National Fish and Wildlife Foundation
Grant Agreement

Final Programmatic Report for:

Subsurface Drainage Water Management to Reduce Manure Contaminated Drain Discharge

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EXECUTIVE SUMMARY

The primary goal of this project was to increase awareness and better address water quality problems associated with land applying liquid manure to subsurface drained lands. The project objectives and phases included a combination of both laboratory- and applied field-based research efforts at EQIP farm cooperator sites to investigate how liquid dairy manure applications may contribute to water quality impairments; and a suite of extension and outreach efforts implemented to include demonstrations of controlled drainage installations, presentations to land improvement contractor professionals, producers and nutrient management planners, Cooperative Extension, Soil and Water Conservation District, and Natural Resource Conservation Service, and development and review of fact sheet publications.

The results of the laboratory-based research with soil columns indicated that liquid manure at a low solids content of 3.5% applied to the soil surface tended to quickly increase the soluble reactive phosphorus load and concentration leached from soil consisting of macropores of 3 mm diameter size in response to a wetting event. The field-based research effort at the EQIP farm cooperator site in New York's Great Lakes Eco-Region where a paired- controlled drainage versus no drainage control field site evaluation was carried out indicated that controlled drainage could reduce the accumulated load loss of phosphorus during a single large storm event by about 10 percent. The reduction, however, was not substantial and the benefit appeared to be offset simultaneously by a somewhat higher loss of total nitrogen. The benefit of controlled drainage for field sites that receive most of their applied nutrients from manure sources appears to require some additional research, particularly with regards to the loss of various organic and inorganic forms of nitrogen. The field-based research effort at the EQIP farm cooperator site in New York's St. Lawrence Champlain Valley Eco-Region showed similar concentrations of nutrients being discharged from the drain as a result of liquid manure applications, but lacking a better paired type control versus uncontrolled monitoring arrangement, few conclusions could be drawn about whether or not there was a benefit with the controlled drain. Any benefit or nutrient load reduction was most likely a result of some reduction in the drain discharge, something the producer was not very pleased with since he pulled the water level control gates out of the structure during one of the larger storm events.

The extension, demonstration and outreach efforts reached a broad array of several hundreds of stakeholders described above as several presentations and discussion of the research was made at a number of different local, state, national, and internationally held meetings. The initial positive impact of this project effort appears to be that producers and nutrient management planners are paying more attention to the liquidity of the manure and how, when, and where it's being applied to drained fields. Producers are more cognizant that the drain effluent may be impaired and are watching it more closely to avoid a potential water quality violation citation. However, perhaps another important lesson learned from this effort is that producers install drainage for the purpose of removing excess soil-water to obtain the benefits of improved field operations timeliness and increased yields, and the nutrients lost in the drain effluent are of minor concern. Thus, further implementation of controlled drainage for the primary purpose of improving downstream water quality will remain an interesting challenge.

SUMMARY OF PROJECT PURPOSE, NEED, AND PHASES

The primary purpose of this project was to better address water quality problems associated with land applying liquid manure to subsurface drained lands. The project combined both laboratory- and field-based research efforts to investigate how liquid dairy manure applications may contribute to water quality impairments. The particular focus of the project was to better understand how liquid manure contaminants, especially phosphorus, may interact with soil macro-porosity which was considered to be an inherent cause for the rapid contaminant transport via preferential flow pathways through soil to subsurface drainage outlets. Given that there are over 600 large and medium sized Confined Animal Feeding Operations (CAFO's) in New York, most of which utilize liquid manure storage and handling systems that land apply their manure according to a Comprehensive Nutrient Management Plan (CNMP), it's important to understand the fate of this applied manure. Furthermore, since many manure application fields have been improved with subsurface (tile) drainage to facilitate cropping management in the humid climate of New York, these liquid manure applications could result in contamination of the tile drainage discharge. In some cases, the impact of this contaminated tile discharge on downstream water quality has resulted in water quality violations to the producer.

Consequently, the project was designed with Objectives and Phases to not only better understand the fate of a liquid manure application to tile drained land but to also implement, demonstrate, and evaluate how drainage water management (i.e., controlled drainage) might reduce the incidence of manure contaminated drain discharges. Without some type of flow control structure on the drainage outlet, the landowner has little control of when tile are flowing. Producers thus struggle with properly timing manure applications to weather and soil conditions because of the uncertainty in weather forecasts. Adding control structures to a drainage system incurs more capital improvement and management costs so landowners want to be assured their effort is worthwhile. The uncertainty as to under what liquid manure application, soil type, and drainage conditions present the highest risk to contaminating the drain discharge is also of interest to nutrient management planners, CAFO advisors, and soil and water management professionals, so the project included substantial extension and outreach efforts as well to address this issue.

THE LABORATORY RESEARCH

Since both the prevalence of preferential flow paths and the viscosity of liquid manure appear to affect transport of manure contaminants like phosphorus to the tile drain, detailed laboratory experiments were carried out to better define under what conditions phosphorus breakthrough occurs. A master's level student was provided a graduate research assistantship to carry out this laboratory phase of the project. Excerpts of her thesis research (Royem, 2012) are as follows.

Experimental Methods

Soil column experiments were conducted to determine differences in effluent phosphorus (P) under four different P-application treatments (tap water, inorganic P (P_2O_5) dissolved in tap water, manure at 3.5% solids, and manure at 7% solids) and macropore sizes. Experiments were conducted on dry-packed soil in twenty-four 30 cm high polyvinyl chloride (PVC) columns with a diameter of 10 cm. Three types of soil columns were constructed: two with macropores (1 mm and 3 mm diameter) and one with no macropore.

The soil used in these experiments was an Odessa silt loam, a fine, illitic, mesic *Aeric Endoaqualfs* (5-10% sand, 50-60% silt, and 30-40% clay) obtained from the top 70 cm of the EQIP cooperators farm field in the Great Lakes Eco-Region of New York. The soil was sifted through a 5 mm screen for homogeneity and packed into PVC pipe to a bulk density of around 1.1 to 1.2 g/cm^3. The column walls were roughened by sanding to diminish soil separating from the walls during shrinking. Duplicate soil columns were made to run experiments with 3, 1, 0 mm macropores for the four P-application treatments.

Macropores were constructed using 1 and 3 mm dowels. The base of each column was fitted with a screen and filled 2 cm high with sand (0.8-0.12 mm). The base of the column was capped and drilled with four 8 mm diameter holes spaced equally around the periphery of the column in order to drain the matrix. A central hole was drilled as the macropore outlet and fitted with a fiberglass wick (15 mm diameter) to collect macropore effluent. The central hole was included in all columns even if there was no macropore in the soil. The fiberglass wicks were rinsed with distilled water to remove any potential P in the wicks.

A system of funnels and tubing was used to collect leachate from the matrix and macropores separately (Figure 1). A small funnel (3.5 cm diameter) captured flow from the wick draining the macropore and was connected to a flexible tube that drained to a sample bottle. A larger funnel (10 cm diameter) was attached to the base of the column to collect flow from the four holes draining the column soil matrix. After filling, the soil columns were soaked in tap water for 24 hours. Wetting was from the bottom-up by placing them in plastic tubs and increasing the water depth 5 cm/hour. The columns were drained for 24 hours to emulate soil conditions at field capacity and preservation of macropore construction. The dowel used to create the macropore was then removed and the manure and P application treatments were applied to the top of the columns.

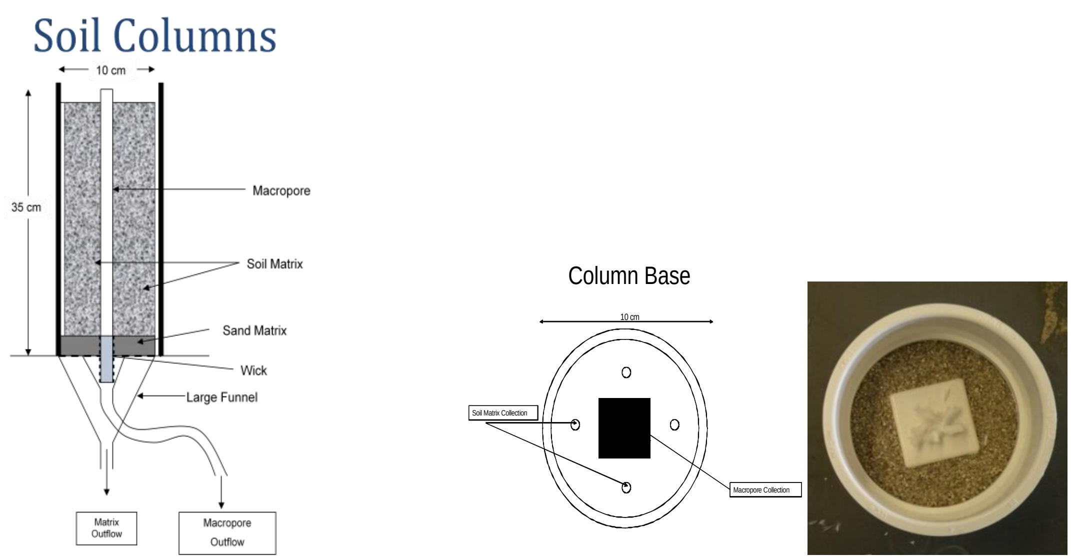

Figure 1. Soil Column Design.

For the P-application treatments, the liquid dairy manure was collected from the EQIP cooperators farm lagoon and immediately analyzed for total Nitrogen (N), P, and potassium (K) and percent solids content by the Cornell Nutrient Analysis Lab. The samples were immediately refrigerated (4 ^{o}C) until experiments commenced. The percent solids from the sampled lagoon were 7% so half of the manure was diluted with tap water for an application treatment of 3.5% manure solids. An inorganic-P (P_2O_5) application treatment was also prepared by dissolving 0.096 grams industrial fertilizer. Each treatment type was applied to the top of each column to represent an equivalent nutrient application rate of 5,000 gal/acre when taken from the lagoon. A control treatment consisted of tap water with no further additives.

The experiment was set-up and conducted in the Soil and Water Laboratory in the Department of Biological and Environmental Engineering at Cornell University where the ambient temperature ranged from 20 to 30 °C. All columns were positioned equidistant from a Pulsator APLT-2-20 sprinkler manufactured by Wade Rain within a circular radius of 2 meters (m) (Figure 2). The sprinkler was adjusted to deliver an average rain intensity of 0.7 mm/hr, representative of a low intensity storm event characteristic of the Great Lakes eco-region events. Rain simulation lasted for 3 weeks until, on average; an entire pore volume passed through the columns. The total average water applied to each column was 53 mm.

Figure 2. Experimental set-up of soil columns equidistant around a small sprinkler.

Leachate was collected in two 50 mL plastic Nalgene vials from each column: one collected macropore leachate and the other one collected the matrix leachate. The same sample vails were used for the entirety of the experiment, rinsed after collection with tap water. Water volumes were recorded every hour for the first week of application, after which collection volumes were recorded at least two times per day and ultimately one time per day by the end of the experiment. Samples were collected for analysis when enough effluent was accumulated (at least 10 ml) or when the vial was full. Because of variability among column hydraulics, samples were collected at varying intervals depending upon the collection volume of effluent from the columns. When effluent sample collection from the columns was unable to be supervised, the sprinkler was turned off and the columns were covered with a plastic top to eliminate evaporation and loss of soil moisture. All column effluent samples were filtered within 24 hours of collection using vacuum filtration through a .45 μm membrane filter. Samples were acidified by adding 200 μL of concentrated HCl to assure pH below 2.0 for preservation and refrigerated at 4 °C until analyzed. The samples were analyzed for inorganic P, referred to as soluble reactive phosphorus (SRP), using ascorbic-acid reduction on an OI Analytical FS-3000 flow injection autoanalyzer.

The soluble Total P was analyzed using Inductively-Coupled Plasma Mass Spectrometry (ICP-AES). The detection limits for these instruments were 0.023 mg/L and 0 .046 mg/L, respectively, based on the calibration standards used for each of the analyzers. The dissolved organic P was calculated as the difference between total soluble P and SRP. (See Appendix)

Experimental Results

Although the individual column results were quite variable and statistical inferences of the data were not very conclusive, a composite of the overall general affect of SRP breakthrough as a result of macropore size shown in Figure 3 indicates more P load was transported through the larger 3 mm diameter macropore columns.

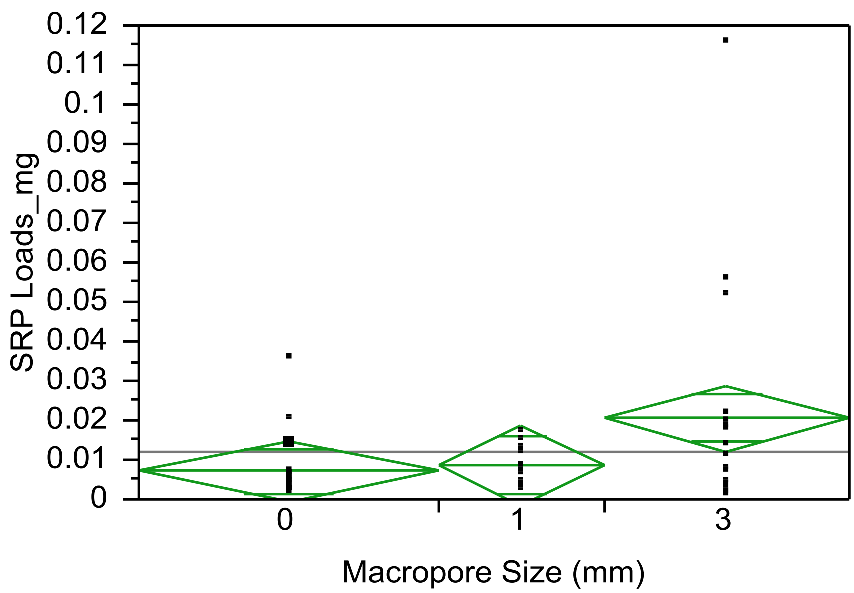

Figure 3. SRP load breakthrough relative to soil macropore size.

The general affect of the liquid manure and P-application treatments shown in Figure 4 indicates that more SRP loading or breakthrough occurred when the P was applied as liquid manure with 3.5% solids content. It's interesting that the breakthrough of SRP from the liquid manure with 7% solids treatment actually appears to be less than that from the other P-application treatments. This result is believed to be attributed to the manure solids likely causing some blockage of the soil pores and reducing the soil's infiltration rate within the columns as sometimes it was observed that water was ponding within the columns.

Statistically, the combined total loads and concentrations of SRP across treatment types were not different when analyzed by a one-way anova. However, the SRP breakthrough results shown in Figure 5 provide a good visual and graphical synopsis of the interrelated effects of the cumulative sprinkler application amount versus the macropore size and P-application treatments. The most significant aspect shown in Figure 5 is depicted in the upper right hand inset where the P-application of 3.5% liquid manure solids was applied to the soil columns with the 3 mm diameter macropores. For that treatment combination one can observe a very rapid and substantial breakthrough of SRP, and where a peak effluent concentration of 2.6 mg/L was obtained, compared to all the other treatment combinations. This result is indicative of what may

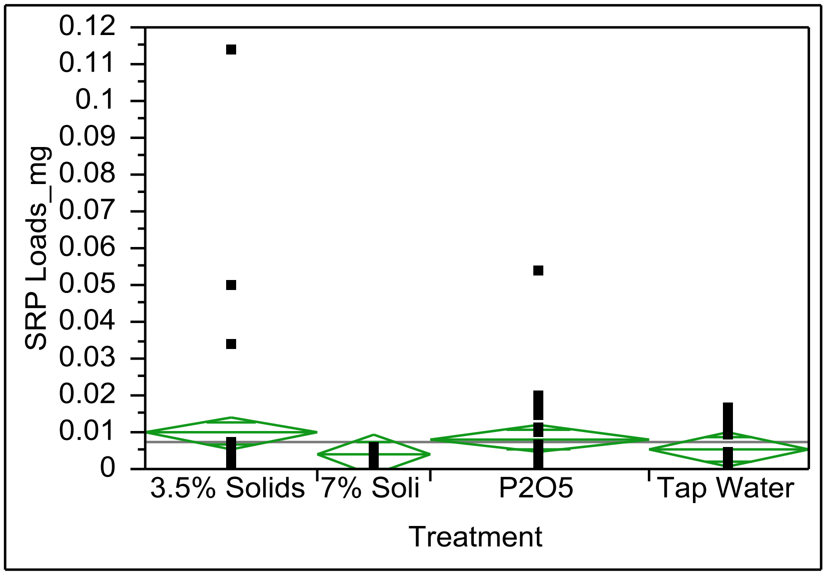

Figure 4. The effect of P-application treatment on SRP loads discharged from the soil columns.

happen in a tile drained field setting when liquid manure with a low solids content is applied to soils with a highly macroporous structure, and followed by a precipitation event. Similar results of rapid and peak SRP concentrations have been corroborated in other studies (Jacobsen et al., 1997; Geohring et al., 1998 and 2001; and Schelde et al., 2002). Interestingly, the next highest SRP load and concentration breakthrough occurred with the inorganic P fertilizer application to the 3 mm diameter macropore columns. The amount of SRP breakthrough from the 1 mm diameter macropore columns which did not receive any additional P other than what may have been in the tap water was likely a result of the background level of P in the soil.

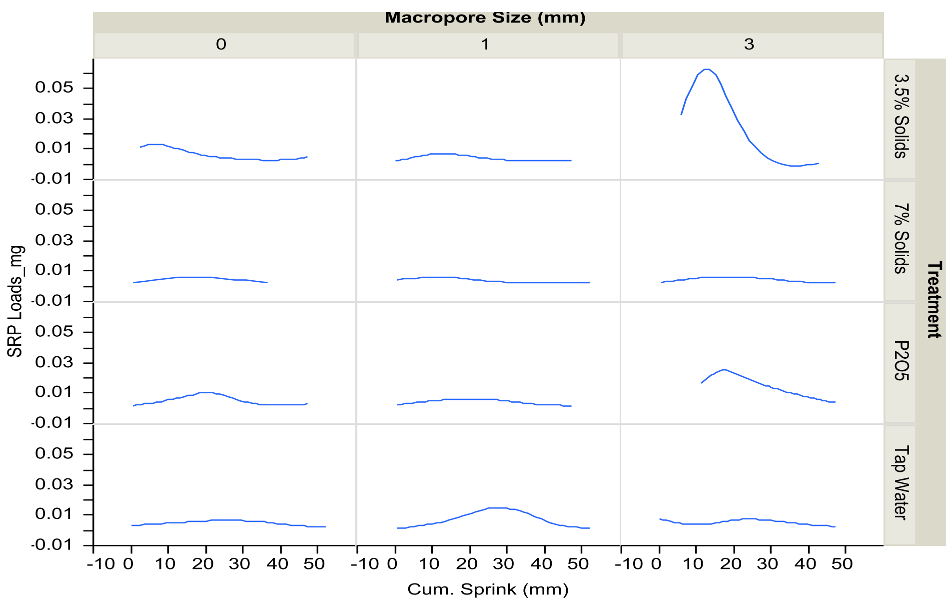

Figure 5. SRP load breakthrough over time with cumulative water application amount and comparing P-application treatments and macropore size.

Conclusions from Soil Column Lab Study

Although there were few statistical differences of note, the columns with macropores produced the majority of SRP loads to the effluent. This study suggests that the 2 mm diameter macropore threshold may be applicable to P transport since we observed substantially higher amounts and concentrations of SRP for the liquid manure 3.5% solids and inorganic P_2O_5 treatments for the 3 mm macropore columns as compared to those for the 1 mm diameter macropore columns. One explanation for the lack of statistical differences among treatments is that the soil itself was likely a major source of SRP, and which thus may have masked the differences among treatments and macropore sizes. Indeed, the soil taken from the farm cooperator's field site that was used to fill the columns had a Morgan's P soil test level of 83 mg/Kg in the top soil layer which would be considered a very high soil test level whereby no additional phosphorus fertilizer would be recommended. Although our columns were constructed from a reasonably well-mixed mixture of the top 70 cm of soil, there was potential for large variation and heterogeneities in the soil P content among columns. Furthermore, a large fraction of P retained in this soil is bound to iron (Fe) III (ferric iron) in the presence of oxygen, and was probably released under anaerobic conditions concomitantly with reduced iron II (ferrous iron). The available Al, Fe, and Mn in the field soil used in these columns was likely associated with some readily mobilized P that could have mobilized into the soil solution during the initial column saturation and during the continued wetting with the sprinkler application. The rapid and substantial breakthrough of phosphorus from the manure containing 3.5% solids in contrast to the liquid manure containing 7% solids also indicates that the higher liquidity of the manure is more readily transported through the macropores. Manure with a higher solid content that's applied to the soil surface may actually serve to block soil pores, limiting infiltration and perhaps facilitating more runoff. Although more research would be needed to better quantify the fate of phosphorus leaching to liquid manures of varying solids content and to specific macroporosity responses, in summary, this laboratory study indicates that liquid manure at a low solids content of 3.5% applied to the soil surface tended to quickly increase the SRP load and concentration leached from soil with macropores of 3 mm diameter size in response to a wetting event.

THE EQIP FARM COOPERATOR RESEARCH

The field-based research and initial selection of sites for this project effort were carefully considered so that the project objectives of implementation, demonstration, and evaluation of how controlled drainage water management might reduce the incidence of manure contaminated drain discharges could best be achieved. Working in cooperation with extension, Natural Resource Conservation Service, soil and water conservation district, nutrient management, and land improvement contractor professionals**, s**everal locations were evaluated and on-site inspections were done where tile drain discharges had been or were suspected of becoming contaminated from liquid manure applications. Based on this review and the discussions that ensued, it was determined that high application rates (i.e., > 10,000 gallons per acre) of liquid manure containing less than five percent solids, and applied when the soil is near field capacity, were the most problematic when these applications were similarly associated with the soils listed as the Soil Moisture Management Groups 3Bp and 3Cp in the New York State Drainage Guide ftp://ftp-fc.sc.egov.usda.gov/NY/engineering_tools/drainage_guide_ny.pdf. Since it was deemed that the design and installation of new drainage systems or any retrofits to existing systems on these types of soils should require particular attention for controlled drainage application, the NY Drainage Guide was amended early on to include language to this effect. Sections on Preferential Flow Considerations (pp. 37-38) and Special Components (pp. 60-62) were added to the Guide and reference was also made to consider utilization of the NRCS Conservation Practice Standard 554 – Drainage Water Management.

The considerations for selecting the farm cooperator sites were that it was deemed important to select the research-based and demonstration sites in different eco-regions of the state and in areas where both dairy farming and land drainage improvement practices are prevalent. Although there were several sites where drainage effluent water quality violations had occurred, not all of those landowners were willing to be project cooperators. At one of these sites where we had a willing cooperator, it was observed that a large clay tile main drain was placed in a swale that had a five percent slope. However, this type of site was not very amenable to a controlled drainage retrofit. Thus, after reviewing several locations, two sites and willing EQIP farm cooperators were identified and are further described as follows.

FIELD SITE IN NY'S GREAT LAKES ECO-REGION

The EQIP farm cooperator site selected in NY's Great Lakes Eco-Region was a dairy farm located within the Seneca-Oneida-Oswego Rivers drainage basin in Cayuga County. The particular field site selected for the installation of a controlled drainage structure ultimately drained to Cayuga Lake and primarily consisted of Odessa silt loam soil, a fine, illitic, mesic *Aeric Endoaqualfs* with field slopes of around 1.5 percent. The Odessa soil is designated as a 3Cp in the New York State Drainage Guide. Since this field site had two subsurface drainage pipe outlets representing similar randomly drained areas of the field, it appeared to be a good research site whereby one of the drainage outlets could be retrofitted with a watertable control structure to essentially conduct a paired- controlled drainage versus no drainage control field site evaluation. The field was being cropped with a corn-forage rotation and liquid manure was applied according to nutrient management recommendations, typically as split fall and spring manure applications to the corn and applications immediately following forage cuttings.

Field Site Set-up

A controlled drainage structure was installed on one of the subsurface drainage outlets and a special 22.5° V-notch weir gate was made and attached to fit inside the drainage control structure. The end of the drain line without any control was also equipped with a catch box and 22.5° V-notch weir. Recording water level pressure transducers were installed upstream of both of these weirs for flow monitoring purposes (Figure 6). The invert of the V-notch in the control structure was set 48 cm below the ground surface, and except for removal during winter months and a brief setting at 10 cm below the ground surface when manure was expected to be spread, the control gate remained at that position throughout most of monitoring and sampling period. The drain discharge was sampled during various flow events from both the controlled and non-controlled systems by taking grab samples using new, clean 125 ml wide-mouth high density polyethylene bottles which were transported back to the Soil and Water Laboratory in the Department of Biological and Environmental Engineering at Cornell University for analysis. The water samples were handled and processed following similar standard analytical protocols as described above in the laboratory experiments and in the Appendix.

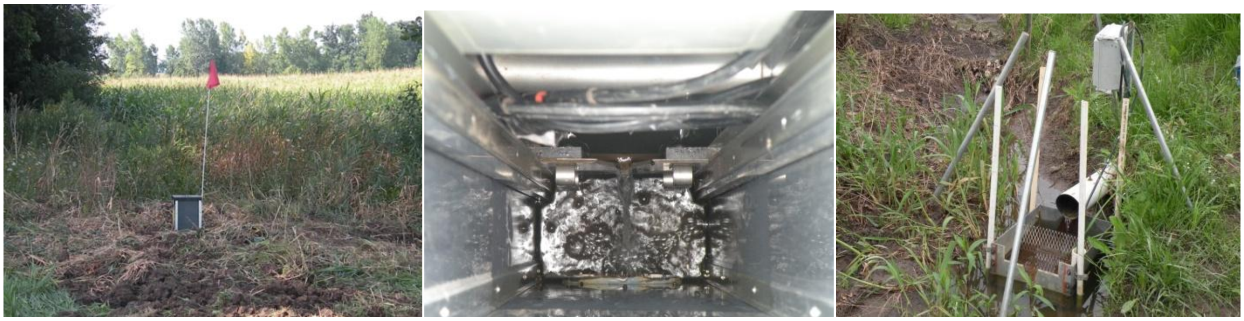

Figure 6. Drainage control structure at edge of cornfield, control structure equipped with a 22.5° V-notch weir, and the non-controlled drain outlet equipped with weir and pressure transducer.

Experimental Results

The most significant and detailed results from this field-based research were obtained during a large storm event when 3.5 inches of rain fell over a two-day period and grab samples were collected regularly during the course of the event. The weir plate within the water level control structure was positioned to retain the watertable about 1.25 feet below the surface as opposed to the drain which had no control and where the watertable equilibrated around 3 feet below the surface. Figure 7 shows the combined response of how the total phosphorus concentration responded simultaneously with the drain discharge to the storm event for both the controlled drain and the drain without any control. The peak discharge from the controlled drain (dotted blue line) was less than that from the uncontrolled drain (dashed red line). Although the initial total phosphorus concentration from the controlled drain (solid blue line) was higher (at 1.5 mg/L) than that for the uncontrolled drain (solid red line), over the course of the storm duration the total phosphorus concentration from the controlled drain continued to drop whereas the total phosphorus concentration for the uncontrolled drain continued to rise and spike at a higher concentration (of 1.75 mg/L) in proportion with the drain flow. The soluble reactive phosphorus (SRP) averaged around 81 percent of the total phosphorus throughout the event and did not vary substantially between the controlled and non-controlled drain discharges. The combined effect of the concentration times the flow or loading rate from the two drainage outlets is shown in Figure 8 where it clearly implies that the controlled drain had an effect of reducing the rate of phosphorus discharge or loss per unit of drain discharge. The accumulated phosphorus load (mass) loss during the storm event for the two systems is shown in Figure 9, and further illustrates the controlled drain had some benefit of reducing the total mass loss of phosphorus from the field during the storm event. Although this total phosphorus load reduction with controlled drainage is only about a 10% reduction and only a fraction of phosphorus loss on a per unit area basis, this cumulative reduction over repeated storm events may help reduce downstream water quality impacts.

For this same storm event, the nitrate-nitrogen concentrations discharged from the controlled and uncontrolled drains during this storm event are shown in Figure 10. The concentrations from the controlled drain were slightly less during the beginning of the storm, but the higher peak flow from the uncontrolled drain appears to have caused more of a dilution effect, resulting in similar concentrations. As shown in Figure 11, the accumulated nitrate-nitrogen unit load was essentially similar between the controlled and uncontrolled drain.

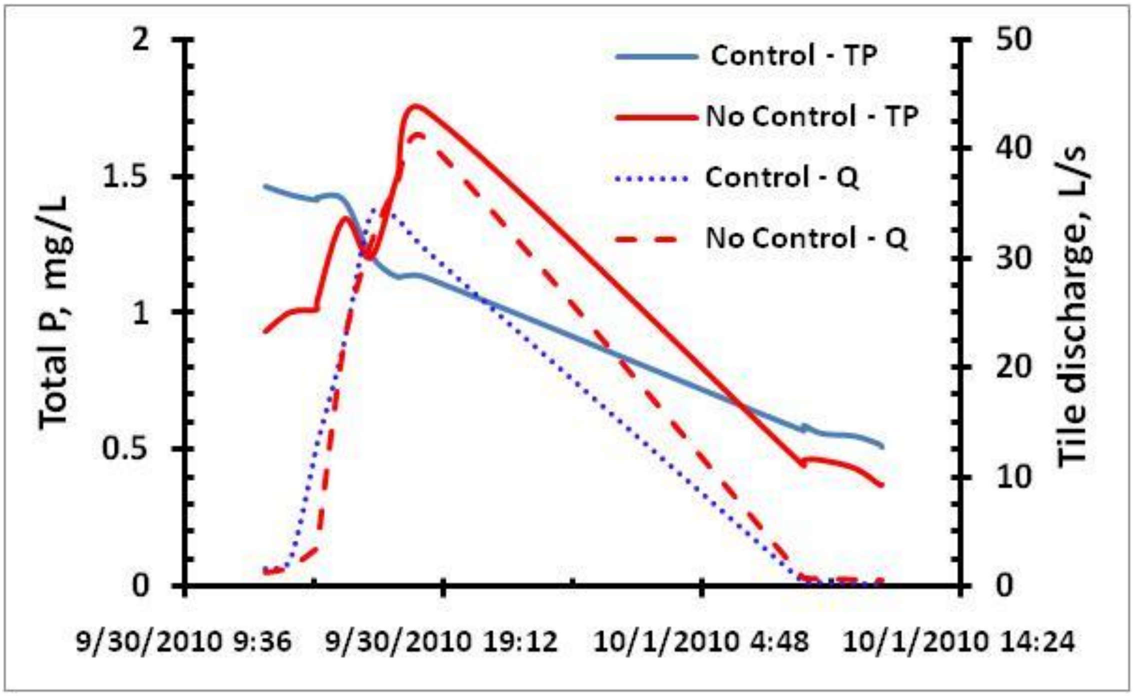

Figure 7. The combined response of total phosphorus concentrations in response to the drain discharge for the controlled and uncontrolled drain outlets.

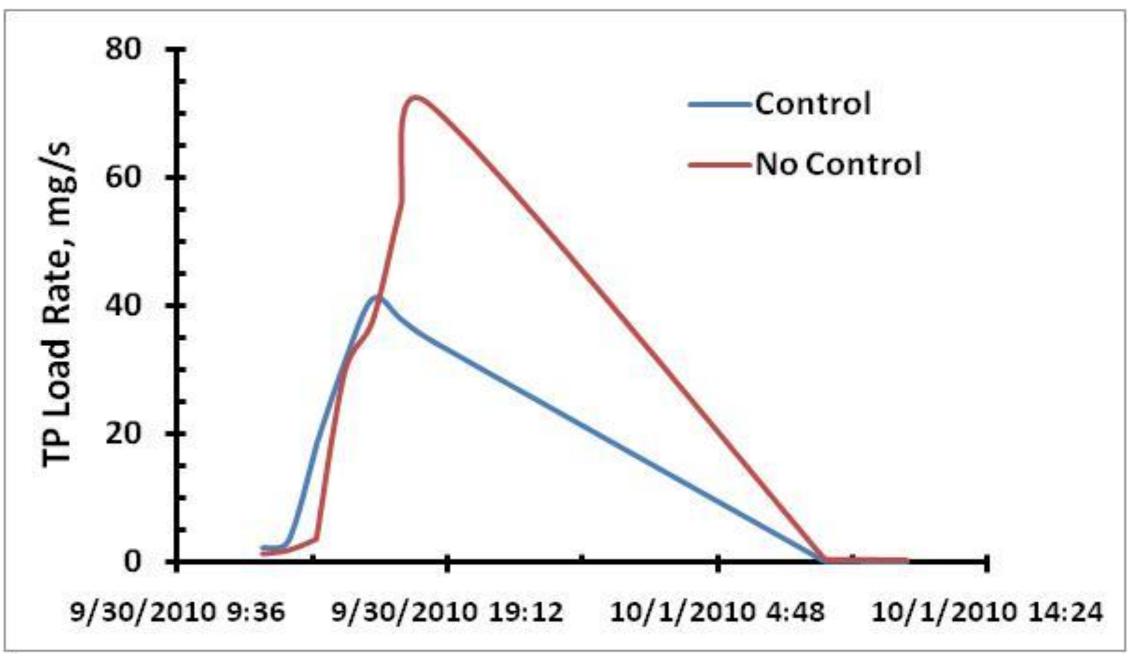

Figure 8. The total phosphorus loading rate per unit of drain discharge for the controlled and uncontrolled drain outlets.

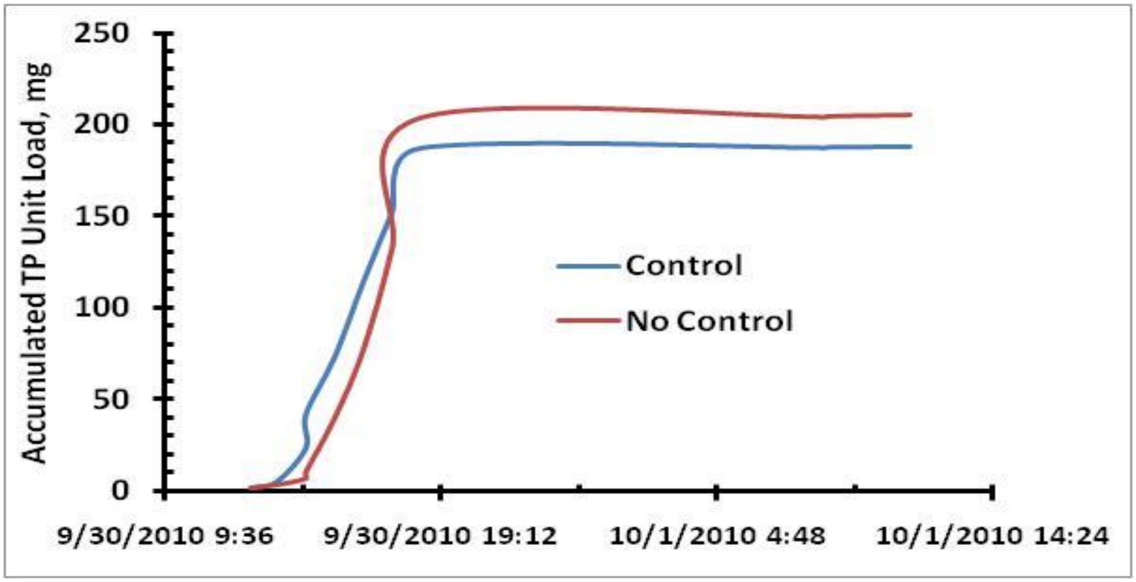

Figure 9. The accumulated total phosphorus load loss from the controlled and uncontrolled drain outlets over the course of a 3.5 inch storm event.

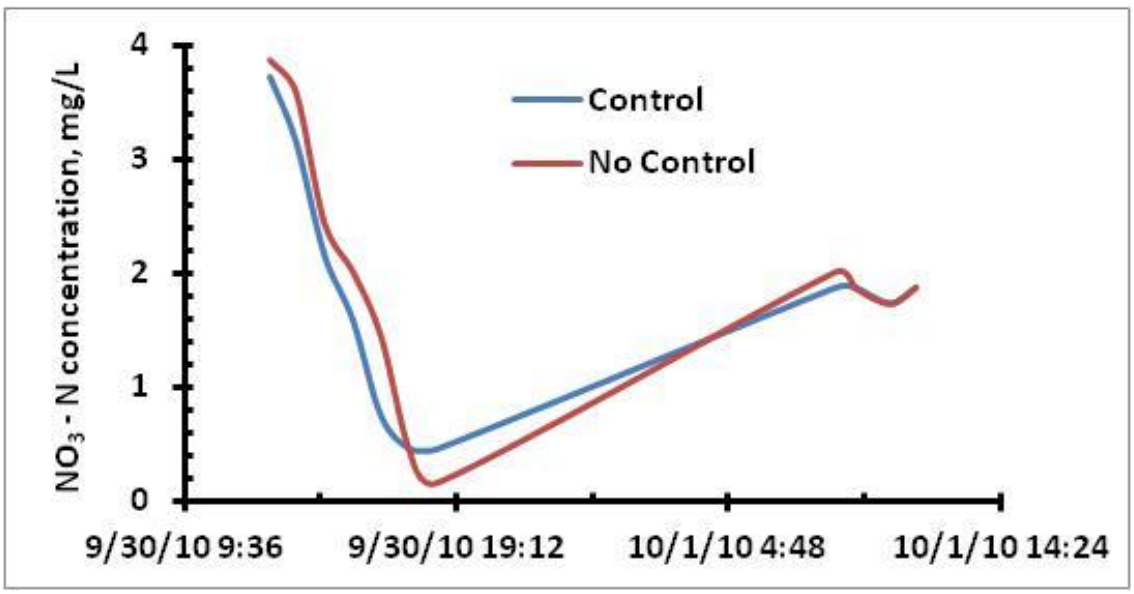

Figure 10. Nitrate-nitrogen concentrations for the controlled and uncontrolled drain outlets.

Since these fields receive most of their nitrogen from manure which consists of mostly organic and ammonia nitrogen forms, the total nitrogen concentration in the drain discharge was also analyzed. The total nitrogen concentrations resulting from this storm event are shown in Figure 12. The concentrations from the controlled versus the uncontrolled drain are also quite similar and show some effect of dilution, but compared to the results in Figure 10 it appears more of the nitrogen is in the organic forms during the peak of the storm event. This is indicative of some preferential flow occurring through the macropores.

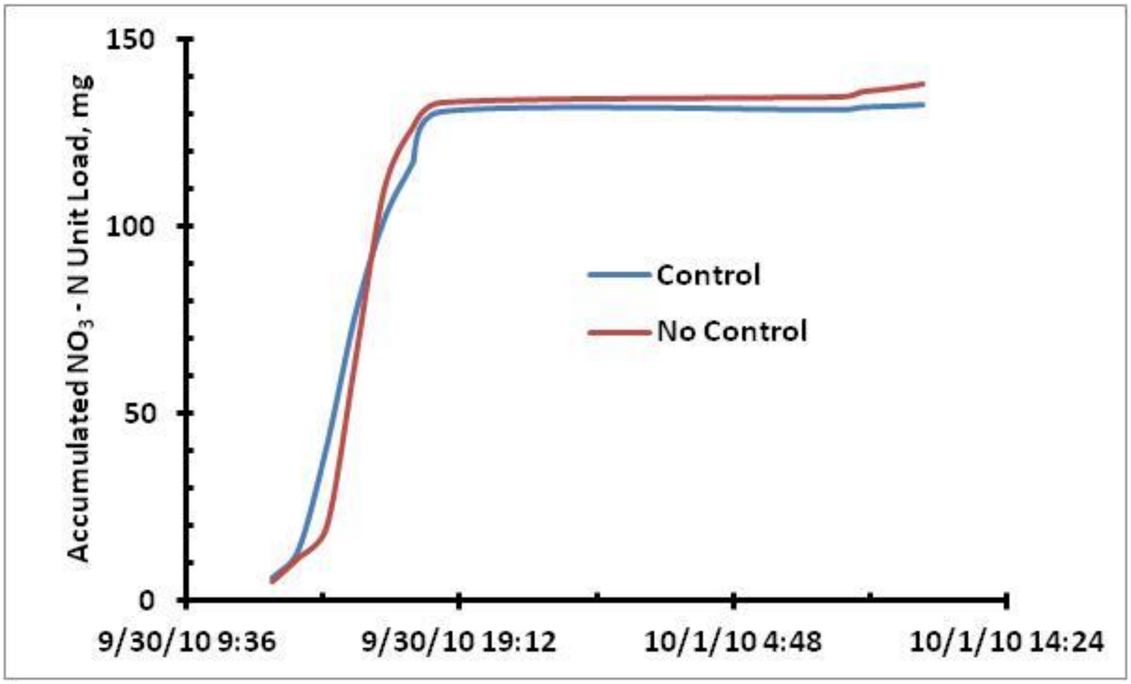

Figure 11. The accumulated nitrate-nitrogen load loss from the controlled and uncontrolled drain outlets over the course of a 3.5 inch storm event.

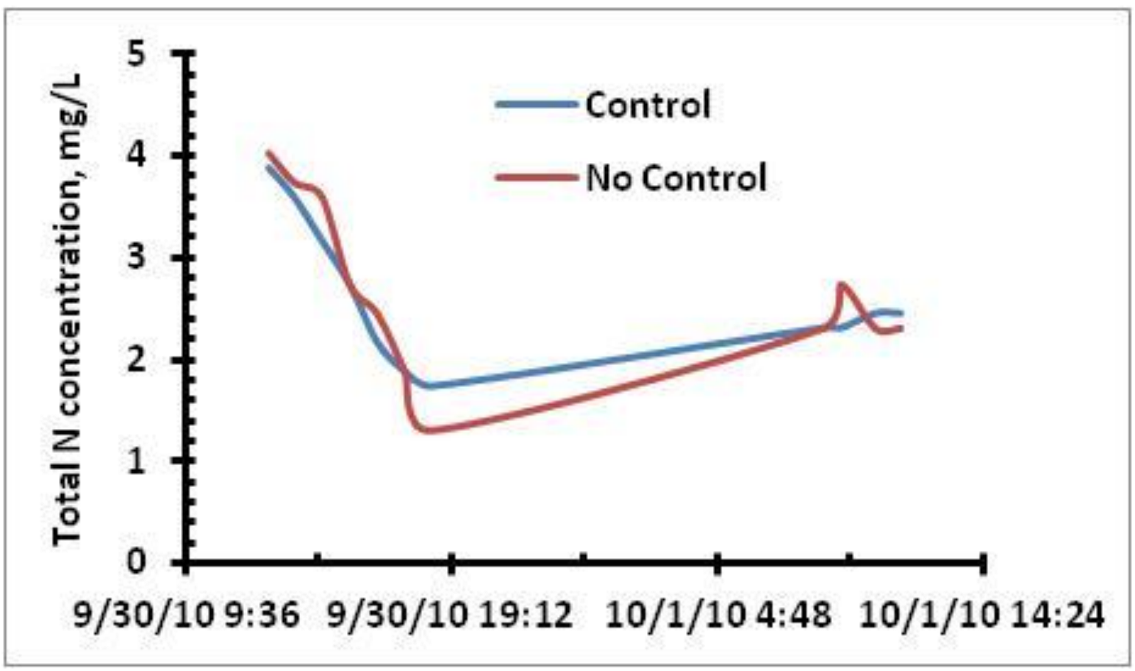

Figure 12. Total nitrogen concentrations for the controlled and uncontrolled drain outlets.

Although the total nitrogen concentration from the controlled drain is also somewhat less than that from the uncontrolled drain at the beginning of the storm and both drains are affected by dilution, as shown in Figure 13 the combined effects on the accumulated loss of total nitrogen now show that slightly more total nitrogen was discharged from the controlled drain. The higher peak and sustained flow from the uncontrolled drain was apparently adequate to dilute more of the organic forms and thus the total nitrogen as measured for this storm duration.

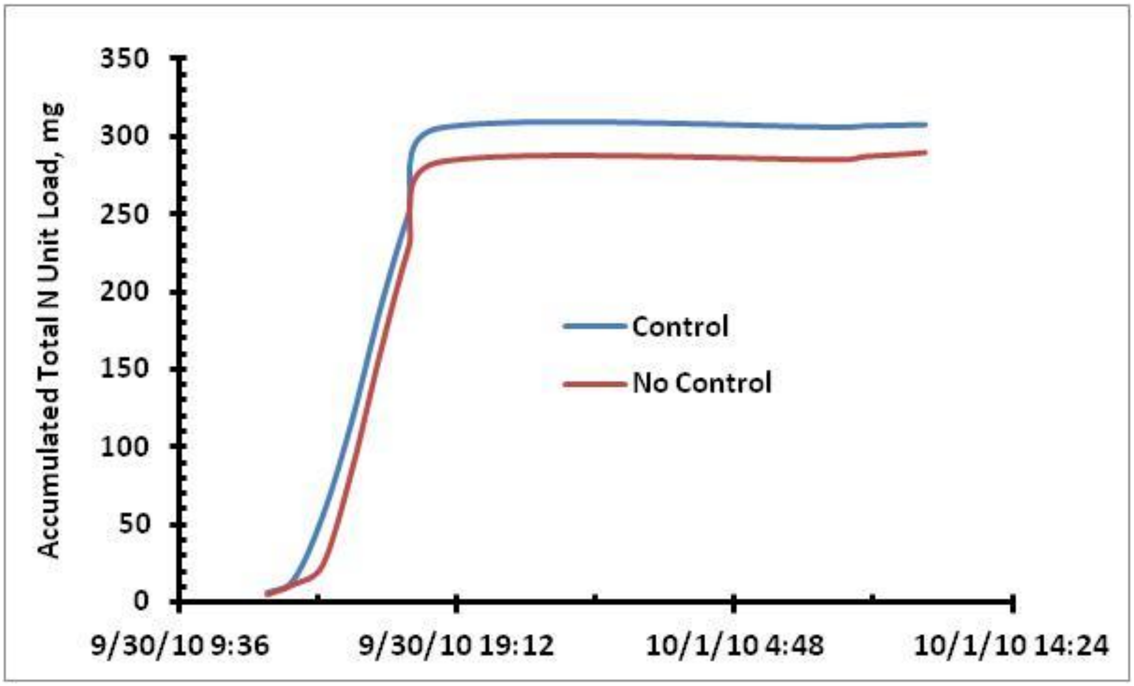

Figure 13. The accumulated total nitrogen load loss from the controlled and uncontrolled drain outlets over the course of a 3.5 inch storm event.

Additional monitoring of this field site resulted in similar observations for phosphorus and nitrogen concentrations and flow variations between the paired controlled versus the uncontrolled drain discharges. For example, Figure 14 shows the drain discharges and soluble reactive phosphorus concentrations for the controlled and uncontrolled drains following a 0.5 inch storm event on September 7, 2011. In this event, both the discharge and the soluble reactive phosphorus concentrations were higher for the uncontrolled drain, and the figure also indicates the concentration increased with increasing discharge. For the controlled drain, the phosphorus concentration decreased somewhat with increasing discharge. The accumulated load reductions as a result of the controlled drain for this event were 48 percent for the soluble reactive phosphorus and 37 percent for the nitrate-nitrogen. Figure 15 shows another example of the total phosphorus concentrations for the controlled and uncontrolled drains during the spring period of May 3-9, 2012. The first paired-sampling points (5/3) represent a low flow condition since no rain had fallen the previous two days. The second paired sampling points (5/4) were taken after a 0.4 inch event occurred. The series of six samples on May 8 were taken as another 1 inch of rain fell during a low intensity, steady rain. In this case, the controlled drain again caused a small reduction in the concentrations and load loss of total phosphorus.

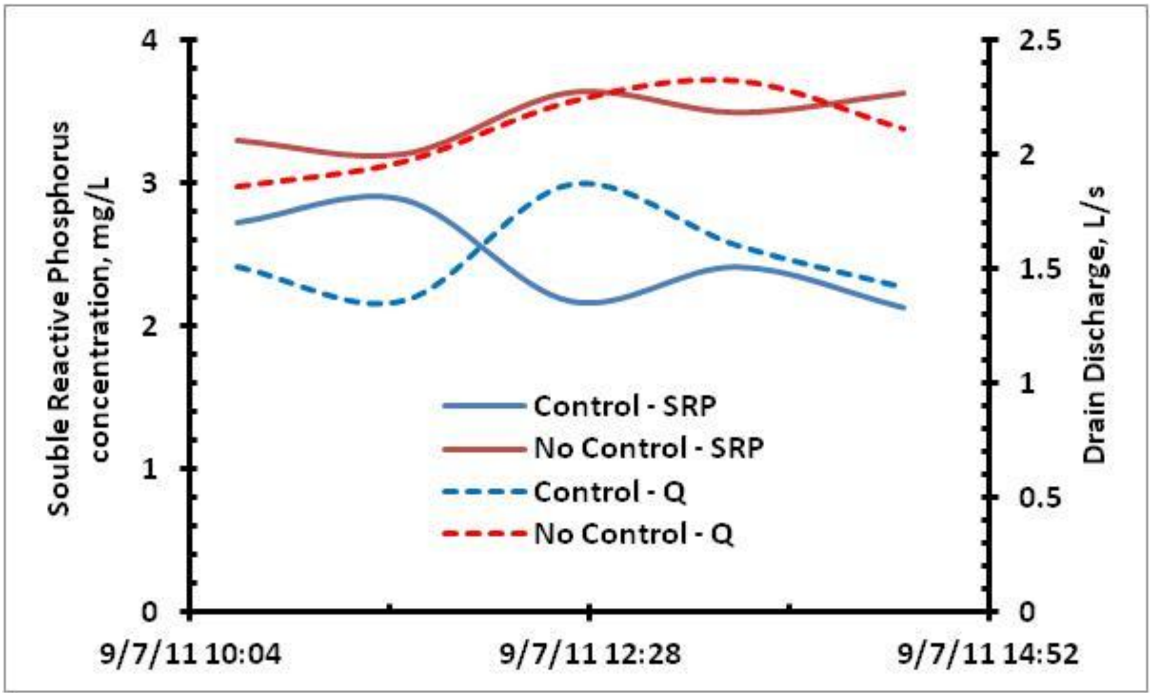

Figure 14. The combined response of soluble reactive phosphorus concentrations in response to the drain discharge for the controlled and uncontrolled drain outlets.

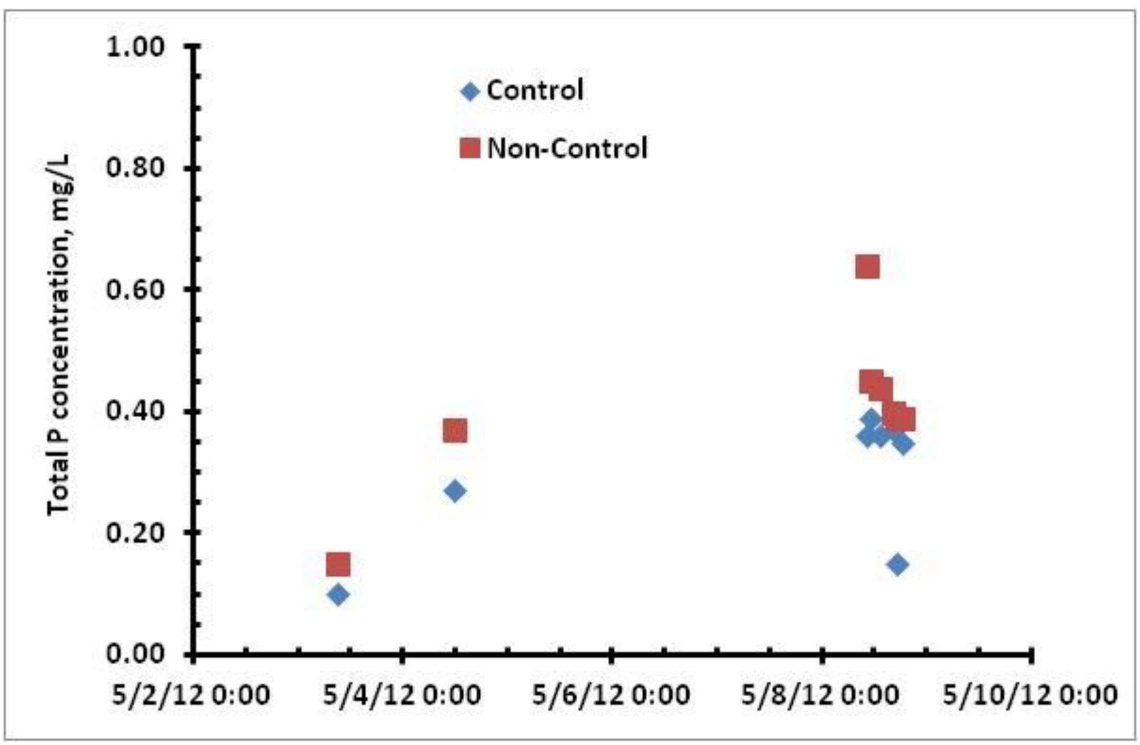

Figure 15. Total phosphorus concentrations for the controlled and uncontrolled drain discharges during the spring of 2012.

For the May 3-9, 2012, sampling period, the drain discharge was also analyzed to independently determine the concentration of nitrate-nitrogen and nitrite-nitrogen. Typically nitrite-nitrogen is included in the total dissolved inorganic forms when samples are analyzed by automated colorimetry with hydrazine reduction, but is generally considered to be an insignificant portion of the total result. However, since controlled drainage and a higher watertable may induce a more reduced root-zone environment, the affect of controlled drainage on the total dissolved inorganic nitrogen speciation in the drain effluent may also be of interest. Figure 16 shows the nitrate- plus nitrite-nitrogen concentrations. These nitrogen concentrations were higher for the controlled drain especially during the low flow condition of May 3rd and May 5th. The concentrations were more variable during the May 8th storm event but generally decreased also during the highest flow periods.

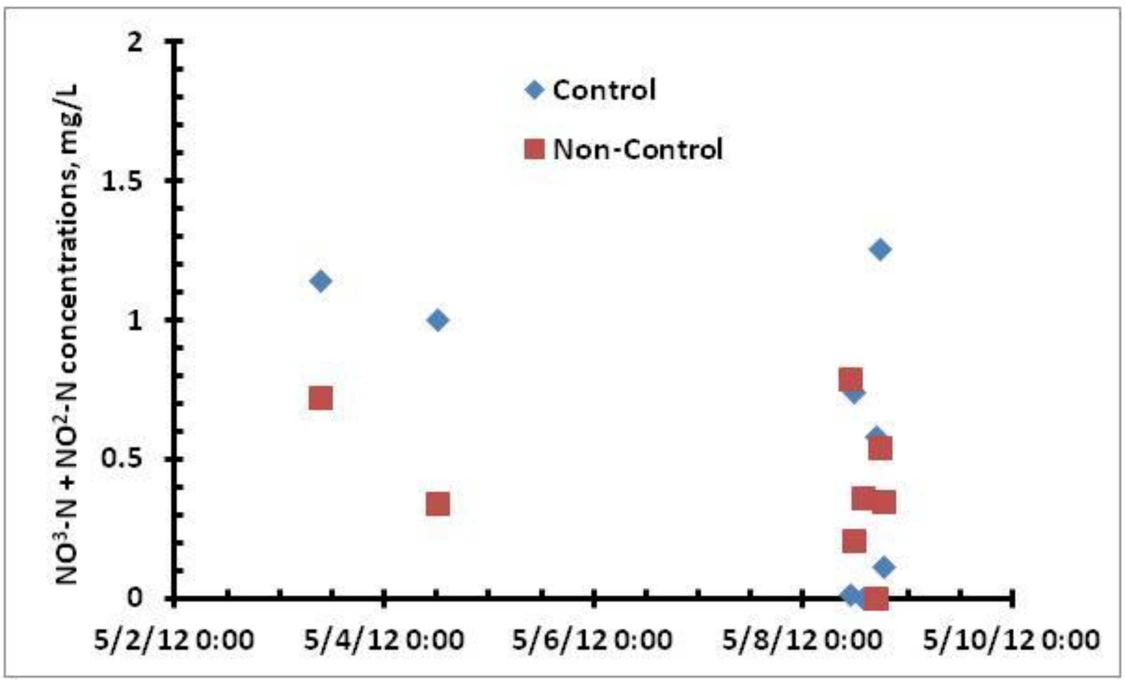

Figure 16. Nitrate- plus nitrite-nitrogen concentrations for the controlled and uncontrolled drain discharges during the spring of 2012.

As shown in Figure 17, it's perhaps noteworthy that the samples from the controlled drain generally had a higher percentage of nitrite-nitrogen making up the nitrate- plus nitrite-nitrogen summation. This is most evident in the May 3rd and May 5th samples when there were low flows. It seems that the affect of controlled drainage versus non-controlled drains on the fate of nitrogen occurring from the discharged effluents warrants further research.

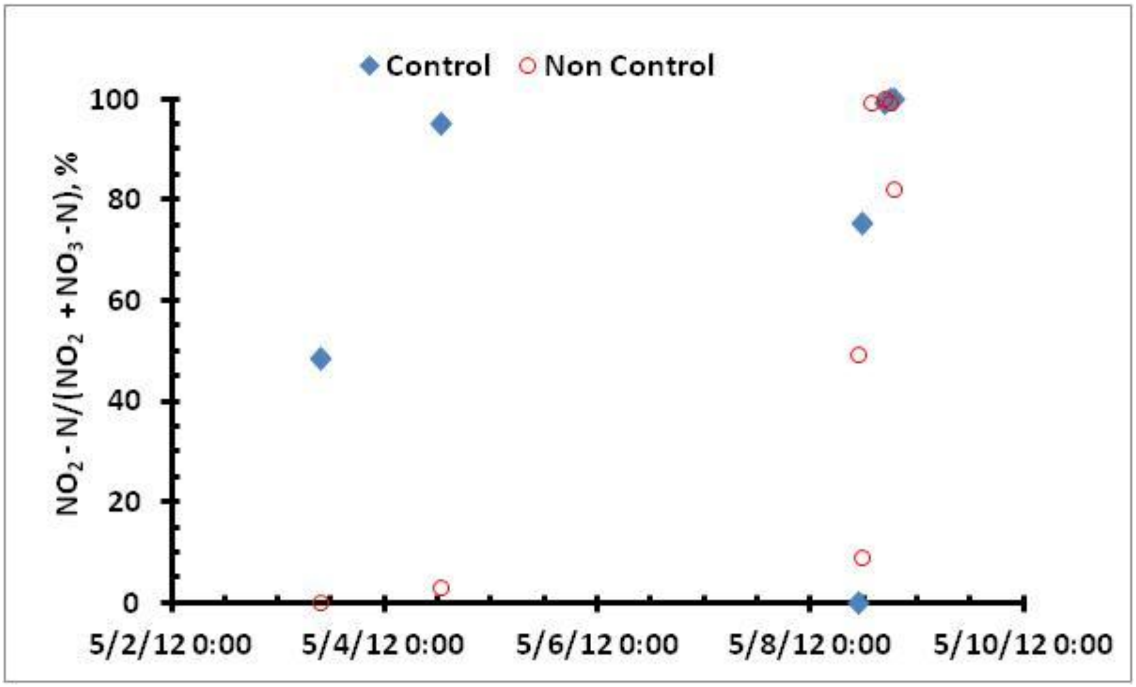

Figure 17. Nitrite-nitrogen as a percentage of both the sum of nitrite- plus nitrate-nitrogen for the controlled versus uncontrolled drain discharges.

A total of 138 grab samples were collected during this field-based monitoring evaluation and 1032 analyses were done for various different parameters. For Quality Assurance/Quality Control (QA/QC) purposes, all samples were collected by rinsing the bottles several times with the sample water; and several dupes, split, and field blank samples were collected. Samples were vacuum filtered through a 0.45 micron filter paper within 24 hours of collection and stored at 4°C until analyzed. In the lab, QA/QC procedures were carefully followed by preparing fresh calibration standards and re-analyzing samples when results seemed questionable. All of the samples were analyzed for soluble reactive phosphorus concentrations which averaged 0.74 (ranging from 0.01 to 2.88) and 0.84 (ranging from 0.01 to 3.63) mg/L for the controlled and uncontrolled drains, respectively. This seemingly high average value likely reflects that most of these grab samples were taken in response to and during various storm events, and thus usually during times of higher drain flows. For example, the average discharge measured at the time the samples were collected was 3.2 L/s (range - 0 to 34 L/s) and 3.7 L/s (range - 0.06 to 41 L/s) for the controlled and uncontrolled drains, respectively. For the controlled drain, some samples were taken from behind the control gate when there was no measurable flow over the gate in order to make some comparisons. For the 107 samples analyzed for total phosphorus the concentrations averaged 0.77 (range - 0.1 to 1.46) mg/L and 0.73 (range - 0.12 to 1.74) mg/L for the controlled and uncontrolled drain, respectively, and in which the soluble reactive phosphorus generally made up around 80 percent of the total phosphorus.

Nitrate-nitrogen was analyzed on 126 samples and the average concentration was 6.7 (range – No Detect (<0.01) to 54) and 4.1 (range – No Detect to 39) mg/L for the controlled and the uncontrolled drains, respectively. The highest nitrate concentrations occurred in mid-August when a one inch rain followed an extended dry period but which induced a very low flow condition from the drains. In this case, the controlled drain reduced the total drain discharge, which also reduces the nitrate loss. Nitrite-nitrogen was analyzed independently for 60 samples and average concentrations were 0.3 (range - <0.01 to 1.3) and 0.2 (range - <0.01 to 0.5) mg/L for the controlled and the uncontrolled drains, respectively. As indicated earlier, nitrite often made up a larger portion of the total nitrate- plus nitrite-nitrogen concentration especially from the controlled drain or during the larger storm and flow events, whereas nitrate was the predominate form during the lowest flow events. Apparently drier soil conditions provide for more mineralization and nitrification which leaches readily with the onset of a flow event. It's also interesting that organic-nitrogen made up the majority of the total dissolved nitrogen in these samples. Total nitrogen was analyzed on 71 samples for an average of 1.7 (range - 0.5 to 3.9) and 1.8 (range - 0.5 to 5.0) mg/L for the controlled and the uncontrolled drains, respectively. About 15 percent of the total nitrogen in these samples was particulate-nitrogen, perhaps another indication that preferential flow to the drains was often occurring at this field site.

Implications of the Paired- Controlled Versus Uncontrolled Drain Discharges

The installation of the controlled drainage structure and follow-up monitoring and evaluation suggest that the use of controlled drainage has mixed effects. On the one hand it appears to provide some benefit to downstream water quality by reducing the amount of phosphorus that is discharged from the controlled drain. The controlled drain provided some reduction in the phosphorus concentration in the drained water, likely by slowing down the velocity of water flow through the soil's macroporosity which provided more time for phosphorus to sorb to the soil matrix. As flow peaked from the uncontrolled drain, phosphorus concentrations rose along with it resulting in somewhat more accumulated total phosphorus load loss. This effect, however, seemed to vary depending on the soil's antecedent moisture condition prior to the rain event. When the field was more consistently wetted from repeated rain events, there was less of a difference and reduction in comparative concentrations between the paired treatments, and which was probably an affect whereby the reduced soil profile behind the controlled drain may have resulted in some desorption and mobilization of soluble phosphorus.

Similar to what other investigators found, nitrate-nitrogen concentrations from drain outlets were generally similar for controlled versus noncontrolled drain discharges so the primary way nitrate discharges are reduced by controlled drainage is that the control provides a means to reduce the overall drain flow (Evans et al., 1996; Ng et al., 2002; Bonaiti and Borin, 2010; Woli et al., 2010). The farm cooperator suggested that he didn't appreciate the field being wetter for extended periods of time as a result of the drainage control, so achieving nitrogen reduction with controlled drainage will be a management challenge. The higher drain flows during a storm from an uncontrolled drain can actually serve to reduce nitrogen concentrations, but which doesn't necessarily result in any reduction in accumulated total nitrogen load loss. For the drained fields receiving most of the nutrients from applied manure, the nitrogen fate and transport dynamics appear to be somewhat different than in most studies where only inorganic nitrogen fertilizers are applied. We observed that organic nitrogen made up a major proportion of the total dissolved nitrogen, and some loss of particulate nitrogen and ammonium nitrogen also occurred. In one of our earlier studies we found that ammonium-nitrogen can be transported to the drain if rain occurs shortly after a surface manure application, but fortunately the concentrations dissipated quickly (Geohring et al., 1998). Nevertheless, the fate of the residual organic dissolved nitrogen has not been well investigated under controlled drainage situations. Furthermore, if controlled drainage and the resultant wetter soil profile results in more nitrogen ultimately lost as nitrite, this may be of concern in the immediate downstream environment also.

FIELD SITE IN NY'S ST. LAWRENCE CHAMPLAIN VALLEY ECO-REGION

The EQIP farm cooperator site selected in NY's St. Lawrence Champlain Valley Eco-Region was a dairy farm located within the Lake Champlain drainage basin in Clinton County. The particular field site selected for the installation of a controlled drainage structure ultimately drained to Lake Champlain and primarily consisted of Muskellunge fine, mixed, active, frigid Aeric Epiaqualfs with field slopes of around 0.5 percent. The Muskellunge soil is also designated as a 3Cp in the New York State Drainage Guide. Since this field site had a very flat slope and was representative of a soil type that is often drained in the Champlain Valley utilizing a closely spaced, parallel laterals drain system, it appeared to be a good research site whereby the outlet could be easily retrofitted with a watertable control structure. The field also had a direct outlet into a nearby perennial stream. The field was being cropped with a corn-forage rotation and liquid manure was applied according to nutrient management recommendations, typically as split fall and spring manure applications to the corn and applications immediately following forage cuttings.

Field Site Set-up

A controlled drainage structure was installed on the main drainage line that collected water from multiple parallel closely spaced field laterals. The control structure was placed on the main drain so that one of the field laterals was not affected by the control. The purpose of this set-up was to be able to use and sample the uncontrolled lateral as a means of comparison to the controlled drainage system (Figure 15). The control structure was equipped with a special 22.5° V-notch weir plate that was fitted inside the drainage control structure, and a water level pressure transducer was positioned upstream to monitor the drain discharge. Unfortunately, the access point to the single lateral uncontrolled drain did not provide a very good site to measure the flow, but as shown in Figure 15, both the control structure and the single line were equipped with automated water samplers to monitor the drain water quality.

Figure 17. Drainage control structure and water sampling equipment at the EQIP farm cooperator site in the Champlain Valley.

Experimental Results

Since this site did not lend itself very well for a paired- control versus uncontrolled drain outlet monitoring protocol, the initial sampling during 2009 was to measure background drain water quality from the drainage system with the major focus on phosphorus concentrations. The monitoring started during the spring of 2009 and the drainage control structure was installed on June 23, 2009, but no water level control gates were put in place. Thus, during 2009, the monitoring data represents an uncontrolled drain discharge, and the soluble reactive and total phosphorus concentrations in the uncontrolled drainage effluent in response to precipitation events and liquid manure applications are shown in Figure 18.

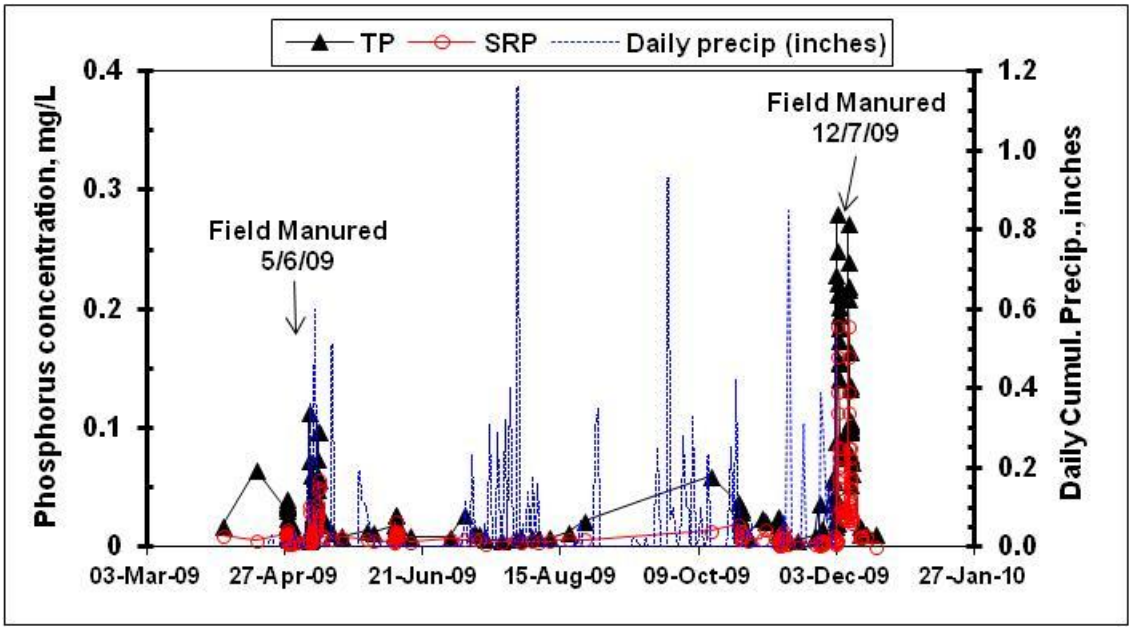

Figure 18. The soluble reactive (SRP) and total phosphorus (TP) concentrations for an uncontrolled drain in response to precipitation and liquid manure applications.

The soluble reactive and total phosphorus concentrations tend to spike shortly after a manure application and in response to a storm event. The concentration spike of total phosphorus during the spring manure application (0.11 mg/L) was much less than that from the fall manure application (0.27 mg/L), a result that most likely reflects a drier soil moisture condition at the time of application. The installation of the control structure and series of rain events during the middle of the summer had little effect on increasing the phosphorus concentrations. However, when the crop was removed, reducing evapotranspiration, and a series of rain events occurred, the soil moisture condition was much higher during the fall manure application. In fact the highest concentration spike (0.28 mg/L) occurred in response to a 0.54 inch rain on Dec. 3rd, four days prior to the manure application. Although no additional rain occurred between Dec. 3rd and the manure application on Dec. 7th, the liquid manure application to the already wet soil and flowing drain impacted the phosphorus concentration in the drain effluent. For this particular situation, a management decision to implement a controlled drain prior to the manure spreading may have likely reduced the loss of phosphorus. However, the producer's management conflict is to also have the field in a dry enough condition to be able to apply the manure.

The nitrate-nitrogen in the drain discharge during the spring and early summer of 2009 is shown in Figure 19. Compared to the background level, the nitrate concentration increased after the manure application and in response to rain events. A side-dress application of additional nitrogen fertilizer in early July while the corn was still small sustained the variable concentrations temporarily until the corn began maturing further.

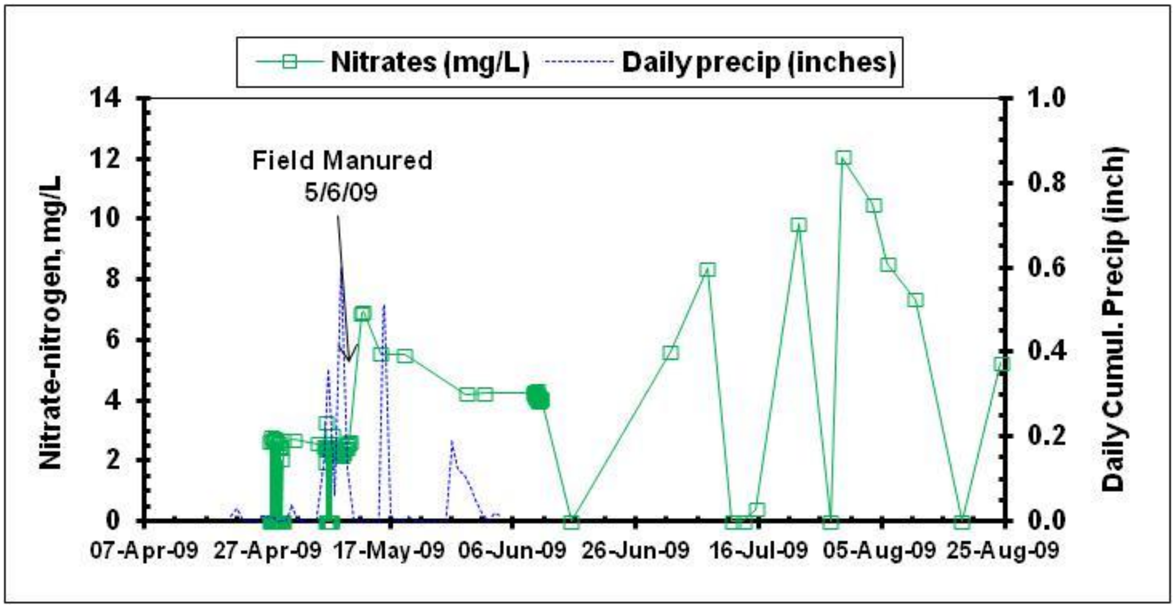

Figure 19. Nitrate-nitrogen concentration in the uncontrolled drain discharge and following the spring and early summer nutrient applications.

The drainage control was initiated during the spring of 2010 and the water level hold back heights within the control structure are shown in Figure 20. The figure also shows the observed water levels or flow hydrograph behind the hold back height in response to storm events. Despite raising the control in early spring and making another small height adjustment, drain flow over the control height still occurred. As the water level receded, the control was lowered further, essentially to keep the drain flow at a minimum during the summer rain events. A large 3.8 inch storm event over a 3-day period in early August still resulted in substantial drain flow. After the water level subsided, the control was raised again in early October and then two successive rain events of 1.65 and 1.7 inches initiated more large drain flows. These storms and the raised control was keeping the field quite wet and so on Nov. 5th the farmer decided to pull out all the control gates so that he could carry out his fall manure application and tillage operations. The control gates were put back in on Nov. 22nd in anticipation of his applying liquid manure. The control was then lowered on Dec. 17th and maintained at that level until the following spring.

The corresponding total and soluble reactive phosphorus concentrations during 2010 are shown in Figure 21. No additional manure was applied in the spring but an application was made during late fall. The highest total (1.2 mg/L) and soluble reactive (0.8 mg/L) phosphorus concentrations for 2010 were observed in January before the drain was controlled. Lower concentration spikes occurred in response to rain events while the drain was being controlled despite some rather large storm events. The 1.65 inch storm event (actually 2.5 inch over 2-days of 9/30 and 10/1) only resulted in a peak total phosphorus concentration of 0.06 mg/L while the control gate was at its lowest setting. The 1.7 inch event (actually 1.9 inch over 4-days of 10/14-17) resulted in a total phosphorus concentration peak of 0.29 mg/L while the control was set at 450 mm hold back height. The higher peak for this latter 4-day storm event was probably caused by the soil having been wetted further from the previous event and the higher control setting. The total phosphorus

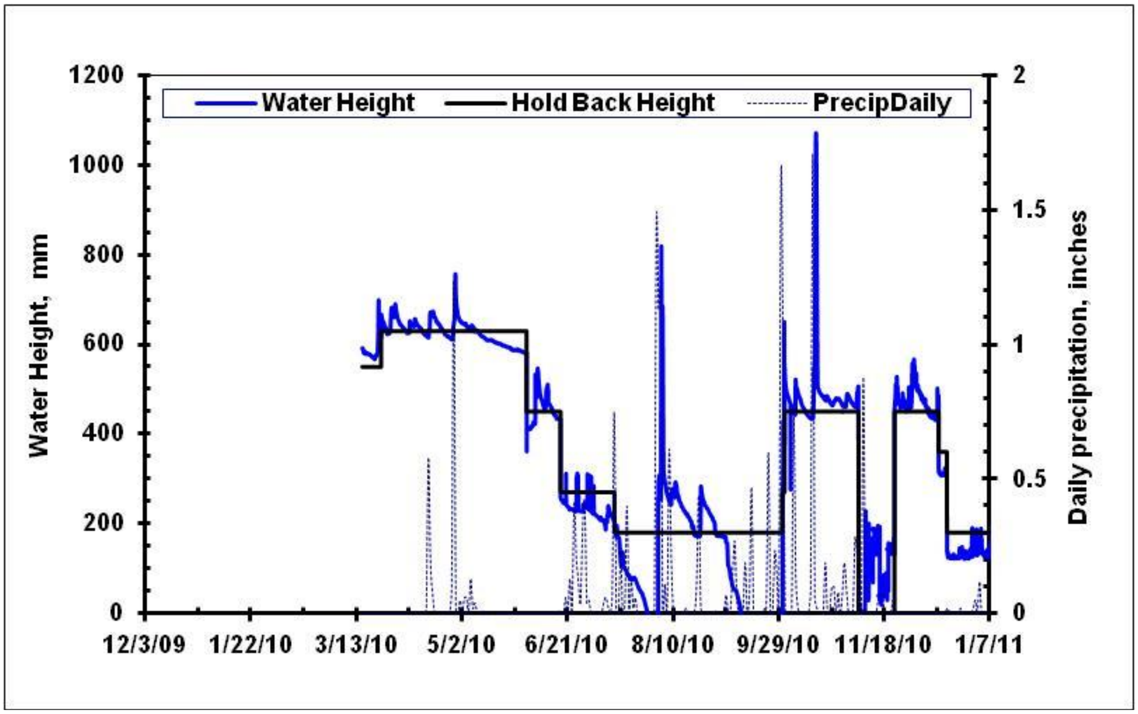

Figure 20. The water level hold back heights and water height or drain flow hydrograph for the controlled drainage period during 2010.

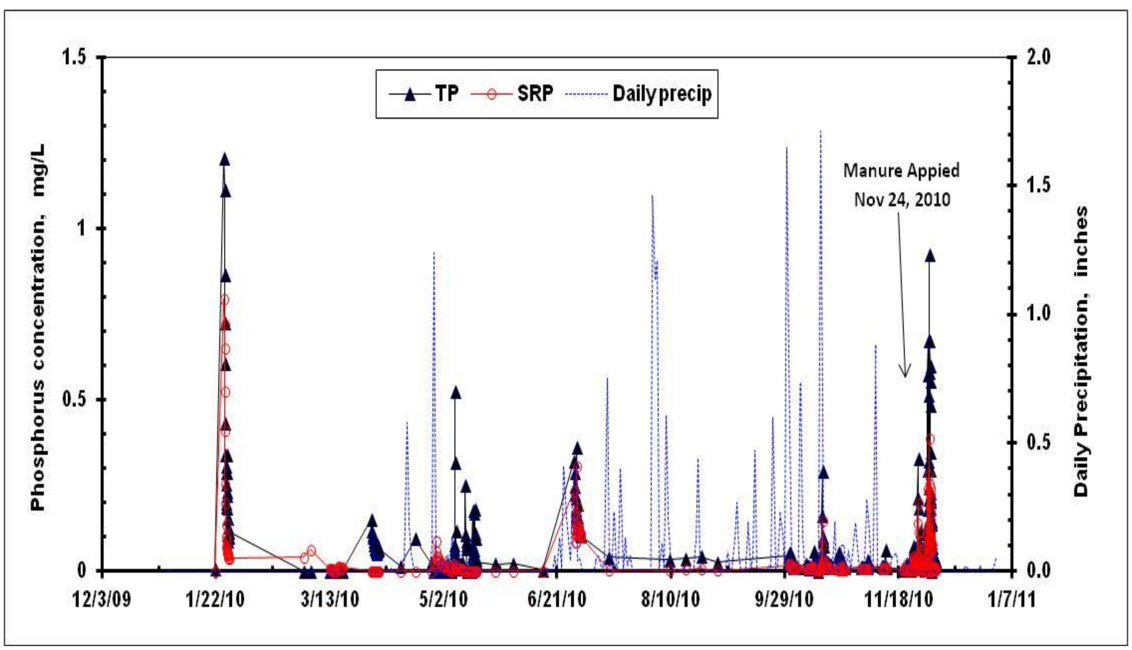

Figure 21. The total and soluble reactive phosphorus concentrations while the drain system was being managed as a controlled drain.

peak concentrations of 0.33 and 0.92 mg/L for Nov. 26th and Dec. 1st, respectively, were not in response to any rain event but did occur shortly after the liquid manure application and raising the level of the control gate. Since the water height in the control structure appears to be fluctuating above the hold back height despite no additional rainfall, the drainage of the soil profile in the entire field has probably not yet come to any equilibrium. The crop has already been removed and the wet fall conditions have sustained the soil moisture to a high level. There may also be an influence of groundwater inflow to the field from adjacent higher elevations which are sustaining the drain flow.

The drainage control management scheme initiated in 2011 was to raise the water level control gates prior to a manure spreading event and then slowly lower them to allow the field to drain to a more acceptable soil moisture condition. The water level hold back heights are shown in Figure 22 along with the observed water levels or flow hydrograph.

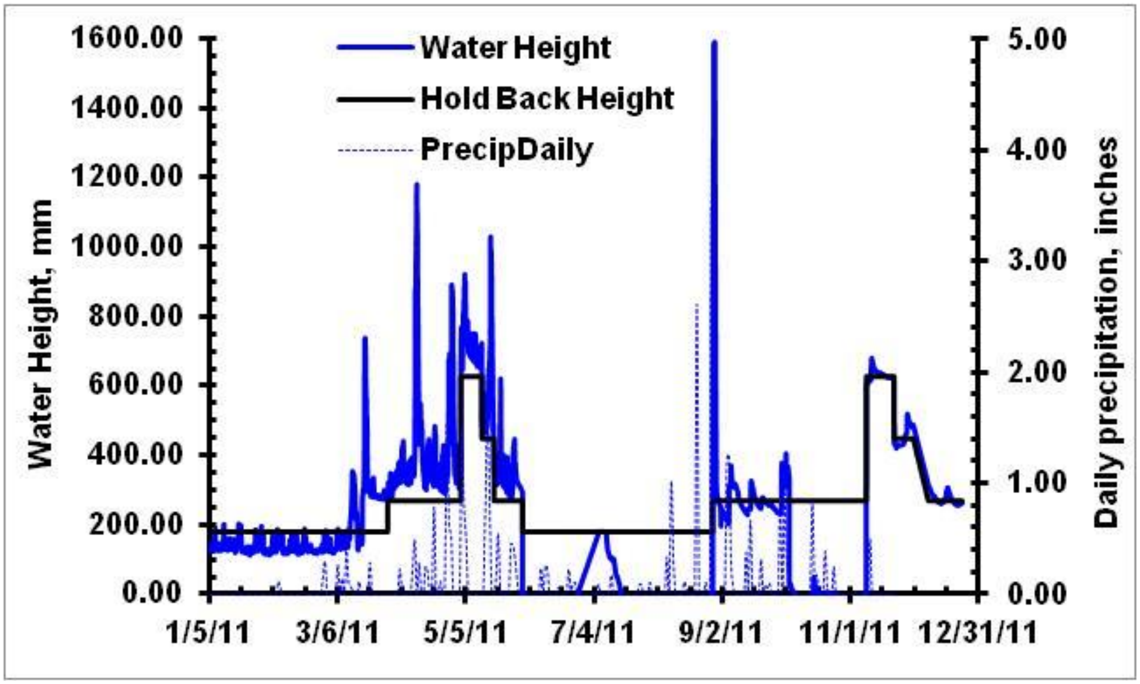

Figure 22. The water level hold back heights and water height or drain flow hydrograph for the two controlled drainage periods around the time of manure application in 2011.

The monitoring results for total and soluble reactive phosphorus concentrations during 2011 are shown in Figure 23. The peak total phosphorus concentration of 2.48 mg/L occurred on May 3rd after the manure application and while a 1.5 inch storm event occurred. The drainage control was set to a hold back height of 630 mm on the day of manure application which reduced the concentration from 0.06 mg/L prior to spreading down to 0.02 mg/L during the morning of May 3rd. However, the storm event overwhelmed the control and high concentrations ensued. Unfortunately, the uncontrolled single lateral drain monitoring site was unreliable for comparative purposes, but based on the paired site monitoring, the controlled drain still likely resulted in somewhat lower concentrations and accumulated loss compared to what may have occurred had no drainage control been in place. For the 59 samples that were taken for the controlled and uncontrolled lateral line during other low flow conditions, the average soluble reactive phosphorus was 0.009 and 0.014 mg/L, respectively. This perhaps indicates there was some benefit of the drainage control at this site certainly during low flow conditions, but a comparison of the total phosphorus samples does not confirm this. Similarly, for the fall time period when the manure was applied on Nov. 8th, the water level gates were raised, and the initial total phosphorus concentration was about 0.02 mg/L and remained at that concentration until Nov. 10th when a 0.5 inch rain event overwhelmed the control water level and created some flow. Although the total phosphorus concentration spiked to 1.2 mg/L, the amount of flow over the control was not large and so the control likely reduced the accumulated loss of phosphorus that would have occurred had the drainage control not been in place.

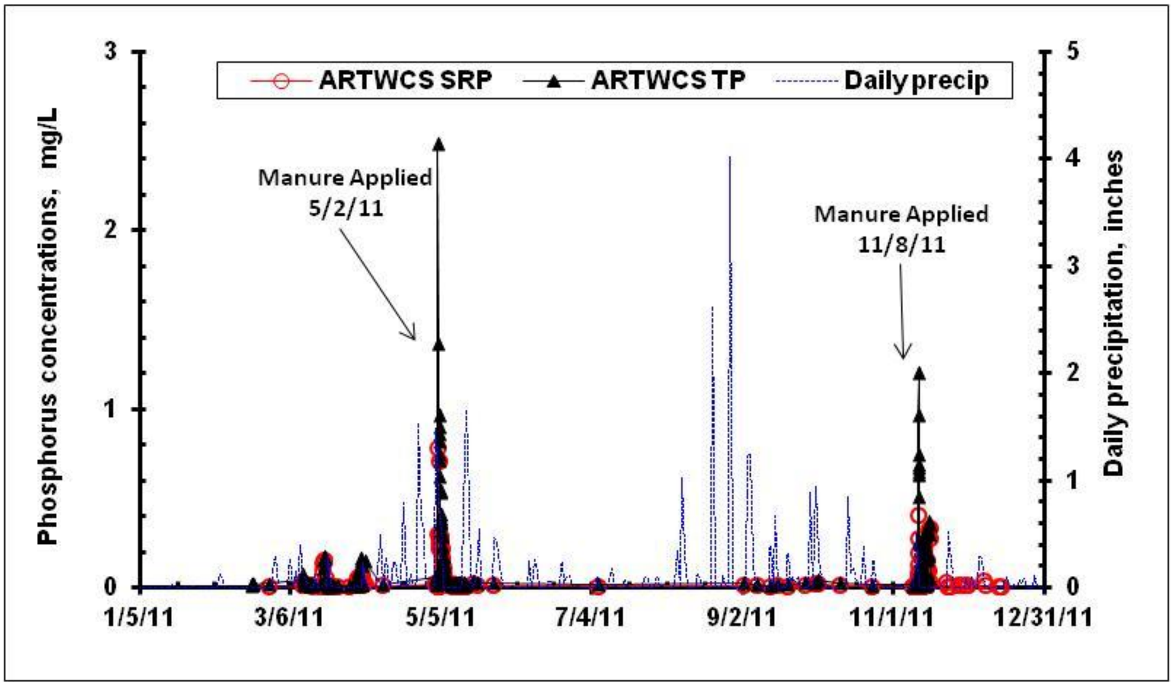

Figure 23. Total and soluble reactive phosphorus concentrations for 2011 and during periods when the drain was managed as a controlled drain during the manure application.

Site Summary

Over 1100 samples were collected for both total and soluble reactive phosphorus analysis for this field site over the three year monitoring period. In summary, the average total phosphorus was 0.08 (range from 0.004 to 2.48) mg/L. The soluble reactive phosphorus averaged 0.04 (range from 0.001 to 0.8) mg/L, and on average represented about 48 percent of the total phosphorus.

Nitrate- nitrogen was analyzed for 124 samples, with about 75 percent of these collected during the first year of the study. Given the study location in proximity to Lake Champlain where phosphorus is the major concern with respect to eutrophication aspects, the nitrate analysis was of lesser concern. Nevertheless, the average nitrate-nitrogen concentration for these samples was 3.8 (range from 0.4 to 12.1) mg/L.

It was unfortunate that a better paired control analysis could not be done and the results for 2009 prior to controlling the drain outflow are probably not directly comparable to when the drain outlet was managed as controlled drainage. The higher peak concentrations observed during the controlled drainage in 2010 and 2011 may be partially a result of maintaining the soil at a higher soil moisture content, but the peak concentrations typically occurred anyway in response to large precipitation events especially when they closely followed the manure applications. It's interesting to note that the farmer commented that the manure needed to be applied prior to a rain event so that the nutrients could be carried into the soil. His applications typically a day or two prior to rain events were not the result of necessity for emptying the manure storage lagoon. The farmer also pulled the control gates when he felt the field was getting to wet, and so that he could apply manure and carry out tillage operations.

PROJECT OUTREACH

Outreach efforts consisted of meeting and communicating with numerous different individuals and groups to assess drainage effluent contamination problems, discussing the aspects of utilizing controlled drainage as a best management practice, demonstrating the installation and use of controlled drainage structures, making several presentations to various groups, and developing and reviewing extension factsheets. In addition to the two watertable control structures that were installed and evaluated on the EQIP cooperator farms, another nine controlled drainage structures were installed at other farm demonstration sites. These installations facilitated field days whereby drainage contractors, farmers, and other interested stakeholders could learn about controlled drainage and perhaps use them to carry out further field-based research and evaluation. In fact personnel at the William H. Miner Agricultural Research Institute located in NY's St. Lawrence Champlain Valley Eco-Region became interested in conducting more controlled drainage investigations and obtained an additional New York State awarded Conservation Innovation Grant to conduct further research and outreach. The applied research and outreach efforts of this Agricultural Research Institute are well received by the local dairy producers in the Lake Champlain region.

Several presentations were given to New York's Chapter of Land Improvement Contractors of America and at Northeast Region Certified Crop Advisor's meetings to inform attendees about the new language in NY's Drainage Guide, the NRCS Code of Practice Standard 554, and on using drainage water management and controlled drainage to address and remediate poor quality drainage water discharges. Presentations about controlled drainage were also made during the basic training sessions given for Certified Crop Advisers. A poster was prepared and presented for a Northeast Region Agronomy Society's Meeting, and several presentations about controlled drainage and project results were given also at the 9th International Drainage Symposium held in conjunction with the XVIIth CIGR World Congress, at the annual NCERA-217 Midwest regional drainage committee meetings, at the Michigan Farm Drainage and Nutrient Management Field Day, at the Northeast Agricultural and Biological Engineering Conference and Canadian Society for Bioengineering meeting, at an American Society of Agricultural and Biological Engineer's annual meeting, and at the CIG Showcase session at the Soil and Water Conservation Society's annual meeting.

With regards to extension publications, two drainage factsheets were prepared (Agronomy Fact Sheets #57 and 58 - http://nmsp.cals.cornell.edu/guidelines/factsheets.html -), and a review was provided for the Drainage Water Management factsheet for the Midwest (http://www.extension.purdue.edu/extmedia/WQ/WQ-44.pdf).

LESSONS LEARNED AND CONCLUDING REMARKS

Based on the responses of the EQIP farm cooperators to controlled drainage, the implementation of this technology as a best management practice for purposes of improving water quality will be quite challenging. The farmers install drainage to remove excess water from their fields and managing it in a way that retains it, especially if no economic benefit is perceived, is certainly not a high priority. With respect to the lessons learned from the laboratory study, whereby liquid manure with a low solids content was more mobile through soil with larger diameter macropores, the producers can perhaps manage the manure at higher solids content, apply to field sites with soil types that are less subject to preferential flow leaching, and/or use tillage to disturb macropores or immediately incorporate. Many producers are already implementing these suggestions based on our early project outreach efforts.

The paired- controlled versus uncontrolled drainage evaluation indicates that some phosphorus load reduction can be achieved during storm events, although the results appear to be variable and dependent on what else may be occurring with the antecedent soil moisture content. A more detailed and carefully managed long term study would be quite useful to better understand the fate and transport dynamics of both phosphorus and nitrogen from manure applied nutrients. Applying manure a day or two prior to storm events, with or without controlled drainage, appears to result in some high nutrient concentration losses. However, it’s not certain from this study that controlled drainage has the effect of reducing nutrient concentrations. Nevertheless, where controlled drainage can be managed to reduce the cumulative water lost, some benefit of nutrient load reduction should occur.

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APPENDIX

Summary of Analytical Methods Used During the Project

Parameter	**Method**	**Detection Level**	**Instrument**
Total Phosphorus (TP)	EPA 365.4	0.01 mg/L	FI Autoanalyzer
Total Dissolved Phosphorus (TDP)	EPA 300.0 (filtered sample)	0.076 mg/L	ICP-AES
Soluble Reactive Phosphorus (SRP)	EPA 365.1 (filtered sample)	0.023 mg/L	FI Autoanalyzer
Organic Phosphorus	TDP - SRP		
Particulate Phosphorus	TP - TDP		
Total Nitrogen (TN)	EPA 351.1	0.05 mg/L	Autoanalyzer
Total Dissolved Nitrogen (TDN)	Persulfate oxidation, Salicylic acid method	0.001 mg/L	Ion Chromatography
Inorganic Anions (NO_3 and NO_2)	EPA 300.0	0.002 mg/L	Ion Chromatography
Dissolved Ammonium (NH_4)	EPA 350.1	0.007 mg/L	Autoanalyzer
Organic Nitrogen	TDN – (NO_3 + NO_2 + NH_4)		
Particulate Nitrogen	TN - TDN		