a measure of the amount of soil mineral N that is remaining in the soil following harvest. This is usually measured to a depth of 60 cm and is a direct measure of the N that may be lost during the non-growing season. In this project, we also measured the amount of NO₃⁻ and N₂O being lost in drainage water in the lysimeter study described in Chapter 2.
5. Partial N Balance – This is a simple N balance calculation based on the N content of the crop yield that allows an assessment of efficiency of the use of N sources. It is a measure that is likely to be of interest to producers as it evaluates the agronomic efficiency of the use of inputs as well as the potential for nutrient loss.

Application of any one of the elements of the framework would result in improved N management. The more elements are used, the more information would be available to the producer, allowing for an even more robust assessment of the N status of the soil and the impact of N management on crop production and environmental impact.

Critical to the development and adoption of any or all of these tools is on-farm calibration. We have, and continue, to work with research organizations such as the Atlantic Grains Council and Perennia to access N response data from research trials conducted in Nova Scotia. There is a potential to utilize these tools to develop an on-farm N management framework to allow the development site-specific N management programs. This approach would also support in field assessment and management of soil N supply and precision farming approaches to N management in Nova Scotia. We are

anxious to work with producers in developing and demonstrating the capacity of this system to improve agronomic and environmental performance of crop production in Nova Scotia.

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