FINAL REPORT

UNIVERSITY OF MINNESOTA - SWROC DRAINAGE PROJECT

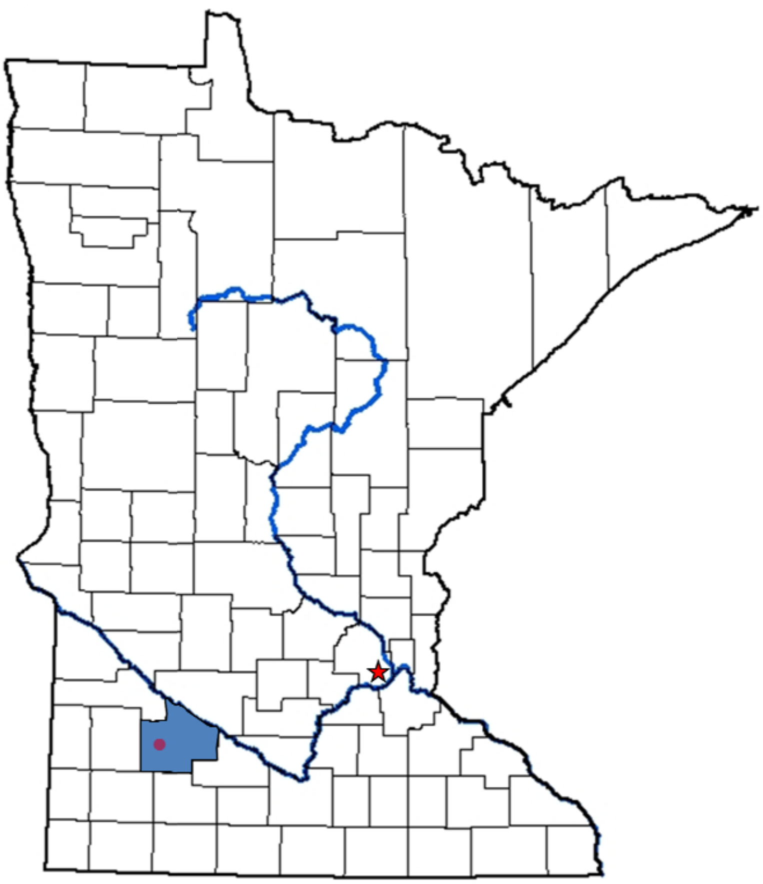
PROJECT INVESTIGATOR
Dr. Jeff Strock

PROJECT ADMINISTRATION
Bruce Montgomery
Russ Derickson

Submitted
March 2010

Submitted to
Minnesota Department of Agriculture

Project Support Provided by
Minnesota Agricultural Fertilizer and Research & Education Council



Drainage Control to Promote High Crop Yields and Diminish Nutrient Losses from Agricultural Fields in Minnesota

Project Summary – The goal of this project was to better understand and quantify the yield, drainage discharge and nitrogen and phosphorus losses from conventional and controlled drainage practices in southwest Minnesota. This project was also designed to develop educational programming and materials on drainage water management practices for a variety of stakeholders. The research data collected at this site clearly demonstrated the environmental benefit of controlled drainage. The two years of data showed that controlled drainage resulted in a 63% reduction in drain outflow compared to conventional drainage. There was also evidence that annual nitrate-nitrogen, total phosphorus, and ortho-phosphorus loads were reduced by 61, 50, and 63%, respectively. However, the reasons for a 33% increase in flow weighted mean total phosphorus concentration under controlled drainage are unclear. Yield results were neutral to positive for the two years of the study. The 3rd Soil and Water Management Field Day and Drainage Design and Water Management Workshop held in August 2008 were very successful. Nearly 100 people attended the field day and 25 farmers, contracts, and agency staff participated in the 1.5 day workshop. In addition, research results were presented to a total of 1430 people at 23 local, regional, national and/or international events during the two year project period.

INTRODUCTION

Widespread adoption of commercial fertilizer use during the 1950's revolutionized agriculture by increasing farm productivity and farm income. Use of commercial fertilizers also increased the amount of farmed cropland because producers were no longer limited by the availability of animal manures for meeting crop nutrient demands. After the introduction of commercial fertilizers, high rates of fertilizer were encouraged to achieve maximum yield and little consideration was given to the potentially adverse environmental impact of excess fertilizer use.

Numerous studies have been conducted to evaluate crop productivity, environmental impact, and/or costs and returns of adopting and implementing various management strategies aimed at optimizing crop productivity and economic return, and minimizing adverse environmental impacts. Farmers are reluctant to adopt and implement management practice changes that for them have been effective over time. A key obstacle to changing management practices is a perceived risk by producers that change will result in decrease crop productivity and farm income.

Despite current trends of increased energy costs, land values, and crop production input costs; high commodity prices, the demand for food and energy security, and the expiration of Conservation Reserve Program (CRP) contracts will result in further intensification of agricultural production on previously retired and existing cropland and increased interest in new management technologies. One technology that has been around for centuries is the practice of water table management through the use of artificial drainage. However, there is increasing societal awareness of and concern about the degradation of natural resources as a result of agricultural production and specifically water quality impairments as a result of artificial drainage. In the United States this concern is reflected in current policy discussions at both Federal and State levels. Government entities desire increased accountability with regard to agriculture's impact on the environment, but do not want the cost of increased regulation. This makes adoption of more responsible, voluntary management practices a preferred option of producers. One of these management practices is water table management through the use of controlled drainage. Controlled drainage is the management of the water table through the use of a water control structure installed in a ditch, or in a main, sub-main, or lateral tile line in order to vary the depth of the drainage system outlet.

Objective – This project seeks to better understand and quantify the yield, drainage discharge and nitrogen and phosphorus losses from conventional and controlled drainage practices. The results will be used to begin to identify optimal drainage water management practices for Minnesota. This project will also develop educational programming and materials on drainage water management practices, and maintaining water quality for stakeholders.

Site Description

Subsurface tile drainage (50-ft spacing, ~ 4 ft depth) was installed on a 91 acre site during fall 2005 at the Hick's family farm near Tracy, MN, Redwood Co. There are no surface inlets at this site connected to the drainage system. The soil at the site is mapped as a Millington loam with 0-1% slope. The field was divided into two management zones, 55 and 36 acres, which outlet into manually operated water table management structures (Figure 1). Each water table management structure is equipped with a stilling well to measure drain flow rate and to collect water samples for determination of drainage water quality.

A paired analysis approach will be used to evaluate the effect of water table management on crop performance, drain flow volume, and nitrate-nitrogen loss from the two management zones. The design will consist of two treatments, conventional and controlled drainage, and two periods of study, a calibration and treatment period. During the calibration period drain flow volume and nitrate-nitrogen data were collected to develop a regression equation between observations from the two management zones. Regression equations developed during the treatment period will be compared with equations developed during the calibration period and tested for differences. The treatment phase of the experiment began in 2008. The west management zone was managed in controlled drainage mode (outlet level maintained at predetermined depths between the drain depth and the soil surface) and the east management zone was managed in conventional drainage mode (outlet level at drain depth).

Data Collection

Water – Two instrument shelters were located near the water level control structures and contain the equipment for measuring water level data and water sample collection from each of the management zones. Each shelter contains two ISCO water samplers (Model #3700) and a

Campbell Scientific Inc., datalogger (CR-10X) used to collect and store stage height (water level) data. Each water level control structure has an attached stilling well with a Druck pressure transducer (Model #CS-420-L) to record changes in stage height in the control structure. The USDA-ARS has a Texas Electronics Inc. rain gauge in the field that collects precipitation at 10 minute intervals.

A combination of grab and storm activated composite and discrete samples were collected for each management zone. Samples were analyzed for nitrate-nitrogen, ammonium-nitrogen, total nitrogen, total phosphorus, and ortho-phosphorus.

Soil – The management zones were grid soil sampled (48 total georeferenced locations) following soybean harvest in order to track soil nutrient status and to interpret crop response. Soil samples were analyzed for available phosphorus and potassium, organic matter, pH, zinc, and sulfur. Composite soil samples at each georeferenced location were collected from the 0-4", 4-8', 8-12", and 12-24" depths. These depths were chosen to assess nutrient levels before liquid swine manure injection following soybean harvest in 2008. All data was entered into a GIS system to spatially join disparate spatial data layers (yield, elevation, soils, nutrients, drainage) into a single database. These data will then undergo spatial statistical inferential analysis. At this time the yield, elevation, and soil nutrient data have been compiled in the GIS system but spatial analysis was not complete at the time of this report.

Yield – At harvest yield is collected using a 6-row combine equipped with a yield monitor. Yield monitor data was processed using Yield Editor software developed by the USDA-ARS. Yield Editor is a tool which allows the user to select, apply and analyze a variety of automated filters and editing techniques used to process and clean yield data.

RESULTS

Educational programming

A combination Field Day and Workshop were held in fall of 2008. The objective of the events was to convene researchers, stakeholders and practitioners to interact on issues related to soil drainage for productivity and environmental enhancement. The 3rd Soil and Water Management Field Day and Drainage Water Management Design Workshop was hosted by the Hicks family (Nettiewyynnt Farm) and was designed to highlight progress on soil and water management research and serve as an example of inter-institutional and inter-agency collaboration. The proceedings from the Field Day included six papers that discuss research projects conducted by scientists from the University of Minnesota, Minnesota Department of Agriculture, and the Agricultural Research Service (USDA-ARS) – Soil and Water Management Research Unit. (http://swroc.cfans.umn.edu/soilandwater/08soilwater_proceeding.pdf). Nearly 100 people participated in the field day and 25 farmers, contracts, and agency staff attended the 1.5 day workshop. Materials developed for the workshop were used at the 2009 Agricultural Drainage and Water Management Workshop in March. The workshop team was also invited to present the workshop as part of the National Land Improvement Contractors Association annual meeting in July, 2010.

Presenters at the Field Day included Dr. Steve Taff, University of Minnesota Extension who discussed the economics of drainage. Drs. John Baker and Rod Venterea, USDA-ARS, St. Paul, presented results of their work on gas emissions from drained and undrained cropland and a managed prairie. Dr. Pam Rice, USDA-ARS, St. Paul and Dr. Adam Birr, MDA, shared results of the fate of acetochlor in drained and undrained cropland and Stacey Feser and Dr. Jeff Strock, University of Minnesota present results about production and environmental benefits and limitations of drainage water management. Finally, Don Pitts, USDA-NRCS, Illinois State Water Quality Specialist was on hand to share the Illinois experience with drainage water management. The field day concluded with the installation of a controlled drainage structure on the Nettiewyynnt Farm.

The 1.5-day Drainage Water Management Design Workshop for contractors was held at the University of Minnesota Southwest Research and Outreach Center. The workshop focused on understanding hydric soils and designing drainage systems with emphasis on designing system for controlled drainage. Workshop instructors include: Dr. Gary Sands, Dr. Jeff Strock, and Dr. Craig Schrader from the University of Minnesota and Dr. Matt Helmers from Iowa State University.

In addition to the Field Day and Workshop, research results were presented to a total of 1430 people at 23 local, regional, national and/or international events during the two year project period.

2008

- Lake Champlain Basin Tile Drainage Conf. – 15 January, 2008. P.K.A Kleinman and J.S. Strock. Controlling P loss from tile drained fields receiving manure. Number of participants: 70.
- AgReliant Agonomy Meeting – 11 March, 2008. Morton, MN. Number of participants: 30.
- 10th International Drainage Workshop of the International Commission on Irrigation and Drainage: Working Group on Drainage – 6-11 July, 2008, Helsinki, Finland. Number of participants: 914300.
- Minnesota Viewers Annual Meeting, 17 July, 2008. Lamberton, MN. Number of participants: 40.
- Soil and Water Management Field Day and Workshop, 13-14 August, 2008. Lamberton, MN. Number of participants: 100.
- The Willow Lake Farm Agro-Ecology Summit: Bio-Energy Crops and Water Quality, 15 August, 2008. Number of participants: 80.
- Heron Lake Watershed District Bus Tour, 11 September, 2008. Number of participants: 20.
- Women's Group – 17 September, 2008. Lamberton, MN. Soil and Water Conservation Practices. Number of participants: 80.
- Lake Crystal tour – 17 September, 2008. Lamberton, MN. Water Management Practices to meet Production and Environmental Goals. Number of participants: 80.
- Agricultural Drainage Management System Task Force Meeting – 18-19 September, 2008. Columbus, OH. Number of participants: 30.
- Iowa-Minnesota Drainage Forum – 2 December, 2008. Owatonna, MN. Number of participants: 90.

- CPM Short Course. – 18 December, 2008. St. Paul, MN. Number of participants. 175.

2009

- Winter Crops Days – 14 & 16 January, 2009. SROC: Waseca, Lake Crystal, and Arlington, MN. Number of participants: 100.
- Hawk Creek Watershed Project meeting – 5 February, 2009. Willmar, MN. Number of participants: 91.
- SWCS Annual Meeting, July 11–15, Dearborn MI. Number of participants: 25.
- Agro-Ecology Summit, The Willow Lake Farm – 21 August, 2009. Number of participants: 90.
- CIG Field Day, Wilmont, MN. 26 August, 2009. Number of participants: 15.
- MN Ag. Expo, 8 January, 2009. Morton, MN.
- MN Land Improvement Contractors Association – 19 January, 2009. Owatonna, MN. Number of participants: 35.
- Agricultural Drainage Workshop – 18 February, 2009. Mankato, MN. Number of participants: 50.
- MVTL Fertility Seminar – 19 February, 2009. New Ulm, MN. Number of participants: 35.
- West Central Inc., Spring Agronomy Update – 25 February, 2009. Owatonna, MN. Number of participants: 79.
- Agricultural Drainage and Water Management Workshop – 10-11 March, 2009. Willmar, MN. Number of participants: 25.

Field experiment

Precipitation

Overall 2008 was below normal precipitation, 21 in., compared to the 30 yr- normal of 28 in. During the growing season, precipitation was below normal between June and September which resulted in soil moisture deficit conditions (Table 1). Above normal precipitation in October contributed to soil moisture recharge. Overall the 2009 growing season was below normal precipitation, 24 in., compared to the 30 yr- normal of 28 in. During the growing season, precipitation was 30% below normal between April and September (Table 1). Above normal precipitation in October contributed to soil moisture recharge. Although the 2009 growing season was dry the crop never suffered drought stress due to cooler than normal temperatures. Air temperatures were below normal for the growing season (data not shown).

Field management

Field management practices used by the grower were typical for the region and are detailed in Tables 2 through 5. In 2008, when soybean was planted there was a seven day difference in planting dates between the east and west management zones which resulted in the producer using two different soybean varieties in the field (Table 2). It appears from the yield map (Figure 2) that there were differences in soybean performance between the two soybean varieties planted in the field. Weed management was accomplished through two applications of Durango and insect management for soybean aphid was accomplished with a single application of Nufos (Table 5). There was a concern that the population of soybean aphid peaked a second time in mid to late August and that no counter measures were taken which may have affected soybean yield. In fall 2008, liquid swine manure was commercially applied using a disc-cover implement to both zones of the field at a rate of 4000 gal/A (Table 4). Analysis showed that the manure contained 42 lb N/1000 gal, 22 lb P/1000 gal, and 32 lb K/1000 gal. Based on this analysis and the assumption that 80% of the nitrogen was available, 134 lb N/A, 88 lb P/A, and 128 lb K/A was applied. Two roundup ready triple stack corn hybrids were planted. The hybrid DeKalb 52-59 provided protection against corn rootworm and corn borer and was planted to 80% of both zones. The hybrid DeKalb 52-62 was planted as a refuge to 20% of both zones to prevent pest resistance. The refuge area was treated with Aztec insecticide at planting. Weed management was accomplished with a single application of Halex GT3 (Table 5).

Soil Test Results

The spatial distribution, horizontal and vertical, of soil test results is shown in Figures 3 through 12. Soil pH is shown in Figures 3 and 4; soil test phosphorus (Olsen P) is shown in Figures 5 and 6; available potassium is shown in Figures 7 and 8; soil sulfate is shown in Figures 9 and 10 and soil test zinc is shown in Figures 11 and 12.

The field is dominated by one soil, Millington loam. The majority of the field tested in the low to medium categories based on the Olsen soil phosphorus test (Table 6 and Figure 5A). This result is likely due to the high soil pH values in the same areas of the field (Table 6 and Figure 3A). Based on soil test results for available potassium, there was sufficient potassium for corn and soybean production in this field (Table 6 and Figure 7A). Soil test results for zinc showed that zinc was not a limiting nutrient based on University thresholds (Table 6 and Figure 9A). Historically, zinc was part of the producer's fertilizer management plan although no recent applications of zinc have been made. Soil test results for sulfate indicate a fairly constant amount (~5 ppm) of sulfate in the soil at the end of the growing season (Table 6 and Figure 11A).

Grain Yield

Yields for the drainage management zones were extracted from combine yield monitor data. Yield differences between the different drainage management practices were determined using GIS techniques. Soybean yields for the east (conventional drainage) and west (controlled drainage) management zones were poor in 2008, averaging 22 and 19 bu/A (Table 7). Drought, variety selection, insect pressure (soybean aphid) and pathogen pressure (soybean cyst nematode) combined to negatively impact soybean yields. The corn yield monitor data required extensive processed using the Yield Editor software to clean up the data (Figure 3). Corn yields for the east and west management zones were very good in 2009 despite dry conditions, averaging 202 and 225 bu/A, respectively (Table 7).

Previous research has demonstrated that the practice of controlled drainage may result in agronomic yield benefits as well as environmental benefits. Although the current research has been conducted since 2006, and side by side comparisons of controlled and conventional drainage have been compared since 2008, to date the yield results have been neutral for soybean (2008) and positive for corn (2009). Yield results at four demonstration sites across southern Minnesota have shown neutral to slightly lower yields when comparing controlled to conventional drainage systems. There is insufficient data at this time to indicate whether the practice of controlled drainage will translate into yield increases for producers in Minnesota.

Drain outflow

The extent of daily precipitation and drainage discharge from the east and west management zones are shown in Figure 12. Controlled drainage resulted in a 61% reduction in drainage compared to conventional drainage between 2008 and 2009. Below average precipitation had an effect on the magnitude and duration of drainage in both years. Total annual precipitation was 15% to 28% below average. Initiation of drain flow and drain volume during average or wet years would be expected to be greater. Despite greater total precipitation, less water drained from the drainage systems in 2009 compared to 2008 (Table 8). This is an artifact of the timing of precipitation and water stored in the soil profile. In April 2008 above average precipitation occurred at the beginning of the drainage season, which extends from March through July in Minnesota. Thus more water was available to be drained. In contrast, dry conditions between March and July and above average precipitation occurred in October 2009 at the end of a dry growing when the soil profile had a lot of storage capacity resulted in less drainage in 2009..

Following harvest in both years the weir boards in the west water level management structure were raised to within six inches of the soil surface which effectively changed the drainage system outlet depth. This is typical for water management with controlled drainage during the non-growing season. Before planting the drainage system outlet is lowered from the non-growing season level 10 to 14 days before planting to allow for adequate drainage before field operations. Spring water management with controlled drainage consisted of lowering the outlet depth of the drainage system to the drain depth which in this case was approximately 4 feet below the soil surface. The weir boards were removed from the east and west management zones on May 15th in 2008 and on April 9th in 2009. A total of 2.5 inches of water was drained from the west management zone between May 15 and May 23 in 2008 and a total of 1.5 inches between April 9 and May 25 in 2009 (Table 8 and Figure 12). Following planting the weir boards were set at 2 feet below the soil surface in the west management zone for the rest of the growing season. No weir boards were installed in the east water level control structure after planting and the drainage system outlet was maintained at about 4 feet below the soil surface for the duration of the growing season. A total of 7.9 and 3.2 inches of water was drained from the east zone during 2008 and 2009, respectively. (Table 8).

Nutrient loss

One of the most significant water quality impairments within aquatic ecosystems is accelerated eutrophication caused by nutrient over-enrichment. Although many factors contribute to eutrophication, most attention has focused on the supply of carbon, nitrogen, and phosphorus.

Nitrogen is usually abundant in freshwater systems and occurs in water as dinitrogen gas, N_2, nitrite, NO_2^-, nitrate, NO_3^-, ammonium, NH_4^+, and in diverse organic forms. Nitrogen availability is usually regulated by microbial processes. Generally, freshwater systems are phosphorus (as orthophosphate) limited. That is, if all the available phosphorus is consumed, plant growth will cease, no matter how much nitrogen is available. Many freshwater systems experience influxes of nitrogen and phosphorus from various external sources. Thus, if sufficient phosphorus is available, high concentrations of nitrate will lead to phytoplankton (algae) and macrophyte (aquatic plant) production. Generally, a phosphate concentration of 10 ug/L (0.01 mg/L) will support phytoplankton production and concentrations of 30 to 100 ug P/L (0.03 to 0.1 mg P/L) or higher will likely trigger algal blooms.

The average annual nitrate-nitrogen load from the west management zone under controlled drainage was 61% lower than from the east management zone under conventional drainage, 4.5 lbs. NO_3-N/A compared to 11.4 lbs. NO_3-N/A, respectively. The two-year average flow weighted mean nitrate-nitrogen concentrations from the east and west management zones were 10 and 7.5 mg/L, respectively. These results indicate that reduced loss of nitrate-nitrogen under controlled drainage versus conventional drainage was mainly due to differences in water outflow between the two systems. More nitrate-nitrogen was transported along with drainage water from the conventional system.

There was considerable variability in nitrogen loss from the conventional and controlled drainage zones between 2008 and 2009. The main explanation for this result is the difference in timing and magnitude of precipitation between 2008 and 2009. The nitrate-nitrogen load from the east management zone under conventional drainage ranged from 2.7 to 20 lb/A. In contrast, the nitrate-nitrogen load from the west management zone under controlled drainage ranged from 2 to 7 lb/A. Likewise, the flow weighted mean nitrate-nitrogen concentration from the east management zone ranged from 4 to 11 mg/L, whereas the, flow weighted mean nitrate-nitrogen concentration from the west management zone ranged from 7 to 13 mg/L.

The average annual total phosphorus load from the west management zone under controlled drainage was 50% lower than from the east management zone under conventional drainage, 0.04 lbs. P/A compared to 0.08 lbs. P/A, respectively. These results indicate that more total phosphorus was transported along with drainage water from the conventional system. The two-year average flow weighted mean total phosphorus concentrations from the east and west management zones were 62 and 93 μg/L, respectively. This result represents a 33% increase in flow weighted mean total phosphorus concentration. The reasons for the increase under controlled drainage are unclear.

There was considerable variability, although smaller in magnitude than for nitrogen, in total phosphorus loss from the conventional and controlled drainage zones between 2008 and 2009. A partial explanation for this result was, as for nitrogen, related to the differences in timing and magnitude of precipitation between 2008 and 2009. The total phosphorus load from the east management zone under conventional drainage ranged from 0.04 to 0.12 lb/A. In contrast, the total phosphorus load from the west management zone under controlled drainage ranged from 0.03 to 0.05 lb/A. Likewise, the flow weighted mean total phosphorus concentration from the east management zone ranged from 55 to 69 μg/L, whereas the, flow weighted mean total phosphorus concentration from the west management zone ranged from 49 to 137 μg/L. Again, the reasons for the increase in flow weighted mean total phosphorus concentration under controlled drainage are unclear.

Similar trends in the results were found for ortho-phosphorus as total phosphorus. The average annual ortho-phosphorus load from the west management zone under controlled drainage was 63% lower than from the east management zone under conventional drainage, 0.015 lbs. P/A compared to 0.04 lbs. P/A, respectively. These results indicate that more ortho-phosphorus was transported along with drainage water from the conventional system. The two-year average flow weighted mean ortho-phosphorus concentrations from the east and west management zones were 33 and 31 μg/L, respectively. This result represents a 7% decrease in flow weighted mean ortho-phosphorus concentration.

Similar trends in variability of results were found for ortho-phosphorus as total phosphorus. The ortho-phosphorus load from the east management zone under conventional drainage ranged from 0.01 to 0.07 lb/A. In contrast, the ortho-phosphorus load from the west management zone under controlled drainage ranged from 0.01 to 0.02 lb/A. Likewise, the flow weighted mean ortho-phosphorus concentration from the east management zone ranged from 19 to 38 μg/L, whereas the, flow weighted mean ortho-phosphorus concentration from the west management zone ranged from 28 to 34 μg/L.

It is unclear what the cause of the variability and higher than expected total phosphorus concentration is from. There are several causal factors which have been ruled out including: coarse textured soil, high soil test phosphorus concentrations, and a long history of manure application. Other plausible reasons for the high total phosphorus concentrations are the installation of the drainage system which disturbed and mixed the soil which could result in soil enriched with phosphorus to be relocated in close proximity to the buried drain pipe. The drainage system was installed in the fall of 2005 and higher than expect total phosphorus concentrations are still being observed. The source of phosphorus could partially be attributed to dissolution of phosphorus from natural soil minerals (i.e. rocks). The glacial parent material suggests that dissolution of phosphorus from soil minerals would not likely be a significant contributor to phosphorus transport from soils at this site. However, the soils at the site have not undergone mineralogical investigation by x-ray diffraction methods to support this hypothesis. Another potential source of phosphorus is that which is stored along with soil organic matter. No organic matter fractionation has been carried out on soils from the site, although the average soil organic matter content ranged from 2.9 to 4.9 % (Table 6). Preferential flow pathways could transport phosphorus to the drain pipe. Soil cracking and earthworm burrows have been observed at the site. Sediment deposition in the drain pipe from installation of the drainage system and possibly preferential transport of soil particles could contribute to situations where deposited sediments act as a source and sink of phosphorus. There are no surface intakes in either zone. Finally, the source of phosphorus could be due to reductive dissolution of phosphorus coupled with microbial reduction. It is well know that increased phosphorus mobility due to dissolution, release of phosphorus into the soil solution, of Fe(III)-phosphate minerals or Fe-oxides with adsorbed phosphorus in soils increases under reduced conditions associated with seasonal flooding and/or water logging of soils. This process has also been coupled with soil organic matter and dissolved organic matter. The very nature of controlled drainage may result in conditions which promote reductive dissolution of phosphorus. The practice of controlled drainage results in elevated variable water table elevations throughout the year; within six inches of the soil surface during the non-growing season, and within two feet of the soil surface during the growing season. Some have argued that the bulk soil does not become reduced long enough or to the extent necessary to cause reducing conditions in the soil that would increase phosphorus mobility. However, it is highly probable that zones exist within the soil, within aggregates, that would favor conditions where reductive dissolution of phosphorus may occur. Clearly the issues surrounding phosphorus and controlled drainage require additional investigation.

Conclusion

The research data collected at this site clearly demonstrates the environmental benefit of controlled drainage. However, a positive yield response to controlled drainage only occurred in 2009. The two years of data showed that controlled drainage resulted in a 63% reduction in drain outflow compared to conventional drainage. There was also evidence that annual nitrate-nitrogen, total phosphorus, and ortho-phosphorus loads were reduced by 61, 50, and 63%, respectively. However, the reasons for the 33% increase in flow weighted mean total phosphorus concentration under controlled drainage are unclear.

Table 1. Monthly precipitation at the experimental site.

Month	Precipitation (in)		
	2008	**2009**	**30-yr Normal**
January	0.3	0.3	0.6
February	0	0.6	0.6
March	1.1	1.1	1.7
April	4.1	1.5	3.0
May	2.4	1.6	3.4
June	0.4	3.2	4.1
July	2.6	2.0	3.9
August	2.5	3.1	4.0
September	2.2	3.3	3.0
October	2.1	4.9	2.0
November	1.4	0.4	1.4
December	1.4	1.9	0.6
TOTAL	**20.5**	**24.0**	**28.3**

Crop rotation: Corn – Corn – Soybean

Table 2. Management

Crop year	Description	
	EAST	WEST
2008		
Soybean variety	Asgrow 2002	Pioneer 92m21
Planting date	05/23/08	05/16/08
Seeding rate	155,000	155,000
Harvest date	10/01/08	09/24/08
2009		
Corn variety	Dekalb 52-59 RR VT (80%) Dekalb 52-62 RR (20%) refuge	Dekalb 52-59 RR VT (80%) Dekalb 52-62 RR (20%) refuge
Planting date	04/22/09	04/22/09
Seeding rate	35,500	35,500
Harvest date	11/02/09	11/02/09

Table 3. Tillage

Crop year	Description
2008	Fall V-rip; Spring field cultivate
2009	Fall sweep swine manure; Spring field cultivate

Table 4. Nutrient inputs

Crop year	Nitrogen ($lb\ N\ A^{-1}$)	Phosphorus ($lb\ P_2O_5\ A^{-1}$)	Potassium ($lb\ K_2O\ A^{-1}$)
2008	160	60	80
2009†	134	88	128

† liquid swine manure, 4000 gal/A; 42 lb N/1000 gal, 22 lb P/1000 gal, 32 lb K/1000 gal

Table 5. Pesticide inputs

Crop year	Name	Ap. date	Active ingredient	Ap. Method	Ap. rate
2008	Durango	6/17/08	Glyphosate	Post	30 oz A^{-1}
	Durango	7/16/08	Glyphosate	Post	30 oz A^{-1}
	Nufos	7/30/08	Chlorpyrifos	Post	1.0 pt. A^{-1}
2009	Halex GT3	6/01/09	Glyphosate, mesotrione, and S-metolachlor	Post	3.6 pt. A^{-1}
	Aztec (refuge)	4/22/09	Tebupirimphos cyfluthrin	Planting	3.2 lb. A^{-1}

Table 6. Soil chemical property data from conventional (east) and controlled (west) drainage management zones following 2008 growing season.

Variable	EAST			WEST		
	Mean	Min.	Max.	Mean	Min.	Max.
0-4 inch						
pH	7.6	7.4	7.8	7.7	7.6	7.8
OM (%)	4.7	3.4	5.4	4.9	3.1	6.1
Bray P1 (ppm)	21	11	39	17	2	42
Olsen P (ppm)	11	5	22	10	4	28
Available K (ppm)	256	181	332	270	156	386
Sulfate (ppm)	5	5	7	5	5	8
Zinc (ppm)	1.4	1.1	1.7	1.5	0.9	2.1
4-8 inch						
pH	7.6	7.4	7.8	7.7	7.6	7.8
OM (%)	4.2	2.9	5.1	4.3	2.5	5.3
Bray P1 (ppm)	7	2	14	6	2	15
Olsen P (ppm)	5	2	22	5	2	22
Available K (ppm)	215	137	261	223	124	348
Sulfate (ppm)	6	5	8	5	5	7
Zinc (ppm)	1.0	0.6	1.6	1.1	0.5	2.6
8-12 inch						
pH	7.6	7.4	7.9	7.7	7.6	7.9
OM (%)	3.3	1.1	4.6	3.6	1.1	4.7
Bray P1 (ppm)	2	2	5	3	2	10
Olsen P (ppm)	3	2	6	3	2	9
Available K (ppm)	164	84	226	188	73	268
Sulfate (ppm)	6	5	8	5	5	7
Zinc (ppm)	0.5	0.3	0.8	0.7	0.3	1.3
12-24 inch						
pH	7.7	7.4	7.9	7.8	7.6	8.0
OM (%)	2.9	1.4	4.0	3.1	0.9	4.9
Bray P1 (ppm)	2	2	2	2	2	4
Olsen P (ppm)	3	2	5	3	2	5
Available K (ppm)	170	105	252	175	77	253
Sulfate (ppm)	6	5	11	5	5	7
Zinc (ppm)	0.5	0.2	0.7	0.6	0.3	1.2

Table 7. Grain yield from conventional (east) and controlled (west) drainage management zones for 2008-2009.

Year	EAST	WEST
	(bu/A)	
2008	22	19
2009	225	202

Table 8. Water quality results from conventional (east) and controlled (west) drainage management zones for 2008-2009.

	2008		2009	
	EAST	WEST	EAST	WEST
Precipitation (inches)	21		24	
Drainage (inches)	7.9	2.5	3.2	1.5
Total nitrogen (lbs/A)	18	8	3.1	2
Nitrate nitrogen (lbs/A)	20	7	2.7	2
Nitrate concentration (mg/L)	11	13	4	7
Total phosphorus (lbs/A)	0.12	0.03	0.04	0.05
Total Phosphorus concentration (mg/L)	69	49	55	137
Ortho-phosphorus (lbs/A)	0.07	0.02	0.01	0.01
Ortho Phosphorus concentration (mg/L)	38	28	19	34

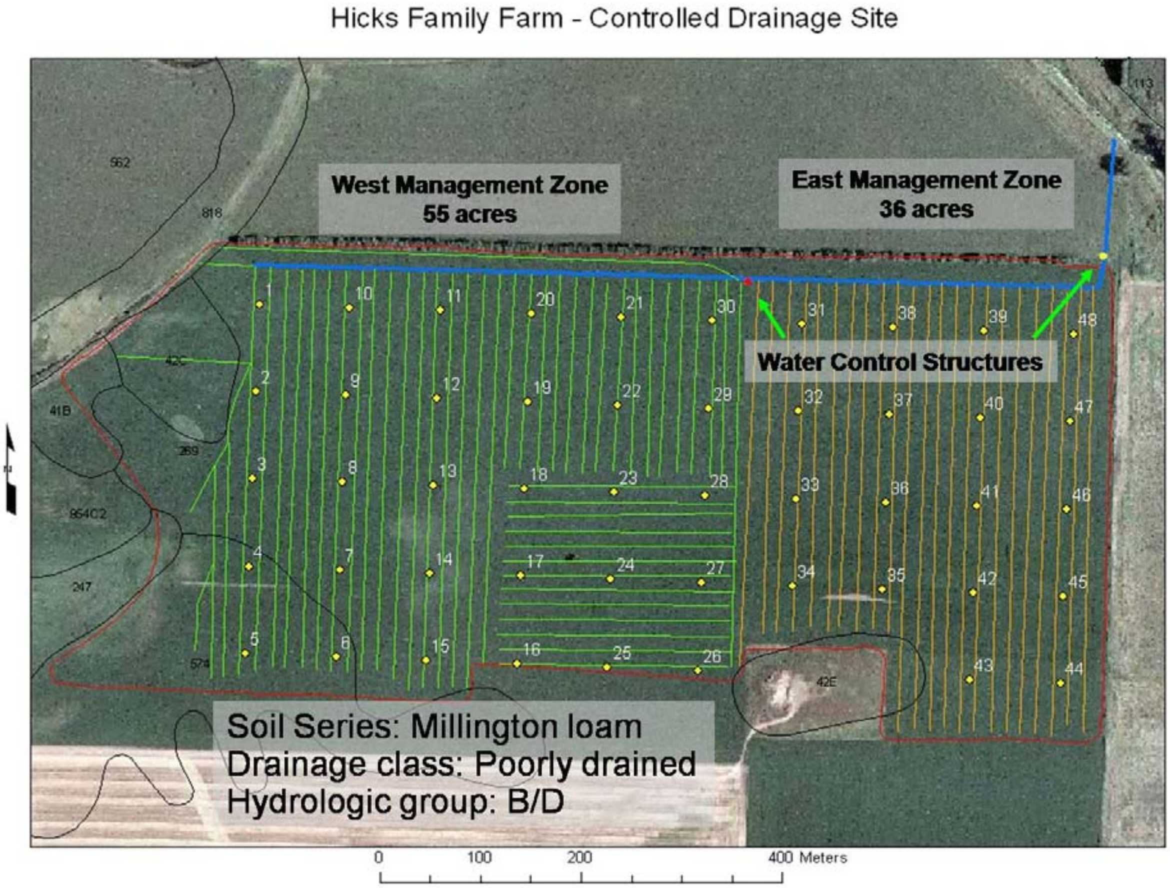


Figure 1. Field site showing soil types, location of water control structures, and drainage system layout.

Figure 2. Soybean yield monitor data from the experimental field, 2008.

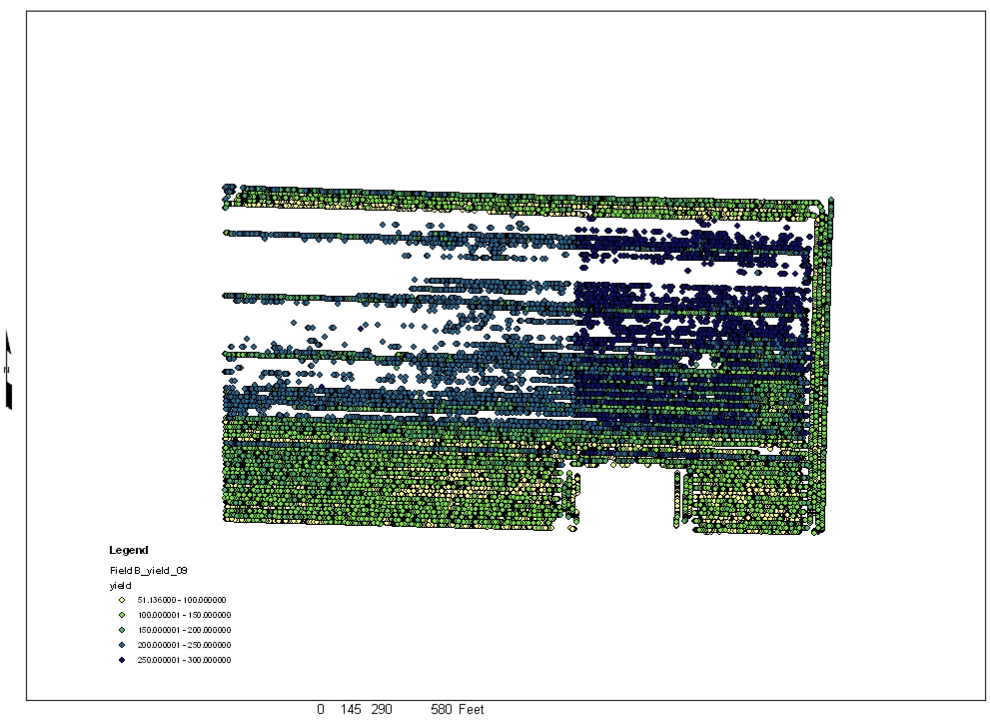


Figure 3. Corn yield monitor data from the experimental field, 2009.

A

B

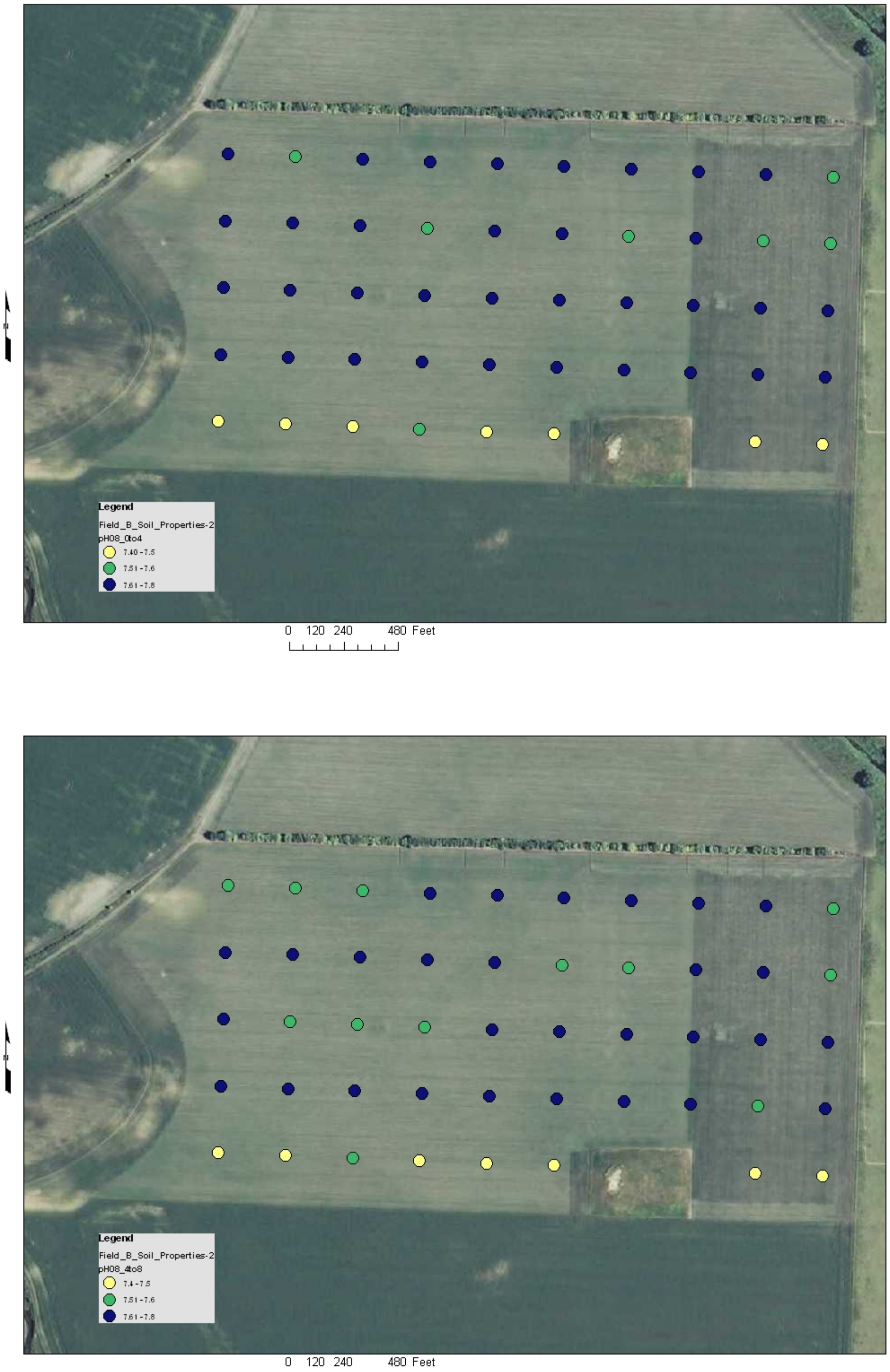
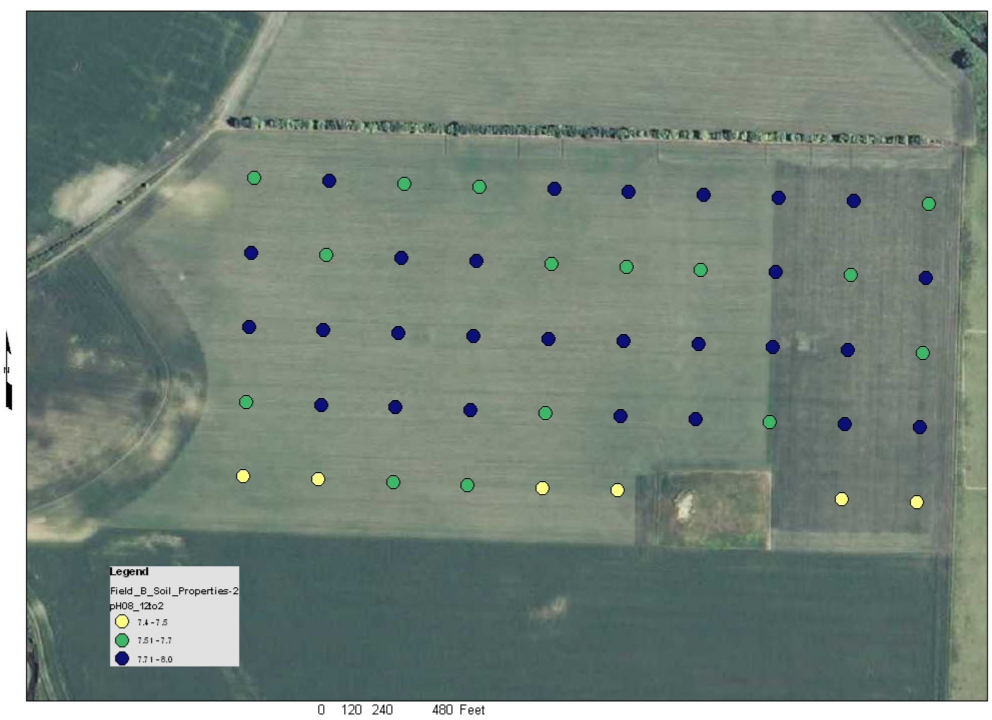


Figure 4. Soil pH values from the: (A) 0-4" depth and (B) 4-8" depth at the experimental field.

A



B

Figure 5. Soil pH values from the: (A) 8-12" depth and (B) 12-24" depth at the experimental field.

A

B

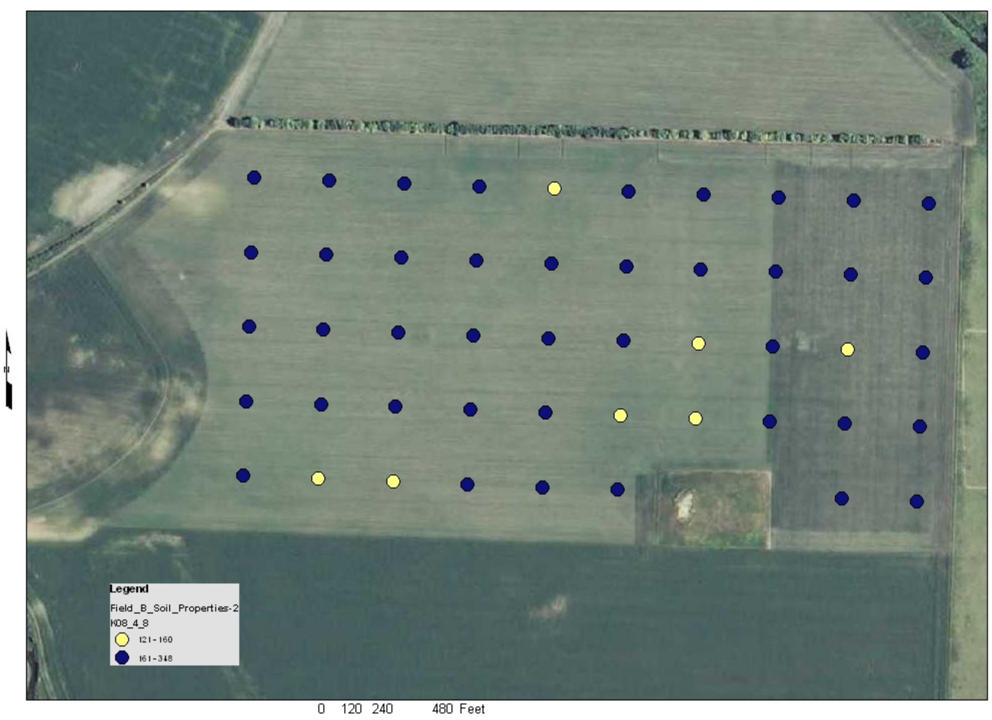
Figure 6. Olsen P values from the: (A) 0-4" depth and (B) 4-8" depth at the experimental field.

A

B

Figure 7. Olsen P values from the: (A) 8-12" depth and (B) 12-24" depth at the experimental field.

A



B

Figure 8. Available potassium values from the: (A) 0-4" depth and (B) 4-8" depth at the experimental field.

A

B

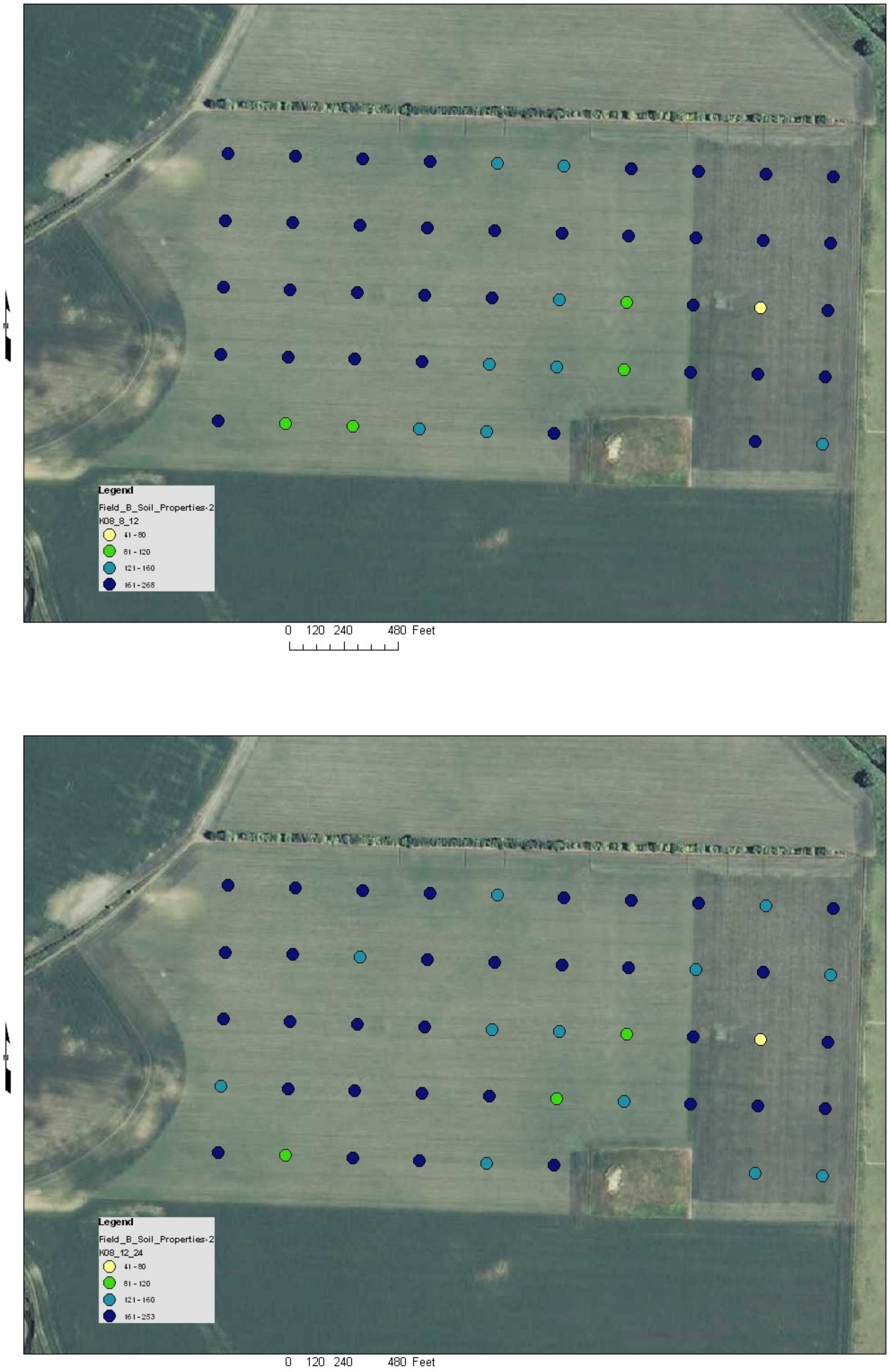


Figure 9. Available potassium values from the: (A) 8-12" depth and (B) 12-24" depth at the experimental field.

A

B

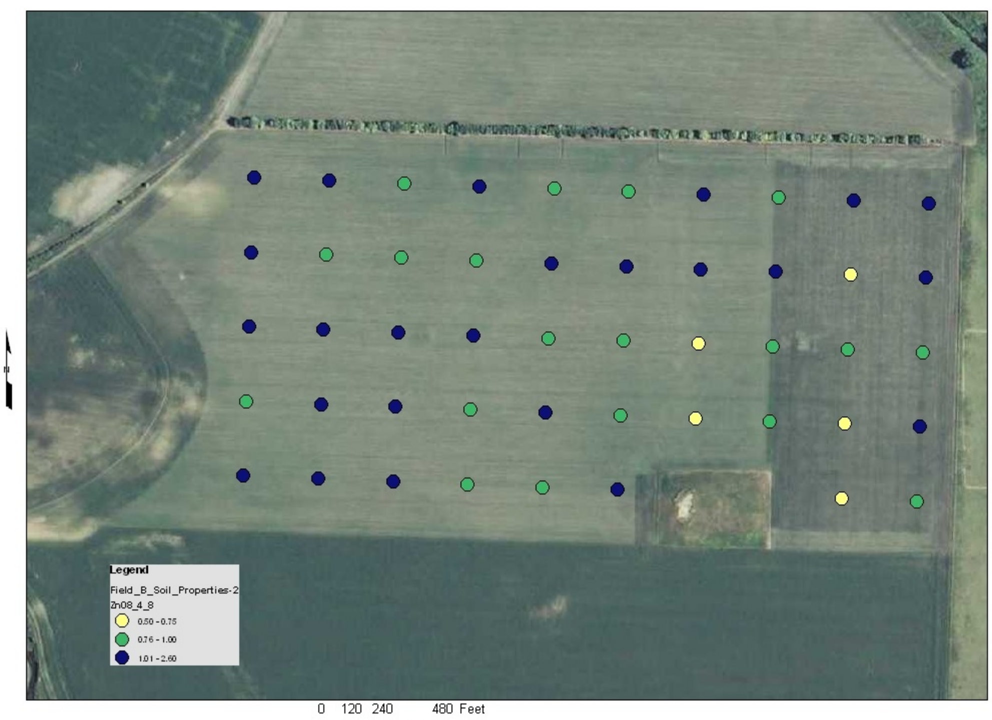


Figure 10. Soil zinc values from the: (A) 0-4" depth and (B) 4-8" depth at the experimental field.

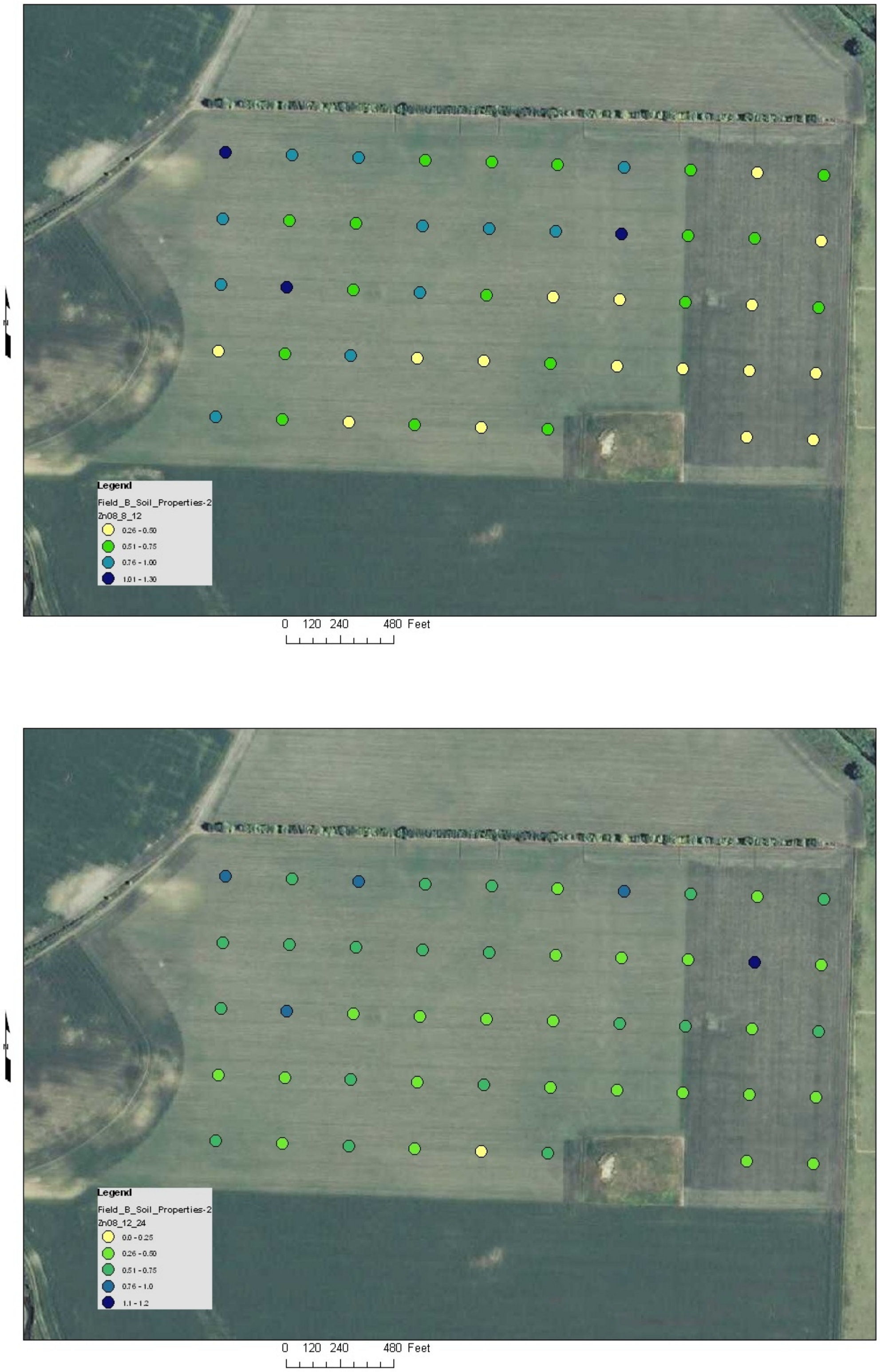
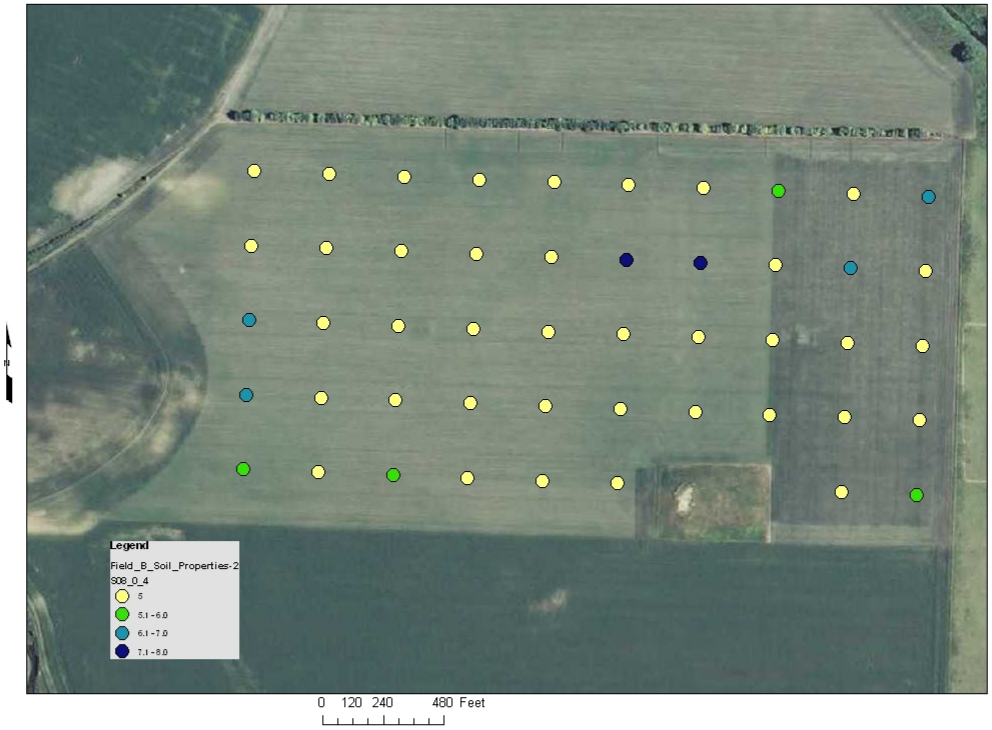


Figure 11. Soil zinc values from the: (A) 8-12" depth and (B) 12-24" depth at the experimental field.



A

B

Figure 12. Soil sulfate values from the: (A) 0-4" depth and (B) 4-8" depth at the experimental field.

A

B

Figure 13. Soil sulfate values from the: (A) 8-12" depth and (B) 12-24" depth at the experimental field.

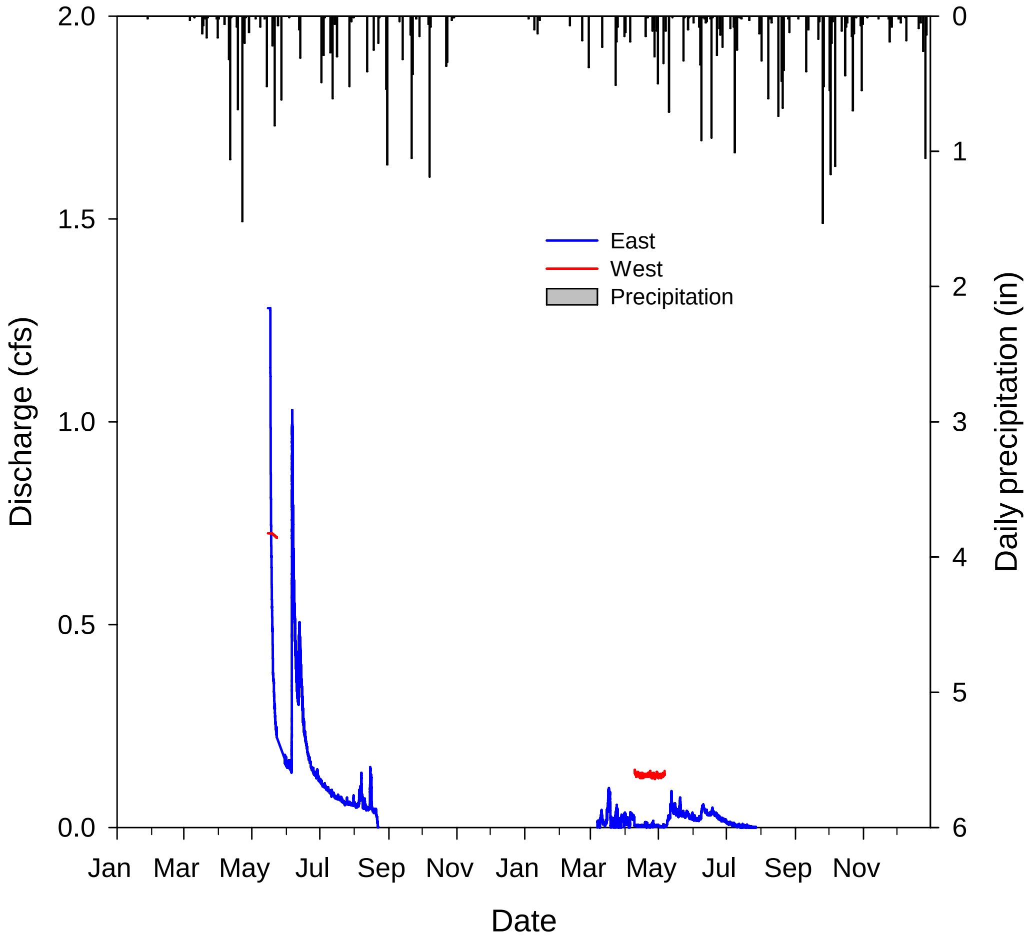


Figure 14. Precipitation and drainage discharge from conventional (east) and controlled (west) drainage management zones during 2008 and 2009.

ACKNOWLEDGEMENTS

This project was established through the leadership of the University of Minnesota, Dr. Jeff Strock. Drainage system designs were completed through an iterative process that included the cooperation of the Dr. Gary Sands. Funding was provided through the Minnesota Agricultural Fertilizer and Research and Education Council.