Design of a field-scale approach for evaluating nitrogen management practices impacts to groundwater

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ABSTRACT

While nitrogen fertilizers and other nutrient sources (e.g., manure, bio-solids, and legume credits) are valued for their ability to increase crop yields, a portion of nitrogen applied through these methods leaches to groundwater as nitrate. Nitrate in Wisconsin's groundwater is a pervasive drinking water contaminant and nitrate exported to surface waters via groundwater contributes to eutrophication and hypoxic conditions in the Gulf of Mexico. Demonstrating through on-farm research what baseline nitrate concentrations can be expected for a given region and under well managed fields is the first step in the setting of achievable water quality goals and prioritizing nitrogen reduction strategies.

This study investigated the utility of a field-based approach for the evaluation of nitrogen management strategies and effects on nitrate concentrations in groundwater. We set out to 1) characterize spatial variability of groundwater nitrate below agricultural fields 2) evaluate seasonal differences in nitrate concentrations at the top of the water table (fall versus spring). 3) provide an evaluation of sampling numbers needed to characterize spatial variability and 4) describe the advantages/disadvantages of using of a geoprobe versus bucket auger for collecting water samples.

Two irrigated agricultural fields were selected from a farm located just south of Plover, WI. Discrete random sampling of the water table below each field was performed in Dec. 2014, Apr. 2015, Nov. 2015 and May 2016. Mean nitrate concentrations ranged from 21 – 61 mg/L nitrate-N and illustrate the challenges of meeting drinking water standards even when fields are being optimally managed. Mean total phosphorus measurements from filtered samples averaged 0.003 – 0.013 mg/L; in these particular fields it does not appear that there is significant transport of phosphorus to groundwater. Mean chloride concentrations ranged from 14 - 42 mg/L. Chloride is often considered a complementary tracer for studies investigating nitrate and its inclusion in studies is useful for providing additional insight into water drainage and solute leaching.

When the location of a sampling grid is sufficient to avoid intrusion of groundwater from adjacent fields, a sample size of 6-10 should be adequate to characterize water quality with respect to nitrate below a 10-acre field of similar soil characteristics with 95% confidence. Based on the mean and standard deviation of the nitrate concentrations measured in samples collected in Dec. 2014 from two different fields, between 9 and 30 samples was determined to be the minimum sample size needed to detect a 20% difference in concentrations between treatments with a Type I error rate of 0.10 and Type II error rate of 0.80.

Discrete sampling shows promise for evaluating groundwater quality below different cropping systems and management practices. When changes in land management are planned, random sampling of the water table is a cost-effective and unobtrusive method for establishing a baseline of groundwater quality. Performed before and after major landscape alteration (ex. grassland/forest to agricultural field) this type of sampling has the ability to assess changes in groundwater quality below a particular land-use without the need for permanent infrastructure. In situations where both a control and treatment effect can occur side by side in a field, this approach shows promise for comparing treatment effects when appropriate sample sizes are used.

INTRODUCTION

Non-point source pollutant inputs are the most widespread contributors to ground and surface water, affecting the drinking water resources and the biotic integrity of many of the nation's water bodies (USEPA, 2009; USGS 2010). The relation between agriculture and nonpoint pollution is well established, and the contribution of pollutants from agricultural lands is significant. While nitrogen fertilizers and other nutrient sources (e.g., manure, bio-solids, and legume credits) are valued for their ability to increase crop yields, a portion of nitrogen applied through these methods leaches to groundwater as nitrate becoming a contaminant for other sectors of society.

Nitrate is widely recognized as the most pervasive contaminant in Wisconsin groundwater. Wisconsin scientists have been interested in nitrate occurrence in Wisconsin groundwater for at least 45 years. Schuknecht et. al. (1975) conducted surveys of nitrate-N in private wells in the late 1960s and early 1970s and found that over 9% of approximately 6,000 randomly-selected wells statewide exceeded the 10 mg/L enforcement standard (ES), in Dane, Columbia, Rock, Iowa, Pierce and Dunn counties the number was greater than 20%. These finding from 45 years ago are strikingly similar to the results of more recent sampling programs in Wisconsin. A 2007 DATCP statewide survey of agricultural chemicals in Wisconsin groundwater showed that an estimated 56% of private wells in the state have a detectable level of nitrate-N (DATCP, 2008). Statewide surveys conducted in 1994, 1996, 2001, and 2007 have estimated 9-14% of private wells in the state exceed the 10 mg/L nitrate-N drinking water standard. The 2007 survey also found that in areas with >75% of the land cultivated for agriculture, 21% of the private wells had nitrate-N levels above 10 mg/L.

Increased nitrate concentrations have significant impacts far from the pollution source. Many rivers and streams are supplied by base flow from groundwater aquifers recharged from agricultural lands. Increased nitrate-N fluxes from groundwater dominated streams has contributed to a doubling of the nitrate-N concentration and a tripling of the nitrate-N flux in the Mississippi River since 1960, where the loading of nutrients from primarily Midwestern states has been linked to worsening hypoxic zones in the Gulf of Mexico (Bratkovich, 1994; Goolsby et al., 2001). From 1980 to 2010, the largest percentage increase in flow-normalized nitrate flux and nitrate concentration at monitoring sites along the Mississippi River occurred at Clinton, IA;

Wisconsin represents a significant portion of this particular sub-watershed (Murphy et al., 2013). Since 57% of the N input to the Mississippi River has been attributed to agriculture, the Chief of the EPA Water Office requested a multi-agency White House committee to review, research, and recommend management steps to reduce N fertilizer use (Kaiser, 1996). States, including Wisconsin, are currently developing nitrogen reduction strategies and recently revised NRCS 590 Practice Standards to come up with strategies that reduce nitrogen leaching risk.

While important questions remain about the implementation and compliance of nutrient management plans over the long term, it is often stated that "Nutrient management planning is one of the best practices farmers can use to reduce excess nutrient applications to their cropland and the water quality problems that result from nutrient runoff to lakes, streams and groundwater" (DATCP, 2013). Wisconsin has a total of about nine million acres of cropland. DATCP estimates that 1.9 million acres of the total cropland acres are currently under a nutrient management plan. Since the recent adoption of state standards, expanded training opportunities, and enhanced cost-share funding, Wisconsin farmers are adopting nutrient plans at an increasing rate. From 2007 to 2008, acres covered by nutrient management plans increased by 60%. Even so, nutrient management plans are in place on only about 26.4% of crop acres in Wisconsin as of November 2013 (DATCP, 2013).

Nitrogen application recommendations for Wisconsin are based on yield studies on various soils with the goal of optimizing economic yield (Laboski and Peters, 2012). Nitrate leaching to groundwater has not been a consideration for setting nitrogen application rates. Some studies suggest that even with the best possible management practices for optimal crop production, the concentration of nitrate-N in drainage water from fertilized agricultural land is often two times or more greater than the nitrate drinking water standard (Andraski et al., 2000; Jemison and Fox, 1994; Kraft et al., 1999). An extensive eleven-year study was performed in Minnesota that showed nitrate losses to tile-drained water, in order of most to least, were continuous-corn, corn-soybean, alfalfa, and conservation reserve program land (Randall et al., 1997). Demonstrating through on-farm research what typical baseline nitrate concentrations can be expected for a given region and under well managed fields is important for the modeling of water quality, setting of achievable goals and prioritization of nitrogen reduction strategies.

An extensive review of management strategies aimed at nitrogen reduction shows varying degrees of effectiveness within proposed strategies (Iowa Nutrient Reduction Strategy, 2016). Those practices which are easiest to implement (i.e. use of nitrification inhibitors, timing, etc.) generally show the lowest potential for reducing nitrate leaching losses. While cover crops showed moderate potential for reducing nitrate leaching losses, there was variable effectiveness measured among the studies and it's not clear the studies are representative of Wisconsin's climate. More research is needed before stating such practices will achieve the same level of reduction in real world settings and under variable site and climatic conditions found throughout the midwest.

Much of the research related to nitrogen impacts to groundwater has been performed on tile-drained fields, but less is known about well-drained soils common to Midwestern agricultural soils and subsequent impacts to groundwater. Understanding the impact current agricultural practices have on groundwater can be challenging. The most obvious are that land uses are always changing, groundwater is always moving, the types of crops grown each year is variable and not well documented, and accounting for commercial N, biological N and nitrogen cycling within the system is difficult. There are also limitations with the various methods and instrumentation that have previously been used to study this issue.

Randomized small-scale block designs are popular and effective research methods for soil fertility research. One benefit of the small plot study approach is that it allows for a large number of treatments and replication on small areas. The approach also facilitates statistical comparisons and interpretation. However, small plot research has been limited in its ability to measure and monitor effects of agricultural practices on groundwater.

Some previous studies of nitrogen management have relied on suction cup samplers to assess water drainage below agricultural systems. By applying suction to a ceramic cup that is greater than the matric potential or tension of the surrounding soil, these devices are capable of sampling soil pore water. Suction cup samplers lack the ability to relate water volume collected to a unit area. While these sampling devices may be useful for measuring nitrate concentrations in the soil profile during the growing season, they are not reliable methods for quantifying cumulative nitrate leaching loads below the root zone (Wang et al., 2012). Reasons why suction cup samplers are not preferred monitoring equipment for groundwater investigations are 1) that they typically are only installed and sampled during the growing season, missing perhaps the most critical time of groundwater recharge following harvest and prior to planting, and 2) concentrations of nitrate in soil-pore water during the growing season can be vastly different than water drainage that ultimately ends up in groundwater (includes both gravitational flow and matric potential flow).

Investigating the impacts of nitrogen inputs to an optimally fertilized corn field and subsequent impacts to groundwater quality has been investigated previously in Wisconsin. Masarik et al. (2014) in work on nitrate leaching at the Arlington Research Farm, WI (silt loam soils), found that an “optimal” application of 170 pounds of nitrogen to corn produced flow weighted mean nitrate-N concentrations of 9.6 and 13.3 mg/L for chisel-plow and no-tillage treatments from lysimeters installed 1.4 meters below the soil surface over a 7-yr period. For that same period the flow-weighted mean nitrate-N concentration below a restored prairie was only 0.04 mg/L. A key finding from this study was that nearly 60% of annual water drainage and approximately 75% of annual nitrate leaching losses occurred during a three-month period from April 1 to June 30 (Masarik et al., 2014). If not for having 7-yrs of data the study may have been limited in its ability to make conclusions regarding nitrate losses. Because of the cost associated with manufacturing, maintenance and sampling of the lysimeter network, each treatment only had two replicates. The large variability between replicate measurements meant that annual results of nitrate leaching losses and nitrate concentrations below corn treatments and the restored prairie often lacked strong statistical evidence even though large differences between treatments were clearly observed. Additional treatments added the last two years studied the effects of excess nitrogen in the form of manure on top of nitrogen applied at optimal levels as commercial fertilizer. Flow-weighted mean nitrate concentrations below excess manure treatments were more than 2.5 times those plots receiving optimal nitrogen (Norman, 2003), but again the strength of statistical evidence was limited because of the small number of replicate measurements and large variation.

Another project in Wisconsin investigated nitrate concentration differences in groundwater below potato plots receiving conventional fertilizer and others receiving polymer-coated urea fertilizers (Bero, 2012). Triplicate 15 m x 15 m plots were established and three groundwater monitoring wells were installed in each plot. Using a bromide tracer they were able to determine that water-table monitoring wells were able to detect initial arrival of drainage at the water table at 7 m below the land-surface, months after the tracer was initially applied. Researchers indicated that interpretation of nitrate concentrations from these wells was confounded by 1) high variability of groundwater nitrate inherent to the agricultural field itself and 2) the influence of groundwater flow or drainage from outside plot boundaries as evidenced by evidence of the tracer in adjacent plots that did not receive bromide. Many groundwater investigations like these would benefit from a better understanding of the variability of groundwater nitrate concentrations below agricultural systems of various soil types.

In addition to the challenges associated with statistical interpretation of water quality data from small-plot research, there are also logistical challenges that can sometimes confound results from these studies. Establishing representative field conditions to study cover crops, manure spreading, tillage, fertilization, etc. can be difficult at a plot scale. Using large farm implements (i.e. tillage, fertilization, manure spreading, planting and harvesting equipment) in small plots while also trying to avoid delicate installations of monitoring wells or buried lysimeters often means making accommodations (hand spreading/planting or tillage) that are meant to simulate but may not accurately reflect conditions in a working field.

Developing approaches to monitor water quality below working fields has advantages to small-plot research but can be wrought with both perceived and logistical challenges. Producers do not like the idea of sacrificing part of a field for equipment like monitoring wells or lysimeters. Farmers prefer the flexibility of performing activities like tillage, planting or harvesting when time and weather permit. They also generally want to retain control over what they decide to plant in a given season depending on the weather and other on the ground factors. All of these things can make the idea of participating in on-farm research unappealing, even if the producer is otherwise supportive of the research. Therefore, developing research strategies that avoid some of these challenges may increase opportunities to measure groundwater quality on working farms.

PURPOSE

This study investigated the utility of a field-based approach for the evaluation of nitrogen management strategies and effects on nitrate concentrations in groundwater. We set out to 1) characterize spatial variability of groundwater nitrate below agricultural fields 2) evaluate seasonal differences in nitrate concentrations at the top of the water table (fall versus spring). 3) provide an evaluation of sampling numbers needed to characterize spatial variability and 4) describe the advantages/disadvantages of using of a geoprobe versus bucket auger for collecting water samples. Objectives 3 and 4 were not in original proposal but are potentially useful for others to consider when designing studies investigating the effects of agricultural practices on shallow groundwater.

METHODS

Study Site

Two fields were selected from a farm located just south of Plover, WI. Soil series of sample locations are classified as Friendship loamy sand (Mixed, frigid Typic Udipsamments). Field A and Field B are approximately 80 and 35 acres respectively. In 2014, Field A was planted in potato while Field B was planted with peas followed by a pearl millet cover crop. Both fields are in a rotation generally consisting of potato – sweet corn – field corn – peas/pearl millet. Rates of nutrients applied are reported for each field based on crop type for years 2012-2015. Application rates used by this farm are consistent with university recommendations for optimal yield (Table 1).

Table 1. Summary of crop rotations and nutrient/element inputs.

	Potato	Field Corn	Sweet Corn	Peas/Pearl Millet
Field	**Year**			
A	2014	2015	2012	2013
B	2015	2012/2013		2014
Nutrient/Element	**lb ac^{-1}**			
Nitrogen	231	206	143	15
Phosphorus	0	31	31	2
Potassium	149	40	40	35
Sulfur	162	0	0	0
Chloride	141	29	29	29

Twenty sample locations were selected from each field using a modified random grid sample design. A ten-acre grid pattern consisting of 20 cells further subdivided into 9 smaller cells was placed within Fields A and B. A random number generator (1-9) was used to select one sample cell from each of the 20 large cells. This approach allowed for spatial distribution across the ten-acre study plot and the ability to evaluate if there was any obvious spatial dependence among the samples. Groundwater flow direction was determined to be from north to south and was considered in placement of the sampling grid. The plot was intended to provide an adequate buffer to avoid possible intrusion of groundwater from an adjacent field, thus providing confidence that water table samples represented in-field recharge. Assuming a groundwater flow rate of 1 ft/day, the placement of the grid was more than adequate to ensure water sampled recharged within the field being investigated. The sample grid was imported onto an aerial photo of the study fields and geographic coordinates of sample locations were obtained using ArcGIS.

In Fall 2014 and Spring 2015, a Geoprobe System® direct push system for groundwater sampling (http://geoprobe.com/sp16-groundwater-sampler) was used to access the top portion of the water table for sampling. The 4-ft screen was set at a depth which intersected the water table and a polypropylene tube inserted into the geoprobe allowed for the collection of water samples from the top portion of the water table. Discrete water table sampling in Fall 2015 and Spring 2016 was performed using a bucket auger to access the water table. A 1-inch pvc with a 4 ft screen was inserted into the hole and a polypropylene tube inserted into the temporary well was used to collect water samples.

Water samples for chemical analysis were collected using a peristaltic pump. Following sample collection, the boreholes were filled with bentonite and properly abandoned. Samples for were filtered back at the laboratory. Samples for nutrient analysis were acid preserved with H_2SO_4, samples for metals were acid preserved with HNO_3, and samples for pH, alkalinity and conductivity were unpreserved. All samples were stored at 4 degrees Celsius until the time of analysis.

In December 2014, one soil core was collected from Field A and one from Field B for the purposes of understanding the vadose zone and accurately locating the water table. Following the collection of the soil core, a temporary well was installed in Field A and one in Field B that allowed for monthly samples to be collected over period from December 2014 through April 2015. Wells were purged prior to sample collection. These temporary wells were removed and properly abandoned in April prior to planting so as not to obstruct any agronomic field operations.

Sample Analysis

All samples were analyzed at the UW-Stevens Point Water and Environmental Analysis

Laboratory. The lab has a formal quality control program in place and holds certification from the Wisconsin (DNR State Certification Lab No. 750040280) and United States Geologic Survey for a wide-array of elements and matrices. Among the practices that the laboratory employs are periodic analyses of laboratory reagent blanks, fortified blanks, duplicate samples, and calibration solutions as a continuing check on performance.

Nitrate-N and chloride were measured colormetrically by flow injected analysis on a Lachat QuikChem 8000. Arsenic, lead, copper, zinc, calcium, magnesium, iron, manganese, potassium, sulfate, phosphorus, sodium were measured by inductively coupled plasma optical emission spectroscopy (ICP-OES). Alkalinity was measured by titration while probes were used to measure laboratory pH and conductivity.

Data Analysis

The statistical software R was used for basic statistical summaries (mean, median, standard deviation, standard error, coefficient of variation) while SAS was used for the determination of ANOVA tables and calculation of Least Significant Difference values.

The sampling in December was extensive from within the 10-acre study location (n=20). The large number of samples from each field was used as the basis for assessing variability in the context of experimental design. The R programming language was used to generate 10,000 random simulations from each of the fields in the December 2014 datasets. Simulations were conducted using a sample number of ranging from 2 to 19. The simulation mean, standard deviation and standard error were evaluated against the 95% confidence interval of the original dataset.

A power analysis was performed to provide sample size guidance for future experiments. The goal is to improve quantification of nitrogen reduction management strategies and their ability to reduce nitrate concentrations in groundwater. Sample means and standard deviations from fields for each date were used to demonstrate how many samples would be needed for a comparison of means. Nitrate-N data was utilized for this analysis since reduction of nitrate below agricultural fields is of greatest interest to the objectives of this project.

Table 2. Summary of water quality for various parameters collected from fields for respective dates.

		n	NO_3-N	Cl	Conductivity	Alkalinity	pH	Ca	Mg	Na	K	S	P	Fe
			-----mg L^{-1}----		umhos/cm	mg L^{-1} $CaCO_3$		-------------------------mg L^{-1}-------------------						
Field A	12 Dec 2014	20	40(1)a	42(1)a	682 (16)	55 (9)	7.1 (0.1)	71 (3)	27 (1)	10 (<1)	28 (1)	74 (3)	0.003 (<0.001)	0.022 (0.003)
	3 Apr 2015	10	38(2)a	41(2)a	-	-	-	-	-	-	-	-	-	-
	2 Nov 2015	10	37(1)a	30(4)b	-	-	-	66 (3)	23 (1)	8 (<1)	24 (1)	89 (5)	0.013 (0.007)	0.039 (0.012)
	11 May 2016	10	21(2)c	14(2)c	-	-	-	-	-	-	-	-	-	-
Field B	5 Dec 2014	20	61(4)b	25(1)b	951(35)	163(11)	7.6 (0.1)	99 (4)	41 (2)	14 (<1)	25 (1)	80 (5)	0.007 (0.002)	0.009 (0.001)
	3 Apr 2015	10	54(3)b	29(2)b	-	-	-	-	-	-	-	-	-	-
	2 Nov 2015	4	61(9)b	29(3)b	-	-	-	104 (8)	33 (2)	12 (3)	18 (3)	73 (10)	0.006 (0.002)	0.045 (0.023)
LSD			9	6										

Values within each column followed by the same letter are not significantly different based on Fisher's least significant difference (LSD) at the 95% confidence level. Standard error in parentheses.

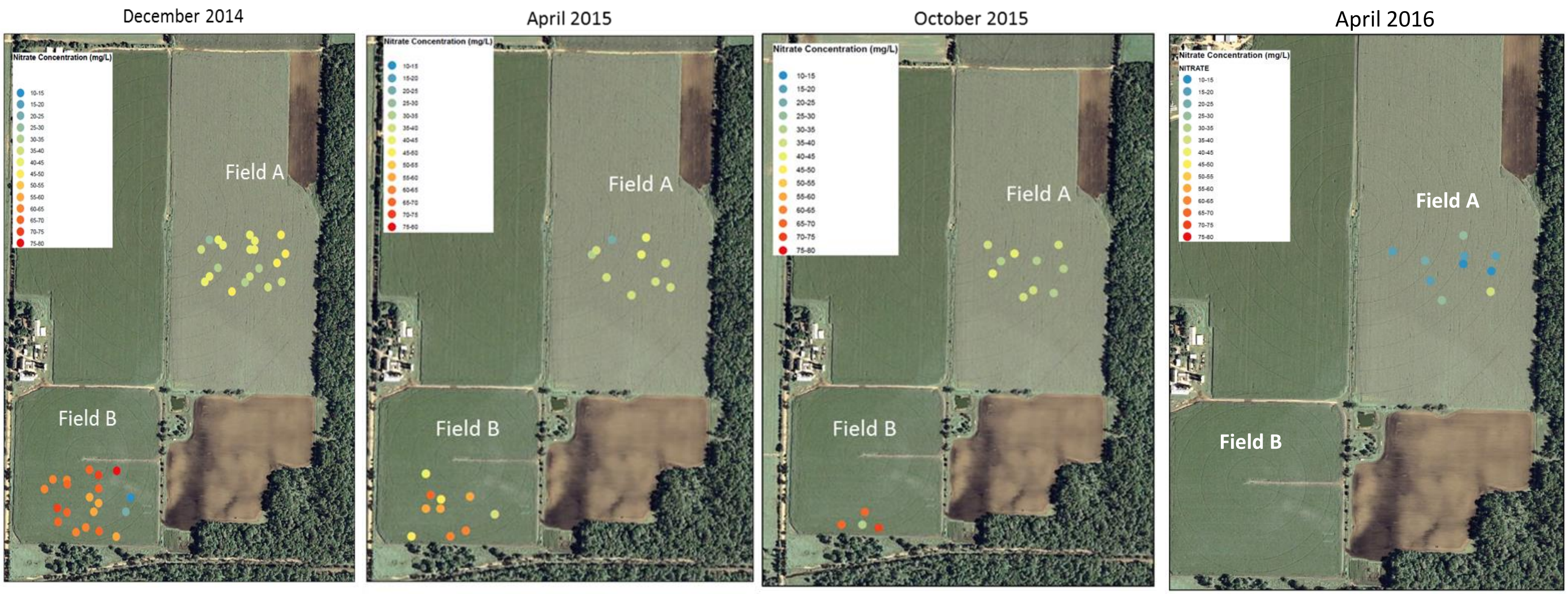


Figure 1. Location of samples and respective nitrate concentrations measured at the water table for each sampling period. General aerial photo, crop types are not representative of time periods.

Sample size was calculated using a power of 0.80 (probability of correctly finding an effect that is there) and Type I error rate (probability of finding an effect that is not there) of 5% for a 2-sample, 2-sided equality comparison (HyLown Consulting, 2016). The measured mean and standard deviation were used as an approximation of sample distribution. Measured mean and estimated means representing differences of 10, 15 and 20% were used to calculate sample size with an assumed sample size ratio of 1. These differences were chosen with the assumption that 10% is the minimum level of reduction needed to consider investment of time and resources into management strategies.

RESULTS AND DISCUSSION

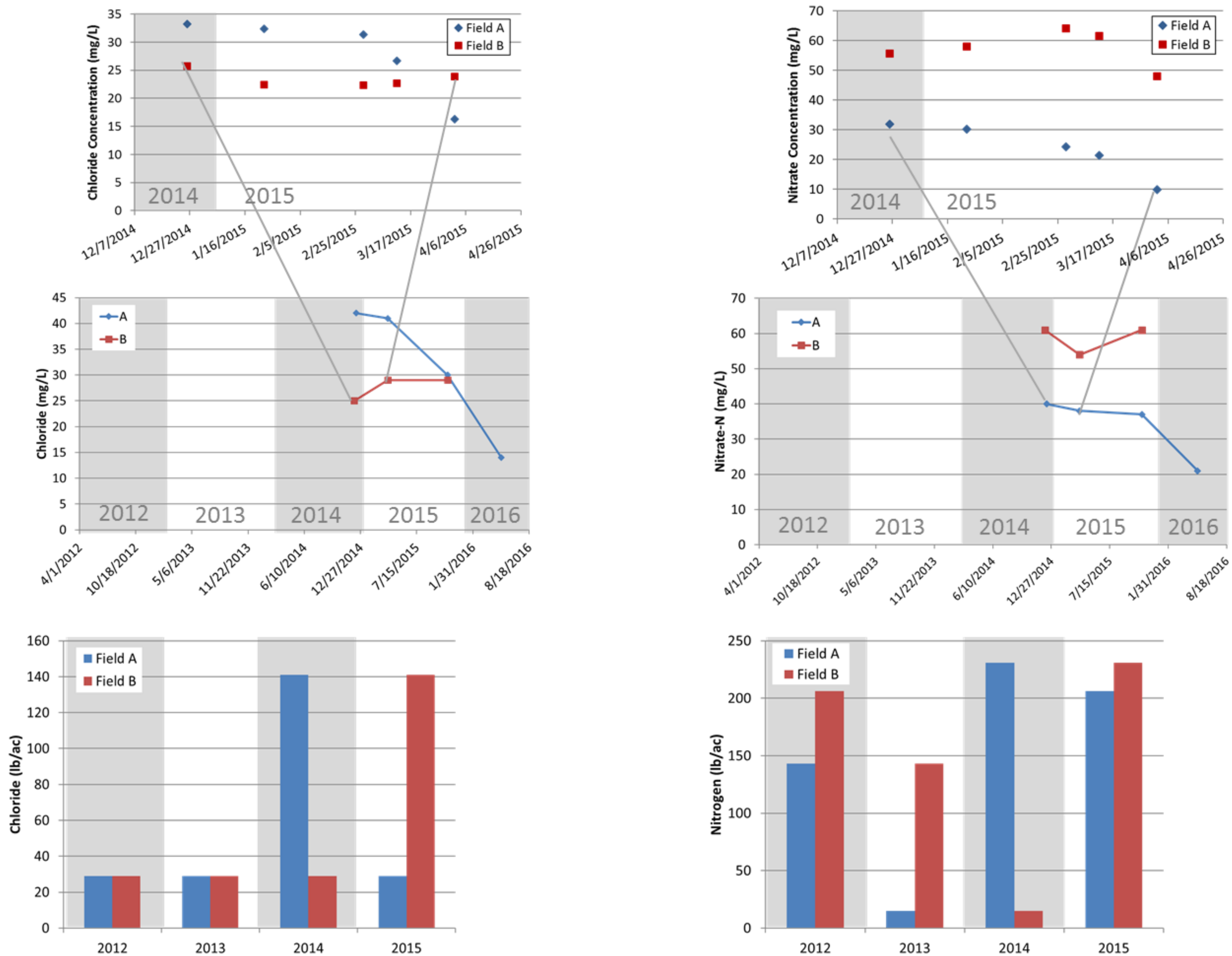
For those periods when both fields were sampled, mean values of nitrate, conductivity, alkalinity, pH, calcium, magnesium were less in Field A than those found in Field B; while only chloride was initially lower in Field B (Table 2). Mean nitrate-N concentrations were stable in both fields for the first three periods. Only Field A was sampled in May 2016, but the nitrate concentrations were noticeably lower than previous sample events (Figure 1). Results show that mean concentrations ranged from 21 – 61 mg/L nitrate-N, illustrating that optimal application rates are unlikely to result in groundwater quality directly below irrigated agricultural fields that meets drinking water standards.

Chloride decreased significantly between the Apr 2015 and Nov 2015 sampling events which likely reflects reduced chloride inputs in 2015 versus 2014. On fields were chloride applications are significantly different from one year to the next, chloride concentrations are a useful tracer that can provide additional context to groundwater nitrate concentrations.

Without additional years of data, deciphering out the effect of rotation on nitrate from such a limited time period is challenging. Questions remain whether differences in water table water chemistry between fields is solely the result of nutrient application rates and crop type, or whether there are other controls that are affecting nitrate concentrations. For instance, subsurface redox features observed at the ~6 ft depth in soil cores of field A could indicate a greater capacity for denitrification of nitrate during transport through the vadose zone resulting in lower groundwater nitrate. Alternatively, Field B soil cores visually indicate more prominent organic matter in the A horizon that could be contributing to greater mineralization rates. More detailed investigation of the subsurface would assist in sorting out some of these differences. Any research into management practices to reduce nitrate leaching losses to groundwater should consider the role of other variables in the vadose zone and have a plan in place to account for these factors. Failure to do so could mistakenly attribute differences in nitrate solely to management practices when there may be other contributing factors.

Limited data exists on the transport of phosphorus from agricultural fields into groundwater. Total phosphorus measurements from filtered samples averaged 0.003 – 0.013 mg/L. These measurements provide insight into phosphorus concentrations below agricultural fields in a well-drained loamy sand. In these particular fields it does not appear that there is significant transport of phosphorus to groundwater below these fields. Additional data should be collected from fields were manure or other bio-solids containing significant phosphorus are applied to understand the mobility of phosphorus from different sources.

Figure 2. Monthly chloride and nitrate-nitrogen concentrations in temporary wells for period from 26 Dec 2014 to 3 Apr 2015 (top). Average chloride and nitrate-nitrogen concentrations of discrete water table samples collected from Fields A and B for Dec 2014, Apr 2015 and Nov 2014 sampling periods (middle). Nitrogen and chloride applications to fields A and B by year (bottom).



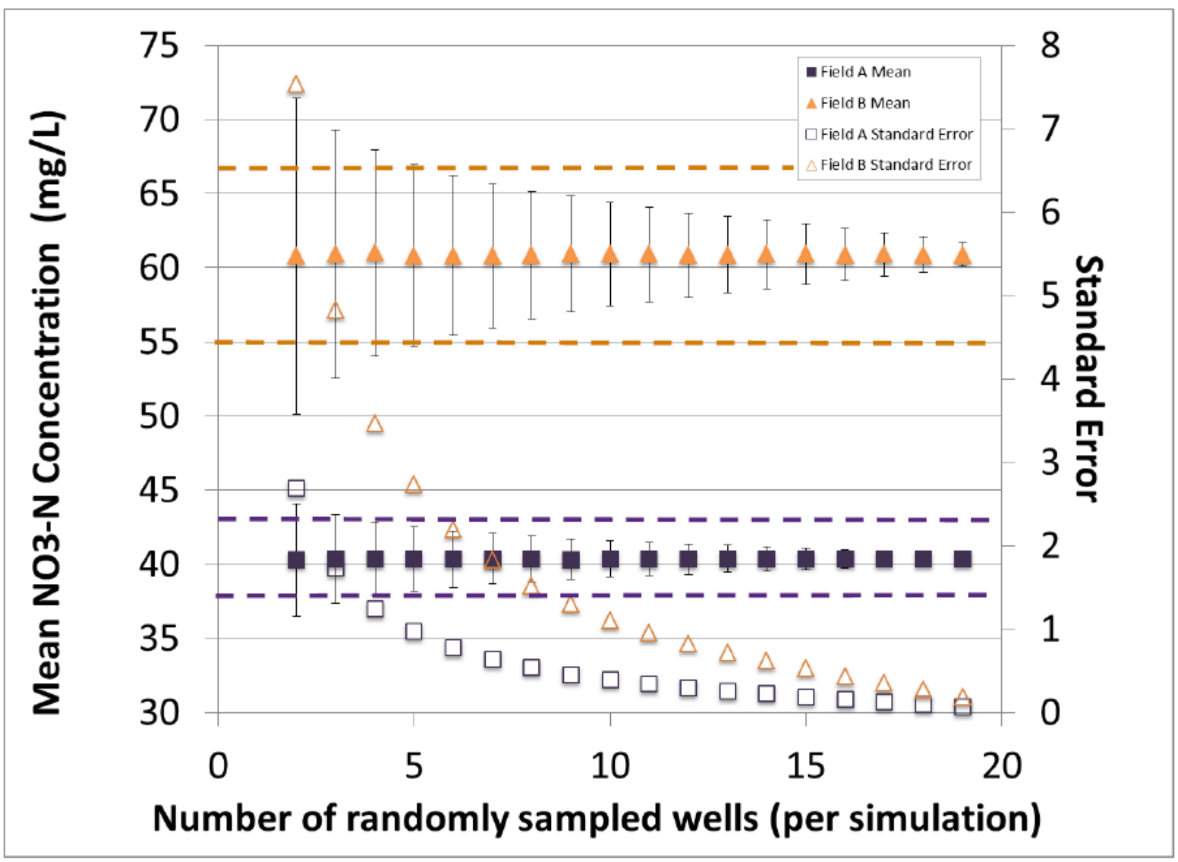
A temporary well installed in Field A showed fairly stable concentrations of nitrate and chloride until March when a sizable decrease in both analytes was observed. The magnitude of the decrease observed in the temporary well was not representative of observations at the field scale. The well in Field B remained relatively steady for chloride, while nitrate showed an initial rise followed by a small decrease for the last sample date (Figure 2). The change in water quality measured in the temporary wells did not always agree with the average from the discrete in-field water table sampling. This could be because of focused recharge or preferential flow near the well or in the materials that the well was located in. Here the discrete sampling helps to more broadly characterize water quality and avoid water quality results being overly influenced by a small number of well locations that may or may not be representative of what is occurring at the field scale. This study originally did not intend to go beyond the spring 2015 sampling period or considerations would have been made to monitor in-field wells during the growing season.

For future applications, sample timing is a critical question. Sampling using the geoprobe can only be performed when there is no actively growing crop in the field or there will be obvious damage of that year's crop. This leaves the post-harvest period to just prior to planting for sampling the water table using this type of approach. Ideally one would consider sampling both post-harvest and pre-planting however cost can be an impediment. If only one sampling can be performed during the year and the intent is to characterize the overall impact of management practices from a particular growing season, then sampling in spring prior to planting/fertilization is the preferred time. Sampling after spring recharge offers an opportunity to account for water volumes that in most years would be expected to have a significant impact on overall groundwater quality. Significant carryover of nitrogen can occur from one growing season into the following spring. Particularly in a dry growing season, sampling immediately after harvest will not accurately capture the full impact of management practices from that growing season on groundwater quality. Waiting until spring offers the best opportunity to account for the lag time that can occur with nitrate leaching from the profile and account for all water drainage to groundwater, not just that which occurs during the growing season. Waiting longer to sample is not practical because water quality is under the influence of different management practices once the following years crop has been planted and fertilizer spread. Sampling just prior to planting/fertilization/etc. also provides a convenient break point to separate one year's activities to the next.

Confidence in mean concentration

The random simulations performed on the datasets collected in December 2014 show the effect of sample number on standard deviation and confidence in the mean (Figure 3). For the analysis it was assumed that the mean of the 20 samples collected from within a ten-acre portion of each field represented the best estimate of the actual mean groundwater concentration below that field. The 10,000 random simulations performed for each sample size provide insight into the effect of sample size and our confidence that the mean will be representative of a particular field. Using the sample mean and standard deviation of Field A, the random simulations reveal that a minimum of 5 samples are needed in order to estimate a mean for which the standard deviation of the simulations is within the 95% confidence interval of the actual mean (n = 20). Performing the same simulations using the sample mean and standard deviation of Field B which had greater variability suggested that a minimum of 6 samples are required.

Figure 3. Data from Fall 2014 was used to investigate the effect of sample number on mean and standard error. Left axis displays the simulation mean (error bars represent standard deviation). Right axis shows the relationship between sample number included in each simulation to standard error. Dashed lines represent the 95% confidence interval for the mean of Field A and B.



When establishing a baseline groundwater quality of a land management activity in a particular field, this analysis suggests that 5-10 samples is generally adequate to characterize a field. In fields where nutrient applications/crop may vary widely from year to year, multiple years of measurements would be needed to understand the overall effect on the rotation. Because soil characteristics and other field properties are variable from field to field, it would also be useful to replicate on additional fields and additional years of climatic variability.

Analysis of sample size

Results of sample size calculations vary with the magnitude of the difference that is of interest and standard deviation of dataset. Field A nitrate concentrations reported smaller standard deviations than Field B. If an experiment were to be conducted solely in Field B where half of the field served as a control and treatment was applied to the other half, a greater number of wells would be needed to achieve the same level of confidence in hypothesis testing than if conducted on Field A. Cost and time will almost always be the limiting factor for sample size; however some consideration should be given to the question of sample number upon initial experimental design. For instance, what is the minimum difference that can be detected reliably or how confident can we be that the mean is reflective of the actual mean? In the absence of preliminary data this information serves as guidance for future experimental design.

Table 3. Sample size (n) estimates to detect respective percent difference in mean nitrate concentrations (μ), power and Type I error rate assumptions for two fields using mean and standard deviation from an extensive sampling event (n=20).

Field	Sample Date	Mean (μ_A)	St. Dev	$\mu_{10\%}$	Adj. St. Dev	$n_{10\%}$	$\mu_{15\%}$	Adj. St. Dev	$n_{15\%}$	$\mu_{20\%}$	Adj. St. Dev	$n_{20\%}$
		mg L^{-1}		mg L^{-1}		n	mg L^{-1}		n	mg L^{-1}		n
Power (1-β) = 0.80, Type I Error Rate (α) = 0.05												
A	**12 Dec 2014**	40.4	5.6	36.4	6.2	**38**	34.4	6.4	**18**	32.3	6.7	**11**
B	**5 Dec 2014**	60.9	15.7	54.8	17.3	**127**	51.8	18.0	**62**	48.7	18.8	**38**
Power (1-β) = 0.80, Type I Error Rate (α) = 0.10												
A	**12 Dec 2014**	40.4	5.6	36.4	6.2	**30**	34.4	6.4	**15**	32.3	6.7	**9**
B	**5 Dec 2014**	60.9	15.7	54.8	17.3	**100**	51.8	18.0	**49**	48.7	18.8	**30**
Power (1-β) = 0.70, Type I Error Rate (α) = 0.10												
A	**12 Dec 2014**	40.4	5.6	36.4	6.2	**23**	34.4	6.4	**11**	32.3	6.7	**7**
B	**5 Dec 2014**	60.9	15.7	54.8	17.3	**76**	51.8	18.0	**37**	48.7	18.8	**23**

This exercise suggests a minimum threshold of 10% reduction in nitrate concentrations is challenging due to the large number of samples needed to detect differences at this level. Less samples are needed if the goals of the experiment are relaxed; accepting less power or greater Type I error would allow for a smaller sample size to meet the stated criteria. Or if the objective is to determine the reduction potential of certain management practices, accepting a minimum difference threshold of 20% rather than 10% requires one-third the number of samples for a power of 0.80 and Type I error rate of 5% (Table 3).

Sampling Method

Two different methods were used to sample the water table. Initial sampling was conducted using a geoprobe while the final two sample periods relied on a hand auger. Both were successful in collecting samples, however each has advantages and disadvantages that are important to consider when designing an experiment and planning a budget.   Table 4 summarizes the two sampling techniques for a loamy sand where the water table was between 8 – 12 feet below the surface.

Time needed to collect a sample was not dramatically different between methods. Using a Geoprobe® approximately 5 minutes was needed to set the screen of the geoprobe while sample collection, including purging of the well added approximately 10 minutes for a total of 15 minutes per sample location. Hand augering while more labor intensive was accomplished in approximately 10-15 minutes time resulting in a total time of approximately 25 minutes including sample collection for a one-person crew.

(Left) Contracted services for use of Geoprobe®. With the water table at ~10-12 feet contractors were able to collect samples from 20 locations per day.

(Right) Bucket auger was also utilized to access the water table. Although more time consuming, it's easier to characterize changes in vadose zone materials and locate the water table.

Cost was a major difference between the two methods. Cost will vary depending on depth to water. If not setting a well and just collecting a water sample, the geoprobe accounted for approximately three-quarters of the cost (geoprobe + sample analysis) of each sample.

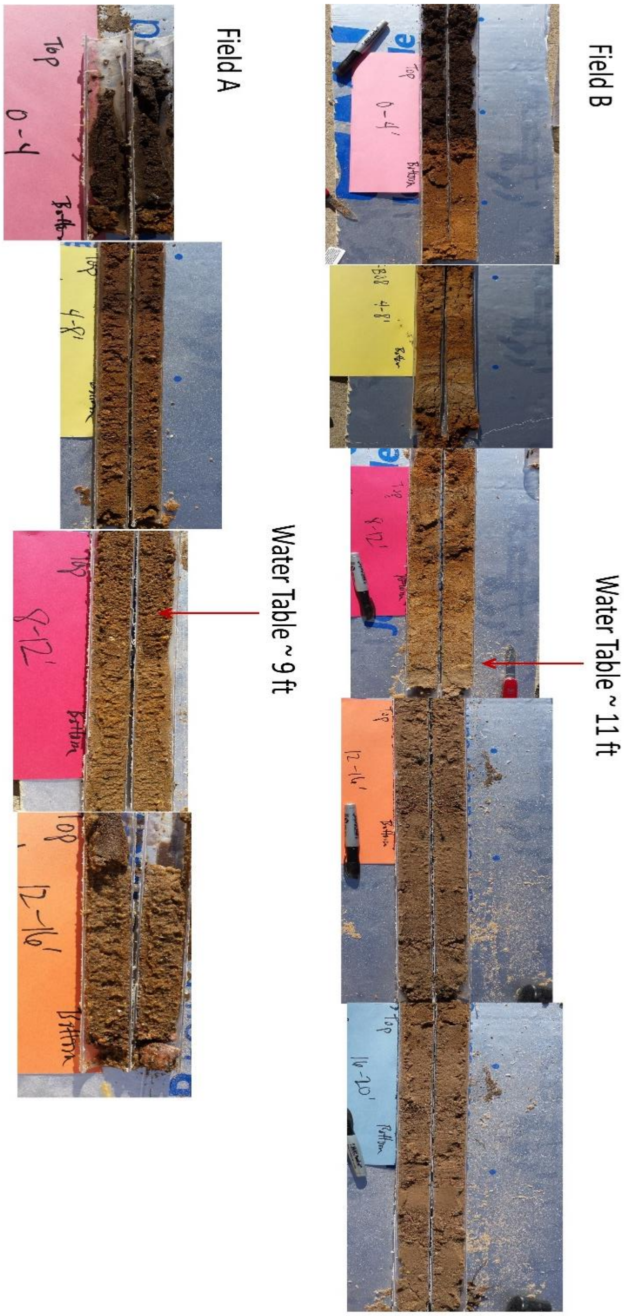
Also important to consider is whether characterization and collection of sediment from the vadose zone is important and how to accomplish this. Depending on the level of detail needed, one method may be preferred. Soil cores can be collected using the geoprobe for an additional expense. An intact core can be collected and saved for analysis at a future date. Collecting core also allows for an accurate measurement of the water table depth. However, using the direct push probe method with the Geoprobe® does not allow for characterization of the vadose zone; and does not allow for easy location of the water table prior to setting the screen. For relatively flat fields locating the water table may be accomplished by setting the screen to the same depth; more variable fields may complicate efforts to locate the water table for the purposes of collecting a discrete soil sample. There is a certain trial and error that goes along with setting the screen so that it crosses the water table but not set into it.

Manual augering allowed for observation and characterization of the vadose zone for each sample location. Differences in texture and other visual cues are easily observed and can be documented. Sediment can be collected from each depth for analysis of a variety of parameters at a later time. Identifying the water table depth for collecting discrete water samples was also straightforward for each location. Refusal with the bucket auger was encountered in a few locations (large cobbles or gravelly lenses), which forced the hole to be abandoned and started over at an adjacent location. However, the majority of locations were sampled with little difficulty which may not be typical of other locations. Manual augering in fine-textured soils or areas where the water table is greater than 15-20 feet may limit the utility of this approach.

In settings where you can expect to encounter coarse textured soils and shallow water table (<20 feet), manual auguring can to be a cost-effective and reliable method for investigating water quality. If cost is an issue using a bucket auger holds some advantages over use of a Geoprobe®. While manual augering is more labor intensive it can generally be done in a comparable amount of time and allows for greater characterization of the vadose zone for each location. For sites with finer textured soils, sites with till and other restrictive layers, or when sampling needs to be performed in winter, the Geoprobe® may be the only option.

Table 4. Comparison of geoprobe versus using the bucket auger to obtain water table

Geoprobe	**Bucket Auger**
Time Estimate	
15 to 20 minutes per sample	20 to 25 minutes per sample
Cost	
$5.50 per foot	Labor only
$350 per day for mobilization/travel of geoprobe rig	
Advantages	
Speed, less time per sample	Able to obtain continuous visual and collect samples of soil layers
Sample collection possible when soil frozen	Able to measure water table depth for every sample
Able to take intact soil cores (for additional cost)	Could be done during the growing season
Disadvantages	
Greater cost associated with contracting equipment/labor	Limited to fields with shallow water table (<20 feet)
Unless you take soil core, have to guess at water table depth for each hole	Might not viable option in areas with till or heavy clay
Can't see soil layers unless you take a soil core.	Labor intensive
Equipment can't enter field during growing season	Can only be performed when soil not frozen



(Left) Examples of cores collected from each field using the Geoprobe®. Cores provide good ability to understand the soil profile. Sample can be saved and analyzed at a later date.

(Right) Example of material removed from a location in Field B using the hand auger. Layering not as distinctive as obtaining core, but allows for simple characterization of profile and collection of material.

CONCLUSION

Using a geoprobe or hand-auger to collect discrete water samples from the top of the water table has potential for characterizing water quality and understanding impacts of field-scale agricultural practices on groundwater. The sampling is minimally invasive and unlikely to affect field operations when performed in fall or spring; with spring being the optimal sampling time for assessing the overall impact from the management of the previous growing season.

Variability within the field is an important consideration for any experiment looking to investigate the impact of land-use on groundwater quality. Data collected from two fields suggests that when location of a grid is sufficient to avoid intrusion of groundwater from adjacent fields, a sample size of 6-10 should be adequate to characterize the mean nitrate concentration of a 10-acre field of similar soil properties with 95% confidence.

The approach holds promise for assessing impacts to water quality from a variety of management practices in a cost effective manner. In the absence of long-term monitoring data, it provides a useful tool for quickly characterizing groundwater quality below a variety of land uses. In areas where land-use changes are planned, sampling can be performed before the change and subsequently after the change in order to understand whether there were changes to groundwater quality. These methods may expand and facilitate opportunities to collect information from working farms on important research and monitoring questions.

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APPENDIX A. Individual sample location water chemistry data for all fields and all sample events.

SAMP_DATE	FIELD_ID	FIELD	PERIOD	SITE	NITRATE	CHLORIDE	ALKALINITY	PH	CONDUCTIVITY	AS	CA	CU	FE	K	MG	MN	NA	P	PB	SO4	ZN
12/5/14	B	2	1	1	63.2	29.4	212	7.18	1112	0.007	120.4	0.003	0.015	29.7	54.2	0.038	17.1	0.002	0.001	104.3	0.009
12/5/14	B	2	1	2	63.3	21.5	152	7.55	942	0.006	95.5	0.001	0.010	25.6	44.2	0.106	12.1	0.002	0.001	71.3	0.004
12/5/14	B	2	1	3	69.5	23.9	172	7.86	1011	0.002	111.5	0.004	0.008	21.0	45.8	0.204	14.6	0.013	0.001	80.3	0.006
12/5/14	B	2	1	4	70.8	27.3	112	8.02	947	0.002	98.0	0.005	0.007	24.0	39.5	0.080	13.7	0.028	0.001	76.7	0.001
12/5/14	B	2	1	5	76.7	27	184	8.06	1050	0.002	109.6	0.003	0.009	26.5	46.9	0.205	14.2	0.024	0.001	72.2	0.001
12/5/14	B	2	1	6	63.1	24.5	256	7.3	1187	0.007	121.0	0.004	0.017	30.8	54.1	0.217	19.0	0.002	0.001	121.3	0.004
12/5/14	B	2	1	7	67.4	26.9	108	6.97	962	0.002	98.8	0.002	0.019	24.5	37.6	0.048	14.7	0.010	0.001	96.0	0.013
12/5/14	B	2	1	8	57.6	24.6	112	7.95	894	0.002	92.3	0.001	0.005	23.1	38.6	0.069	10.2	0.002	0.001	63.5	0.001
12/5/14	B	2	1	9	69.6	22.9	108	7.94	933	0.002	95.3	0.003	0.005	22.1	38.9	0.049	11.5	0.013	0.001	62.4	0.001
12/5/14	B	2	1	10	13.4	14.4	292	8.12	516	0.002	53.5	0.004	0.008	22.2	25.0	0.400	6.4	0.012	0.001	35.0	0.001
12/5/14	B	2	1	11	71.1	26.2	204	7.54	1106	0.005	119.2	0.003	0.007	27.9	45.7	0.281	16.1	0.002	0.001	94.7	0.001
12/5/14	B	2	1	12	66	24.1	108	7.2	927	0.002	92.1	0.001	0.006	23.4	39.2	0.053	15.2	0.002	0.001	82.9	0.001
12/5/14	B	2	1	13	59	21.9	124	7.32	897	0.002	94.2	0.001	0.006	24.0	35.3	0.044	16.5	0.002	0.001	92.1	0.001
12/5/14	B	2	1	14	59.2	23.9	128	7.97	875	0.002	86.6	0.002	0.005	26.3	36.7	0.069	11.5	0.002	0.001	64.0	0.015
12/5/14	B	2	1	15	21.2	19.5	212	8.04	608	0.002	59.1	0.003	0.007	21.3	29.2	0.236	7.1	0.002	0.001	46.3	0.001
12/5/14	B	2	1	16	69.6	28.9	164	7.55	1109	0.002	118.5	0.002	0.006	26.7	43.6	0.238	17.8	0.002	0.001	98.0	0.001
12/5/14	B	2	1	17	64.9	23	148	7.88	932	0.002	89.7	0.002	0.007	25.6	38.5	0.160	13.8	0.010	0.001	68.2	0.001
12/5/14	B	2	1	18	64.7	23.4	152	7.52	1025	0.002	105.6	0.003	0.020	26.5	42.2	0.141	20.3	0.012	0.001	108.5	0.007
12/5/14	B	2	1	19	67.8	30.2	152	7.39	1041	0.002	111.1	0.006	0.009	24.5	40.8	0.134	18.1	0.002	0.001	89.3	0.035
12/5/14	B	2	1	20	59.4	25.7	156	7.33	956	0.002	107.6	0.006	0.010	23.1	38.6	1.233	16.3	0.002	0.001	81.5	0.003
12/12/14	A	1	1	1	28.9	42.6	140	7.85	716	0.002	85.9	0.007	0.008	24.9	33.5	0.029	7.9	0.002	0.001	84.1	0.018
12/12/14	A	1	1	2	40.6	40.7	120	7.73	800	0.002	86.0	0.003	0.009	25.6	36.3	0.002	10.9	0.002	0.001	72.5	0.004
12/12/14	A	1	1	3	42.7	43.2	60	6.84	734	0.002	74.8	0.003	0.069	30.1	27.8	0.078	10.6	0.009	0.001	78.7	0.155
12/12/14	A	1	1	4	40.6	46.2	28	6.28	666	0.002	64.9	0.001	0.015	31.7	24.4	0.048	8.5	0.002	0.001	75.7	0.012
12/12/14	A	1	1	5	48.8	41	72	7.4	854	0.004	93.5	0.003	0.020	29.4	36.2	0.042	9.9	0.002	0.001	106.7	0.007
12/12/14	A	1	1	6	39.3	42.8	92	7.83	722	0.002	79.0	0.004	0.011	30.6	32.3	0.046	10.1	0.002	0.001	68.4	0.001
12/12/14	A	1	1	7	41	38.9	56	6.64	736	0.002	72.6	0.004	0.015	31.8	28.4	0.039	12.3	0.002	0.001	93.7	0.008
12/12/14	A	1	1	8	43.6	38.2	40	7.04	712	0.002	76.0	0.003	0.013	27.0	26.0	0.046	9.5	0.002	0.001	88.4	0.006
12/12/14	A	1	1	9	42.7	46	24	6.85	659	0.002	64.5	0.001	0.014	34.4	24.1	0.050	10.9	0.002	0.001	62.7	0.006
12/12/14	A	1	1	10	49.4	54.2	16	6.52	725	0.002	70.4	0.001	0.014	31.9	27.2	0.038	9.9	0.002	0.001	67.0	0.004
12/12/14	A	1	1	11	41.7	43.6	28	6.95	669	0.004	62.3	0.001	0.018	34.5	25.5	0.047	11.0	0.002	0.001	73.8	0.013
12/12/14	A	1	1	12	31.5	46.8	16	6.43	558	0.002	54.5	0.003	0.033	26.6	18.4	0.030	8.6	0.002	0.001	66.8	0.001
12/12/14	A	1	1	13	37.8	35.9	40	7.49	619	0.002	57.9	0.001	0.018	31.5	23.4	0.036	10.0	0.002	0.001	63.4	0.005
12/12/14	A	1	1	14	34.3	35.5	120	8.12	649	0.002	71.2	0.002	0.031	25.8	30.9	0.149	9.1	0.002	0.001	57.3	0.001
12/12/14	A	1	1	15	47.9	31.1	12	6.88	607	0.002	56.9	0.001	0.017	23.5	21.1	0.038	9.1	0.002	0.001	49.1	0.005
12/12/14	A	1	1	16	41.7	46.6	24	6.35	652	0.002	67.1	0.001	0.053	28.6	22.9	0.085	10.5	0.002	0.001	77.3	0.005
12/12/14	A	1	1	17	45.9	40.4	60	7.47	704	0.002	78.8	0.003	0.013	26.6	30.2	0.019	11.0	0.002	0.001	69.9	0.005
12/12/14	A	1	1	18	33.4	35.9	108	7.92	677	0.005	86.5	0.003	0.017	20.3	29.7	0.064	9.6	0.010	0.001	79.1	0.034
12/12/14	A	1	1	19	39.7	34.6	16	6.36	581	0.002	65.6	0.003	0.033	21.6	19.9	0.565	10.9	0.002	0.001	75.6	0.018
12/12/14	A	1	1	20	35.7	55.8	20	6.7	600	0.002	59.8	0.001	0.023	28.7	23.3	0.184	9.6	0.002	0.001	59.9	0.013
4/3/15	A	1	2	1	25	26															
4/3/15	A	1	2	2	43.1	41.2															
4/3/15	A	1	2	3	35	40.4															
4/3/15	A	1	2	4	35.7	43															
4/3/15	A	1	2	5	43.7	41.9															
4/3/15	A	1	2	6	39.4	44.1															
4/3/15	A	1	2	7	38.8	41.9															
4/3/15	A	1	2	8	39.6	43.8															
4/3/15	A	1	2	9	39.2	41.1															
4/3/15	A	1	2	10	38.6	44.1															
4/3/15	B	2	2	1	42.5	22.3															
4/3/15	B	2	2	2	65.1	30.8															
4/3/15	B	2	2	3	48.6	27.5															
4/3/15	B	2	2	4	56.9	27.5															
4/3/15	B	2	2	5	59.7	30.3															
4/3/15	B	2	2	6	57.7	29.7															
4/3/15	B	2	2	7	38.6	21.6															
4/3/15	B	2	2	8	48.1	44.2															
4/3/15	B	2	2	9	61.5	25.7															
4/3/15	B	2	2	10	61.7	27.7															
11/1/15	A	1	3	1	39.1	37.4				0.003	77.0	0.003	0.030	25.5	29.8	0.007	8.4	0.006	0.001	76.6	0.004
11/1/15	A	1	3	2	37.1	1.6				0.008	62.5	0.002	0.010	16.2	19.1	0.179	7.4	0.002	0.001	102.3	0.006
11/1/15	A	1	3	3	30.6	31.5				0.006	72.5	0.003	0.003	21.4	28.2	0.005	7.4	0.013	0.003	75.8	0.003
11/1/15	A	1	3	4	40.3	34.8				0.003	66.4	0.004	0.005	23.2	24.2	0.004	7.6	0.002	0.001	72.8	0.003
11/1/15	A	1	3	5	35	30.1				0.003	58.4	0.003	0.016	24.1	21.1	0.007	8.2	0.002	0.001	78.5	0.001
11/2/15	A	1	3	6	43.4	45.4				0.003	64.5	0.003	0.023	32.1	24.8	0.023	10.0	0.002	0.001	93.5	0.006
11/2/15	A	1	3	7	30.7	27.6				0.003	46.6	0.002	0.046	27.4	17.3	0.021	7.2	0.007	0.003	89.2	0.003
11/2/15	A	1	3	8	36.2	28.3				0.003	67.1	0.004	0.084	23.6	20.7	0.006	7.9	0.010	0.001	95.4	0.002
11/2/15	A	1	3	9	39.3	34.4				0.003	80.5	0.004	0.122	21.1	27.5	0.004	9.1	0.081	0.001	89.9	0.001
11/2/15	A	1	3	10	33.6	29.8				0.003	61.5	0.003	0.058	25.6	19.0	0.090	8.4	0.007	0.001	118.4	0.002
11/2/15	B	2	3	1	74.2	28.6				0.008	126.7	0.008	0.003	11.8	37.8	0.004	13.3	0.002	0.001	75.6	0.001
11/2/15	B	2	3	2	34.6	23.1				0.006	99.3	0.012	0.024	13.5	28.7	0.038	4.5	0.010	0.001	46.4	0.001
11/2/15	B	2	3	3	68.6	27.9				0.003	92.1	0.003	0.152	25.1	31.0	0.004	18.1	0.010	0.001	95.2	0.001
11/2/15	B	2	3	4	66.9	36				0.003	98.5	0.003	0.003	23.4	32.7	0.004	13.7	0.002	0.003	75.7	0.001
4/30/16	A	1	4	1	25.7	22.5															
4/30/16	A	1	4	2	16.8	8.5															
4/30/16	A	1	4	3	24.1	9.9															
4/30/16	A	1	4	4	19.2	14.7															
4/30/16	A	1	4	5	13.7	9															
4/30/16	A	1	4	6	17.9	20.1															
4/30/16	A	1	4	7	13.1	3.9															
4/30/16	A	1	4	8	16.5	10.1															
4/30/16	A	1	4	9	36.5	25.6															
4/30/16	A	1	4	10	25.3	19.9															