2015

Effects of drainage water management in Southeast Iowa

Linda Rae Schott
Iowa State University

Recommended Citation

Schott, Linda Rae, "Effects of drainage water management in Southeast Iowa" (2015). *Graduate Theses and Dissertations*. 14863.
http://lib.dr.iastate.edu/etd/14863

Effects of drainage water management in Southeast Iowa

by

Linda Rae Schott

A thesis submitted to the graduate faculty

in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Major: Agricultural and Biosystems Engineering

Program of Study Committee:
Matthew J. Helmers, Major Professor
Amy Kaleita
Chris Rehmann

Iowa State University

Ames, Iowa

2015

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENTS

First and foremost, I would like to thank and acknowledge my major professor, Dr. Matthew Helmers. Matt’s stimulation of critical thinking within a positive environment and encouragement of independence has promoted my professional development while his generosity has furthered my personal development. I would also like to thank my two other committee members. Both Dr. Amy Kaleita and Dr. Chris Rehmann provided much me needed writing critiques and suggestions.

Secondly, I would like to thank Carl Pederson for sharing his knowledge of farming and extensive assistance with my project. Thank to Dr. Aaron Daigh and Dr. Ainis Lagzdins for helping to summarize and digest the substantial amount of data I had for this project. I would also like to thank Greg Brenneman, who is the Agricultural Engineering Extension Specialist for Southeast Iowa, and Myron Rees, who is the Superintendent at SERF. I also owe thanks to the other graduate and undergraduate students within the group. Without them, field work would not have been completed in a timely manner nor would it have been as enjoyable. Thank you to Connie Cannon and the rest of Matt’s team for their kindness and assistance along the way.

I am very grateful for not only the love and support my family and friends have given me throughout my time at Iowa State but also the laughs and great memories. I am truly thankful to have a husband who regularly encourages me to follow my dreams and supports me any way he can while I do. The Department of Agricultural and Biosystems Engineering at Iowa State is like one big family. While I am saddened that my time here has come to an end, I am glad to have had the opportunity to be a part of it.

This research is part of a regional collaborative project supported by the USDA-NIFA, Award No. 2011-68002-30190, “Cropping Systems Coordinated Agricultural Project: Climate Change, Mitigation, and Adaptation in Corn-based Cropping Systems.” Project Web site: sustainablecorn.org. Research data and supporting metadata are stored in the team’s centralized Climate and Cropping Systems database.

ABSTRACT

Subsurface drainage, while necessary for maximizing row crop production in Iowa, short-circuits nitrate-N downstream. Drainage water management practices, such as controlled drainage and shallow drainage, have been shown to reduce NO_3-N loss by reducing the volume of water leaving the field.

The first investigation in this thesis focuses on how drainage water management effects crop yield, drainage volumes, NO_3-N loss, depth to water table, and volumetric water content using data eight years of data collected from 2007 to 2014 at a drainage research site in Southeast Iowa from four treatments: controlled drainage, shallow drainage, conventional drainage, and no drainage. Controlled and shallow drainage reduced NO_3-N loads by 49% and 42%, respectively. There were yield reductions from the shallow and controlled drainage treatments, as well as no drainage, especially in wet years.

The second investigation concentrates on if drainage water management practices effected the planting dates of corn from 2012 to 2015 at the same research site. None of the four treatments affected volumetric water content near the surface where corn would be planted. Soil temperature at 10 cm was significantly greater in the undrained and shallow drainage treatments, but the reason is unknown. There were differences in depth to water table between treatments, which may impact the date of planting if the water table is near the surface.

The third study investigates how shallow and controlled drainage practices affected peak drainage and water table recession time compared to the conventional treatment for four small drainage events. There was no difference between treatments in the time to peak discharge, but shallow drainage increased peak discharge in two events wile controlled increased peak discharge during one event. There was no difference between treatments in time of water table recession,

Due to growing concerns over the hypoxia zone in the Gulf of Mexico, further research should be conducted for both drainage water management practices at other sites in Iowa and across the Midwest as a practice to reduce nutrient losses. This research should focus on how these practices can either maintain or increase crop yields to make these practices more affordable to producers.

CHAPTER 1. GENERAL INTRODUCTION

Background

In 2011, a five-year grant from the United States Department of Agriculture National Institute of Food and Agriculture (USDA-NIFA) began funding a transdisciplinary project: Climate Change, Mitigation, and Adaptation in Corn-Based Cropping Systems (CSCAP). This project included 11 Midwestern institutions: Iowa State University, Lincoln University, Michigan State University, The Ohio State University, Purdue University, South Dakota State University, University of Illinois, University of Minnesota, University of Missouri, University of Wisconsin, USDA Agricultural Resource Service-Columbus, Ohio, and USDA-NIFA. Personnel involved in the project include soil scientists, sociologists, anthropologists, economists, agricultural engineers, modelers, climatologists, extension field specialists, and next generation scientists in the form of graduate and post-doctoral students. The goals of the project were to create a suite of practices, which include tillage, crop rotations, cover crops, drainage water management, and nitrogen sensors, for corn-based systems that retain and enhance soil organic matter and nutrient and carbon stocks, reduce off-field nitrogen losses that contribute to greenhouse gas emissions and water pollution, better withstand droughts and floods, and ensure productivity under different climatic conditions using data gathered from over 20 field sites and thousands of farmers in nine Midwestern states. The long term objectives of the project were:

1. Develop standardized methodologies for estimating carbon, nitrogen, and water footprints of corn production.

2. Evaluate the impact of the suite of practices in the field on carbon, nitrogen, and water footprints using the methodologies from objective 1.
3. Apply climate and physical models to synthesize results from the field in order to predict climate and economic scenarios.
4. Perform comprehensive life-cycle analyses of the practices in order to evaluate the socio-economic-environmental willingness of producers to adopt new practices using social science research, field research, and modeling of corn production systems.
5. Integrate education, extension, outreach, and stakeholder participation across all aspects of the program (Morton, 2011).

Drainage water management is designing the subsurface drainage system in order to reduce the drainage volume by either installing the subsurface drains at a shallower depth or managing the outflow, known as shallow and controlled drainage, respectively (Figure 1.1). Historically, subsurface drains, also known as tile lines, are typically installed below the rooting depth between 0.6-1.2 m with spacing ranging from 10-30 m depending on the soil properties and cost (Pavelis, 1987). While these drains are necessary in agricultural land in areas with poor natural drainage for maximized crop production, tile drainage also short circuits nitrate-N loss in the Mississippi River Basin contributing to the hypoxia zone in the Gulf of Mexico (Turner & Rabalais, 1994). The number of tile drained acres in the Midwest is unknown; in Iowa, it is estimated to be at least 3.6 million acres, which is approximately 40% of agricultural land (Baker et al., 2004) while in other states it can be as high as 50% of all agricultural land (Skaggs et al., 1992). Overall, it is estimated that a significant portion of nitrate-N export to the Gulf of

Mexico originated from tile drainage (David et al., 2010). Drainage water management was chosen as one of the practices as a focus for the CSCAP grant due to research indicating that controlled drainage can reduce drainage volume and nitrate-N losses by 18%-80% and 18%-79%, respectively (Skaggs et al., 2012) while shallow drainage can reduce drainage volumes and nitrate-N losses by 20% -46% and 18%- 29%, respectively (Helmers et al., 2012; Sands et al., 2008). The project principal investigators of CSCAP hypothesized that drainage water management would reduce off-field nitrate-N pollution and increase resiliency to floods and droughts by retaining more water in the field (Morton, 2011). The objectives of this thesis are to:

1. Investigate how drainage water management practices effect nitrogen and water footprints on a field site in Southern Iowa.
2. Explore how drainage and drainage water management might affect the date of planting.

Thesis Organization

Chapter 2 addresses objective 1 and investigates how drainage and drainage water management impact crop yields, soil volumetric water content, depth to water table, drainage volumes, and nitrate-N export during the growing season at a field-site in Southeastern Iowa. Chapter 3 addresses objective 2 and examines in further detail how drainage and drainage water management impact soil volumetric water content, soil temperature, and depth to water table during a 51 day period from April to May when corn must be planted in Iowa to qualify for crop insurance. In order to further understand how drainage water management practices effect nitrogen and water footprints, peak flow and water table recession time of shallow and controlled drainage systems are compared to a conventionally drained system in Chapter 4. Chapter 5 then summarizes the conclusions drawn from this thesis and discusses how this research fits within the larger USDA-NIFA project. This chapter also suggests areas of future research for drainage water management. References for each chapter are given at the end of the individual chapters.

References

Baker, J.L., Melvin, S.W., Lemke, D.W., Lawlor, P.A., Crumption, W.G., & Helmers, M.J. (2004). Subsurface Drainage in Iowa and the Water Quality Benefits and Problem. ASABE Paper No. 701P0304. St. Joseph, MI: ASABE.

David, M.L., Drinkwater, L., & McIsaac, G. (2010). Sources of Nitrate Yields in the Mississippi River Basin. *Journal of Environmental Quality*, 39, 1657-1667.

Helmers, M.J., Christianson, R., Brenneman, G., Lockett, D., & Pederson, C. (2012). Water Table, Drainage, and Yield Response to Drainage Water Management in Southeast Iowa. *Journal of Soil and Water Conservation*, 67(6), 495-501.

Morton, Lois Wright. (2011). Project Narrative. Retrieved from http://sustainablecorn.org/doc/Project_Narrative_May2011.pdf

Pavelis, G.A. (1987). *Farm Drainage in the United States: History Status, and Prospects.* Washington, D.C.: USDA Economic Research Service.

Sands, G.R., Song, I., Busman, L.M., & Hansen, B.J. (2008). The Effects of Subsurface Drainage Depth and Intensity on Nitrate Loads in the Northern Cornbelt. *Transactions of the ASABE,* 51(3), 937-946.

Skaggs, R.W., Breve, M.A., & Gillham, J.W. (1992). Environmental Impacts of Agricultural Drainage. In T. Engman (Ed.), *Irrigation and Drainage: Proceedings of the ASCE Water Forum '92* (pp. 19-24). New York, NY: ASCE.

Skaggs, R.W., Fausey, N.R., & Evans, R.O. (2012). Drainage Water Management. *Journal of Soil and Water Conservation,* 67(6), 167-172.

Turner, R.E., & Rabalais, N.N. (1994). Coastal Eutrophication near the Mississippi River Delta. *Nature,* 368(6472), 619-621.

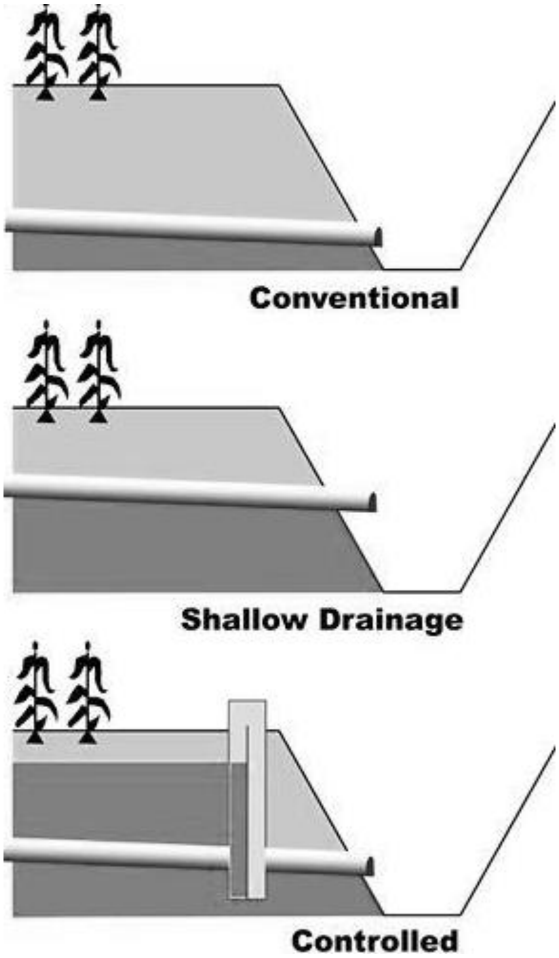

Figure 1.1. Comparison of drainage systems. The top figure is an example of a conventional drainage system. The middle figure is an example of a shallow drainage system where subsurface drains are installed at a shallower depth than the conventional system. The bottom figure is an example of a controlled drainage system where subsurface drains are installed at the same depth as the conventional drainage system but has a control structure for water table depth regulation during key times of the year.

CHAPTER 2. EFFECTS OF DRAINAGE WATER MANAGEMENT ON YIELD, DRAINAGE, WATER TABLE, AND SOIL WATER STORAGE

A paper to be modified for submission to *Journal of Water and Soil Conservation*

Linda R. Schott[1], Ainis Lagzdins, Aaron L. Daigh, Carl Pederson, Greg Brenneman,
Matthew J. Helmers

Abstract

Subsurface drainage removes excess water from agricultural land, especially during the rainy spring months when the timeliness of field operations, such as planting, are important. Although it optimizes row crop production, subsurface drainage also short circuits nitrate-N loss downstream. The objective of this study was to determine the impact of shallow, controlled, conventional, and no drainage on crop yields, depth to water table, soil volumetric water content, subsurface drainage volumes, and nitrate loss through subsurface drainage. This research was conducted at the Iowa State University Southeast Research Farm near Crawfordsville, Iowa from 2007 to 2014. The site consists of eight plots with two replicates for each of the four treatments. Each plot had half planted in soybeans (*Glycine max* L. Merr.) and the other half in corn (*Zea mays* L.), and the halves were rotated every year in accordance with a typical corn-soy rotation. Over the eight year study, controlled and shallow drainage reduced annual flow by 45% and 51% while reducing NO_3-N loads by 49% and 42%, respectively. Corn yields were reduced in the controlled drainage treatment by 4%, in the shallow drainage treatment by 3%, and in the undrained treatment by 6%. Only the undrained treatment had a reduction

---

[1] Primary author and researcher

in soybean yield, an average of 12%, when compared to the conventional treatment. The undrained treatment had a shallower water table than the other treatments and also had a significantly higher ($p < 0.05$) number of hours during the growing season when the water table was within 30 cm of the ground surface than the other treatments. However, there was no difference in soil water content in the top 80 cm of the soil profile during the growing season between drainage treatments. This study highlights the effectiveness of shallow and controlled drainage to reduce NO_3-N loads.

Introduction

Subsurface drains are used to remove excess water from the soil profile of agricultural land in areas with poor natural drainage. If the water table is within 30 cm of the soil surface, it begins to decrease trafficability potentially leading to planting delays and increasing the risk of compaction at the time of field activity, as well as contributing to excess water stress to the crop (Skaggs & van Schilfgaarde, 1999). Although there are benefits to subsurface drainage, there are also negative environmental impacts. Drainage has increased the loss of nitrate-N from agricultural lands in the Mississippi River Basin contributing to the hypoxia zone in the Gulf of Mexico (Turner & Rabalais, 1994). Furthermore, David et al. (2010) found that a significant portion of nitrate-N export originated from subsurface drainage. Historically, subsurface drains were made of concrete or clay tile, leading to the nickname of tile drainage or tile lines. Today, drains are often made of perforated plastic tubing. In a conventional drainage design, drains are installed below the crop rooting depth between 0.6 to 1.2 m with spacing ranging from 10 to 30 m depending on the soil properties and cost (Pavelis, 1987).

One practice being proposed to combat NO_3-N loss is drainage water management. Drainage water management can be defined in two ways. The first definition is the design of the subsurface drainage system in order to reduce the drainage volume by installing the drains at a shallower depth than what is conventionally done. This is known as shallow drainage. The second definition of drainage water management is the management of the subsurface drainage outlet. In this case, the subsurface drainage system is designed in the conventional way but includes water table control structures. This is known as controlled drainage. These control structures regulate the water table outflow height using boards, which are managed so drainage is reduced or eliminated during times of the year when it is not necessary (Strock et al., 2011; Skaggs et al., 2012).

Drainage water management has been shown to reduce drainage volume and nitrate-N losses compared to conventional drainage. Sands et al. (2008) found that shallow drainage reduced drainage volume by 20% and NO_3-N loss by 18% when compared to conventional drainage systems. Using 20 controlled drainage sites in the Midwest and Eastern United States and Canada, Skaggs et al. (2012) reported an 18% to 80% reduction in annual drainage volume and an 18% to 79% reduction in NO_3-N loads when compared to conventional drainage with no impact on NO_3-N concentrations. Across those same sites, the effect of controlled drainage on crop yield ranged from no impact on soybean yield to increases of 10% while corn yield ranged from no effect to an increase of 19% depending on the site and weather conditions.

The soil water content is important to plants and their health. The amount of water in the soil matrix influences gas exchange and the diffusion of nutrients to plant roots. The force with which the water is held in the soil matrix effects how much water can be adsorbed by plants and the drainage of excess water by gravity (Jury & Horton, 2007). Too much or too little water in the plant root zone can negatively impact yield (Skaggs & van Shilfgaarde, 1999). The depth to water table, which is altered with drainage, effects how much water is in the soil profile. Madramootoo (1993) used controlled drainage to maintain the water table at shallower depths using sub-irrigation, and soil moisture significantly increased. Skaggs and Chescheir (2003) had similar findings using DRAINMOD.

There are also some potential negative economic impacts of drainage water management. The cost of the installation of a drainage water management system is higher than conventional drainage due to increased materials and labor. If subsurface drains are installed at a shallower depth, the distance between drains must be reduced to maintain the same coefficient of drainage, which is the depth of water removed in a day. For controlled drainage, a control structure is needed for every 30 to 60 cm change in elevation within the field in order to maintain a constant water table elevation. This not only increases the cost of materials, but it also increases the management needs of the system and reduces the areas that can feasibly utilize this type of drainage (Frankenberger et al., 2007; Sands et al., 2008). The increased cost of drainage water management systems can be a drawback to producers, especially if there is not a yield benefit. With limited research directly comparing shallow and controlled drainage systems to a conventional system in the Midwest at the same site, the objective of this study was to evaluate the effect of shallow, controlled, conventional and undrained drainage treatments on crop yields, drainage volume, NO_3-N loss, soil water content, and depth to water table.

Materials and Methods

Site location and design

Research was conducted at the Iowa State Southeast Research Farm (SERF) near Crawfordsville, Iowa (41°11'38" N, 91°28'58" W) from 2007 to 2014. The site has eight research plots with two replications for each of the following drainage treatments: undrained, conventional drainage, shallow drainage, and controlled drainage (Figure 2.1). The plots were blocked into a north and south replication because the site consists of two poorly drained silty clay loam soils. Kalona (silty clay loam, fine, smectitic, mesic Vertic Endoaquolls) is found predominantly in the northern plots while Taintor (silty clay loam, fine, smectitic, mesic Vertic Argiaquolls) is predominantly in the south. The site is relatively flat with less than a five meter elevation change over 17 ha. The plots were designed to have a maximum drainage coefficient of 1.9 cm day^{-1}. Individual plots range in size from approximately 1.2 to 2.4 ha. The conventional and controlled drainage plots have a drain depth and spacing of 1.2 and 18 m, respectively. The shallow drained plots have drains at a depth of 0.76 m with 12.2 m spacing.

Originally, the plots were split down the middle and cropped east to west with both corn (*Zea mays* L.) and soybeans (*Glycine max* L. Merr.) each year, which were alternated each consecutive year to replicate a typical corn-soybean rotation in Iowa. In 2012, however, 24 rows of continuous corn were added on the north and south edges of the site, so each plot had rotational corn, rotational soybeans, and continuous corn every year creating three subplots per drainage plot. Subplots were chisel plowed in the fall following corn, and all subplots were field cultivated prior to planting. For the subplots planted to corn, nitrogen fertilizer in the form of anhydrous ammonia was applied in the spring prior to planting at a rate of 169 kg ha^{-1} and 224 kg ha^{-1} for rotational and continuous corn, respectively.

At this site, the boards in the controlled drainage treatment were removed in mid to late April approximately two weeks prior to planting to allow free drainage and replaced in late May to early June after planting was completed to a depth of 60 cm. Removal of the boards prior to harvest in the fall was not required at this site due to low water table conditions, but in the first few years, the boards were raised to be within 30 cm of the ground surface following harvest (Table 2.1).

Data collection

Daily rainfall was measured using a manually-read rain gauge located approximately 1 km from the research plots from 2007 to 2014. At the end of December 2013, a weather station, part of the Iowa State University Soil Moisture Network, containing a non-heated tipping bucket was installed adjacent to the research plots, which provided higher resolution rainfall data. As a result, beginning in 2014, the two rainfall data sets were averaged. The 50 year precipitation averages are from the National Weather Service Cooperative Observer Program where volunteers report daily precipitation, including melted snowfall, for Mount Pleasant, located approximately 15 km away.

Tile lines for all plots were laid out in a north-south orientation. The interior tiles were continuously monitored for flow rate with a 13 cm tall 45° V-notch weir and a Global Water pressure transducer (Global Water, Sacramento, California) logging in 5 to 30 minute intervals. To account for differences in plot areas, drainage volumes were normalized to a depth of drainage. Border tiles were installed in each plot to hydraulically isolate the treatments but were not monitored. In the controlled drainage plots, the border tiles also had water table control structures. Grab samples were collected weekly at the outflow when flow was present. The water samples were analyzed for NO_3-N concentrations by the Wetland Research Laboratory at Iowa State University using the second-derivative spectroscopy technique (Crumpton et al., 1992). A linear interpolation was performed between NO_3-N sample data to estimate daily concentrations (Wang et al., 2002). The resulting daily concentrations were multiplied by daily flow volume to estimate total NO_3-N loss from each drained plot. The annual NO_3-N loss was then divided by annual flow volume in order to calculate the average annual flow-weighted NO_3-N concentration.

In 2007, water table monitoring wells were installed in half the plots to a depth of 1.5 to 1.75 m midway between an interior set of tile lines in each plot (plots 2, 3, and 4). In the undrained plot (plot 1), the monitoring well was installed in the middle of the plot. In 2009, the monitoring wells were moved to the middle of each plot between the rotational corn and soybeans to minimize the impact of farming operations. At this time, additional monitoring wells were installed in the four remaining plots in the same manner as the previous four. Depth to water table was monitored hourly using Global Water pressure transducers.

Bulk density samples were collected in 2011 using a modified Uhland sampler for depth increments of 0-10, 10-20, 20-30, 30-40, 40-50 and 40-60 cm at eight locations transecting each plot across all crops (Kladivko et al,. 2014). Soil bulk density was determined by oven drying samples at 105°C (Blake & Hartge, 1986). Soil samples for nutrient and texture analyses were collected using a 6 cm diameter hand probe at depth increments of 0-10, 10-20, 20-40, and 40-60 cm at 12 locations transecting each cropping subplot in the early summer in 2011 and 2013 (Kladivko et al., 2014). The hydrometer method was used for particle size analysis (Gee & Or, 2002) in 2011. Total C and N soil concentrations for 2011 and 2013 were determined using 250 µm sieved samples by direct combustion with a TruSpec CHN Analyzer (LECO, St. Joseph, MI) (Kladivko et al. 2014). Gravimetric C and N at all depth increments were converted to a volumetric basis for the 0-60 cm soil profile using the depth incremented bulk density measurements and adding the depth increments together.

ECH$_2$O 5TM (Decagon, Pullman, Washington) soil moisture sensors were installed in the center of each plot in the continuous corn in May 2011. The soil volumetric water content (VWC) and temperature were measured at five depths: 10, 20, 40, 60, and 100 cm. Data was recorded every five minutes using an Em50 logger. Maximum VWC values were capped to individual plot soil porosity at the sensor depth increments. Using the bulk density samples collected in each plot in 2011, soil porosity was calculated for the 10, 20, 40, and 60 cm sensors using the corresponding depth bulk density values for 0-10, 10-20, averaged 20-30 and 30-40, and averaged 40-50 and 50-60, respectively. Porosity for the sensor at 60 cm was used for the sensor at 100 cm. Average daily VWC was calculated for the top four depths, and average daily soil water storage from 0-80 cm was calculated using weighted depth increments (0-15, 15-30, 30-50, 50-80 cm) for the top four sensors.

Yield data were collected with a yield monitor where readings were constrained to the center 12 to 18 rows of corn and soybeans for each plot depending upon the equipment used. The length monitored was 36.6 m for each plot. The start and end of monitoring locations were midway between tile lines in the center of the plots.

Data analysis

Statistical analyses were conducted using Statistical Analysis System software (SAS, 2011). The general linear model (GLM) procedure was used with two replicates per treatment to determine the statistical significance of treatment effects on subsurface drainage volume, crop yield, soil total C and N, flow-weighted NO_3-N concentration, and NO_3-N loss. The mean values for subsurface drainage volume, crop yield, soil total C and N, flow-weighted NO_3-N concentration, and NO_3-N loss were separated using a least significance difference (LSD) test at $p = 0.05$ ($LSD_{0.05}$). The generalized linear mixed model (GLIMMIX) procedure was used with two replicates per treatment to determine the statistical significance of treatment effects on average daily VWC at 10, 20, 40, 60 cm, and soil water storage for the top 80 cm, as well as average daily depth to water table.

In order to evaluate the effects of drainage and drainage water management over the lifetime research project for this thesis, data that that has already been published from 2007-2010 in Helmers et al. (2012) has been included in the analyses. This allows a comprehensive record of the data to be summarized in one location. For submission to the Journal of Soil and Water Conservation, we will remove duplication with the 2012 publication. This submission will be different from the original publication for a couple of reasons. Statistical analyses of the depth to water table as well as the effects of drainage on volumetric water content were not included in the original publication, and the precipitation patterns were markedly different.

Results and Discussion

Precipitation

Seasonal rainfall at SERF from March to October is approximately 800 mm according to the 50 year average near the site (Table 2.2). Overall, there were four years of above average rainfall, two years of below average rainfall, and two years of average rainfall. Both 2011 and 2012 had below average rainfall, receiving 23% and 20% less, respectively. The four years from 2007 to 2010 were characterized with above average rainfall with the site receiving between 13% and 41% greater rainfall than average. The last two years of the study, 2013 and 2014, received average rainfall.

Soils data

Consistent with the soil survey, all treatments had a silty clay loam soil texture (Table 2.3). There were no treatment differences ($p < 0.05$) in total C or total N in the 0-60 cm soil profile. Drainage treatment did not affect the bulk density of the soil profile.

Water table

Expectedly, drainage affected the depth to water table. In nearly every month in all six years from 2009 to 2014, except during the drought in 2012, the water table was significantly shallower ($p<0.05$) in the undrained treatment (Table 2.4). Overall, the water tables in the other three drainage treatments were not statistically different ($p<0.05$) from one another. Generally, the water table in the conventionally drained treatment was the deepest followed by controlled then shallow. The northern replication had statistically shallower ($p<0.05$) water tables than the southern replication.

When the water table is within 30 cm of the ground surface, there is a greater risk of excess water stress to the crop, which can result in yield reductions (Skaggs & van Schilfgaarde, 1999). The number of hours the water table was within 30 cm of the ground surface was significantly higher ($p<0.05$) in the undrained treatment than the other three treatments for 2010-2014 (Table 2.5). There were also significantly more ($p<0.05$) hours in the undrained treatment that the water table was within 60 cm of the ground surface in 2010, 2011 and the five year average. There were no statistical differences ($p<0.05$) between the four treatments in the number of hours the water table was within 60 cm of the ground surface in 2012 and 2013. In 2014, the number of hours the undrained treatment was within 60 cm of the ground surface was only significantly greater ($p<0.05$) than the controlled and conventional treatments. Overall, even with shallower drains during the growing season, the shallow and controlled drainage treatments did not increase the risk of excess water stress to the crop when compared to the conventionally drained treatment.

Volumetric water content

VWC content at 10 cm did not statistically differ ($p<0.05$) in any month of the growing season from 2012-2014 (Table 2.6). Comparing all three years, there was no clear pattern of drainage effect at this depth. There were drainage treatment effects in VWC at 20 cm (Table 2.7). During the growing season from June 2013 until the end of 2014, the shallow drainage treatment had significantly lower ($p<0.05$) VWC than the other three drainage treatments. VWC at 20 cm tended to be slightly higher than at 10 cm in all treatments in all years. At 40 cm depth, there were no statistical differences ($p<0.05$) in VWC between drainage treatments (Table 2.8). The VWC at this depth was once again slightly higher than the depth above it, especially at the end of the growing season. The VWC at 60 cm had different drainage effects than the depths above it (Table 2.9). In early 2012, the shallow drained treatment had a significantly higher ($p<0.05$) VWC than the controlled drainage treatment. In July of that year, the effect changed, and the undrained treatment had significantly greater ($p<0.05$) VWC than the conventional and controlled drainage treatments, which were significantly greater than the shallow drainage treatment. By August, there was no statistical difference ($p<0.05$) between controlled, conventional, and undrained treatments. All treatments, except shallow in 2013, had smaller VWC at 60 cm than at 40 cm.

There were no statistical differences ($p<0.05$) in total soil water storage for an 80 cm soil column (Table 2.10), except in October of 2013. Overall, there were no drainage treatment effects because all four drainage treatments tended to have the same amount of soil water storage. In October 2013, the shallow and undrained treatments had significantly less ($p<0.05$) soil water storage than the controlled drainage treatment, which is opposite of what would be expected. In 2012, all four treatments had similar amounts of soil water storage during periods of wet weather (Figure 2.2). The same trait also occurred in both 2013 (Figure 2.3) and 2014 (Figure 2.4).

Initial thinking would indicate that there should be a difference in soil water storage since the depth of drainage is different between treatments. Skaggs and Chescheir (2003) also predicted increased VWC with a shallower water table. However, due to soil type, it is not surprising that there are no differences in VWC or soil water storage between the different drainage treatments even though there were differences in the depth to water table. The soil water retention curve for this site (Figure 2.5) shows that the

VWC does not change much as the capillary pressure head increases from 0.5 to 3.3 m. The capillary pressure head can also be thought of as the depth to water table. The monthly time scale for comparison may also be too large to discern differences between drainage treatments. Soil volumetric water content changes due to rainfall, evapotranspiration, and other factors, which vary on an hourly or daily time scale.

Drainage

Drainage occurs during the time period when soils are not frozen, which is normally mid to late March until late November. In most years, the majority of drainage occurred in April, May, and June due to the timing of rainfall in the region (Table 2.11). In 2012, nearly 100% of total drainage from the conventionally drained treatment occurred during these months but only 30% in 2014. In the other years, over 50% of drainage occurred from April to June. Annual average drainage volumes (Figure 2.6) from the conventional treatment ranged from 49.2 cm in 2009 to 12.4 cm in 2011. Drainage for the controlled drainage treatment ranged from 31.2 cm in 2010 to 4.2 cm in 2012, while drainage from the shallow treatment ranged from 26.9 to 5.9 cm for the same years. Drainage from the conventionally drained treatment in 2009, 2013 and 2014 was significantly greater ($p<0.05$) when compared to the other two drainage treatments. While all the other years had drainage reductions, they were not statistically different ($p<0.05$) due to variability between replicates. There was also no difference in drainage volumes between the north and south replicates ($p<0.05$).

Over the eight years of the study, controlled drainage reduced flow volumes by 45% while shallow drainage reduced flow by 51% when both were compared to conventional drainage. In this time period, both drainage water management treatments had significantly reduced ($p < 0.05$) drainage than the conventionally drained treatment. Helmers et al. (2012) reported reductions in the shallow and controlled drainage treatments of 37% and 46%, respectively. For the years 2011-2014, drainage reductions in the shallow and controlled drainage treatments were 59% and 62%, respectively. Skaggs et al. (2012) reported average drainage volume reductions between 18% and 85%, and the last four years of the study from 2011-2014 were on the higher end of this range. The flow volume reduction from the shallow drainage treatment in this study was much higher than the 20% reduction reported by Sands et al. (2008). The reductions in the last four years of the study were greater than the reductions in the first four years. The four years from 2007-2010 all had above average rainfall while the last four years had below average and average rainfall. This is probably due to increased drainage from the drainage water management treatments due to high water tables throughout the season in the years with above average rainfall rather than seepage below the drains or crop uptake that probably occurred in the years with below average and average rainfall.

Flow reductions of controlled drainage compared to conventional drainage varied annually. The smallest reduction, 3%, from controlled drainage occurred in 2008. This was probably due to water held in the fall of 2007 released in April 2008 when the controlled drainage treatment had over 2 cm more drainage than the conventional treatment and more than 3.5 cm than the shallow drainage treatment. The flow from the controlled drainage treatment in 2014 was reduced 68% compared to conventional since most of the seasonal drainage occurred in June, July and October when the water table control gates were closed. The flow reduction of the shallow drainage treatment was also annually variable with the smallest reduction also occurring in 2008 with a decrease of

29%. The largest reduction of flow, 79%, from shallow drainage treatment occurred in 2011. Even though the majority of drainage during most years at the site occurred when the controlled drainage treatments were freely draining, there were still flow reductions. The shallow drainage treatment was also not statistically different than the controlled drainage treatment. This indicates that at least at this site, both drainage water management practices are effective at reducing drainage volumes.

Nitrate-N loss

Flow-weighted nitrate-N concentration in the tile flow of the shallow drainage treatment was significantly higher ($p<0.05$) than the conventional and controlled drainage treatments during the eight year study with an average concentration of 12.4 mg L^{-1} (Table 2.12). The nitrate-N concentrations for the conventional drainage treatment was statistically higher ($p<0.05$) than the controlled drainage treatment. The former had an average concentration of 10.9 mg L^{-1}, and the latter had an average concentration of 10.0 mg L^{-1}. When comparing shallow to conventional drainage designs, Burchell et al. (2005) found that nitrate-N concentrations were statistically greater in the shallow drainage treatment. They concluded that there were two explanations for the increase in concentration. They had evidence of preferential flow of water directly to the shallow drains and also hypothesized that during and directly following a rainfall event, the water retention time is too short for denitrification due to unsaturated flow near the drains. In their overview of twenty controlled drainage studies, Skaggs et al. (2012) reported that controlled drainage did not affect nitrate-N concentrations in drainage water. However, Adeuya et al. (2012) reported that although there wasn’t a difference in nitrate-N concentrations between their controlled drainage and conventional drainage treatments over the course of a full year, the controlled drainage treatment did reduce NO_3-N concentrations during the dormant season. This observation was also observed by Ng et al. (2002) and can be attributed to greater denitrification due to the higher water table.

The southern replication had statistically greater ($p<0.05$) nitrate-N concentrations than the northern replication. In conjunction with the shallower water tables in the northern replication and the lack of differences in soil total nitrogen, the lower nitrate-N concentrations in the drainage water could be an indication of greater denitrification due to anaerobic conditions in the saturated soils.

Nitrate-N loads from the conventionally drained treatment varied from 56.4 kg ha^{-1} in 2014 to 16.2 kg ha^{-1} in 2012 (Figure 2.7). The NO_3-N loads from the controlled and shallow drainage treatments varied from 22.4 and 25.6 kg ha^{-1} in 2007 to 5.1 and 9.0 kg ha^{-1}, respectively, in 2012. The smaller NO_3-N loads in all three drainage treatments in 2012 can be attributed to reduced drainage volume due to the drought. There were only two years, 2009 and 2014, that the shallow and controlled drainage treatments significantly reduced ($p<0.05$) nitrate-N loads. This is most likely due to the variability of flow between the treatment replicates, and the shallow drained treatment had lower flow volume but higher NO_3-N concentrations.

Controlled drainage significantly reduced ($p<0.05$) NO_3-N loads by 49% over the eight year study period when compared to conventional drainage while shallow drainage also had significant reductions of 42%. Helmers et al. (2012) reported reductions of 36% and 29% for controlled and shallow drainage treatments, respectively for the years 2007-2010. The last four years of the study, 2011-2014, had much higher reductions than those previously reported. The controlled and shallow drainage treatments reduced NO_3-N loads by 61% and 56%, respectively. Like the reductions in drainage volume, the nitrate-N load reductions from the last four years of the study from 2011-2014 were at the higher end of the range of 18% to 79% reported by Skaggs et al. (2012) and is much higher than the 18% reduction reported by Sands et al. (2008). Nitrate-N load reductions followed the same trends as drainage reductions. Both controlled and shallow drainage treatments reduced NO_3-N loads the least in 2008, with reductions of 11% and 15%, respectively, when compared to the conventionally drained treatment. Controlled drainage had the greatest nitrate-N reduction, 72%, in 2014, while shallow drainage had the greatest reduction, 70%, in 2011.

Crop yield

Overall for corn, the conventional drainage treatment tended to have the highest yields followed by the shallow, controlled, and undrained treatments (Figure 2.8). For the eight year period, shallow drainage reduced corn yields by 3%, controlled drainage reduced corn yields by 4%, and no drainage caused a reduction of 6% when compared to conventional drainage. In the first four years of the study from 2007-2010, shallow drainage reduced yields by only 2%, controlled drainage by 6%, and no drainage by 7%. In the last four years of the study from 2011-2014, all three treatments reduced yields by 3% to 4% compared to conventional. Controlled drainage reduced corn yields in 2009 while the undrained treatment reduced corn yields in 2009 and 2014. Skaggs et al. (2012) reported drainage water management impacts on corn yields ranging from no effect to 19%. Helmers et al. (2012) were the only authors to report a corn yield decrease. Even Jaynes (2012) reported no corn yield impacts for an Iowan drainage water management site that received four years of above average rainfall. One possible reason for the decrease in yield in the controlled drainage treatment is that there was no active water table management during the summer months regardless of the rain amount resulting in a higher water table. This is supported by the reduction in corn yields in the controlled drainage treatment in 2009, which was the wettest year of the study.

Soybean yields followed a slightly different pattern than corn. There were no differences between the conventional, shallow, and controlled drainage treatments (Figure 2.9). Over the eight year study period, no drainage reduced yields by 12% when compared to conventional. In the first four years of the study, shallow drainage reduced yield by 7%, controlled drainage by 2%, and no drainage by 17%. Yield differences between treatments were not as dramatic in the years from 2011-2014; soybeans in the shallow drainage treatment yielded 1% greater than conventional while controlled drainage yielded the same as conventional. The undrained treatment had a 6% reduction compared to conventional. In 2009, 2010, and 2014, soybean yields were reduced in the undrained treatment when compared to the conventional treatment. These results are consistent with Skaggs et al. (2012) who reported drainage water management effects on soybean yields ranging from no effect to a 10% increase.

For both corn and soybean yields, the northern replication had a significant reduction ($p<0.05$) when compared to the southern replication. The northern replication also had shallower water tables and lower NO_3-N concentrations. While the shallow water tables seemed to enhance denitrification, they also seem to have negatively impacted yields.

Conclusions

This study showed that over the eight year study, which contained years of above average, average, and below average rainfall, drainage water management reduced drainage volume and NO_3-N losses. Controlled and shallow drainage reduced annual flow by 45% and 51% while reducing NO_3-N loads by 49% and 42%, respectively, when compared to conventional drainage. The reductions in drainage and nitrate-N from 2011-2014 were 59% and 61% for controlled drainage and 62% and 56% for shallow drainage. These reductions were greater than the reductions reported by Helmers et al. (2012) for the years 2007-2010. The higher reductions occurred during the four years when average rainfall was below average or average rather than the above average rainfall that occurred in the first four years of the study. These results agree with a literature review by Skaggs et al. (2012) indicating average drainage volume reductions between 18% and 85% and NO_3-N reductions between 18% and 79%. Soybean yields were also congruent with previous studies (Skaggs et al., 2012) indicating no yield differences between drainage water management and conventional drainage treatments. However, controlled drainage reduced corn yields by 4% while shallow drainage reduced corn yields by 3% when compared to conventional drainage. Greater yield reductions occurred in the first four years of the study when rainfall was greater, especially in the corn.

Drainage treatment had an effect on the water table but not on VWC, unlike what was predicted by Skaggs and Chescheir (2003). The undrained treatment had the shallowest water table and a significantly higher ($p<0.05$) number of hours that the water table was within 30 cm of the surface, which can negatively impact crop production. There was little difference between conventional, shallow, and controlled drainage treatments in the number of hours the water table was within 30 cm of the ground, but conventional drainage had the deepest water table. Even with the higher water tables found in the undrained, shallow, and controlled drainage treatments, there was no difference in VWC between any of the treatments, likely due to soil type.

Overall, this study illustrated that while drainage is important to agricultural production at this site, and drainage water management reduced nitrate-N loss downstream by reducing drainage volume. Future work should focus on how to manage controlled drainage fields more effectively during wet years to mitigate yield losses from high water tables.

Acknowledgements

This research is part of a regional collaborative project supported by the USDA-NIFA, Award No. 2011-68002-30190, “Cropping Systems Coordinated Agricultural Project: Climate Change, Mitigation, and Adaptation in Corn-based Cropping Systems.” Project Web site: sustainablecorn.org. Research data and supporting metadata are stored in the team’s centralized Climate and Cropping Systems database.

References

Adeuya, R., Utt, N., Frankenberger, J., Bowling, L., Kladivko, E., Brouder, S., & Carter, B. (2012). Impacts of drainage water management on subsurface drain flow, nitrate concentration, and nitrate loads in Indiana. *Journal of Soil and Water Conservation*, 67(6), 474-484.

Blake, G.R., & Hartge, K.H. (1986). Bulk Density. In A. Klute (Ed.), *Methods of Soil Analysis, Part 1. Physical and Mineralogical Methods* (2nd ed., Vol. 5, pp 363-375). Madison, WI: ASA and SSSA.

Burchell, M.R., Skaggs, R.W., Chescheir, G.M., Gilliam, J.W., & Arnold, L.A. (2005). Shallow Subsurface Drains to Reduce Nitrate Losses from Drained Agricultural Lands. *Transactions of the ASAE,* 48(3), 1079- 1089.

Crumpton, W.G., Isenhart, T.M., & Mitchell, P.D. (1992). Nitrate and organic N analysis with second-derivative spectroscopy. *Limnology and Oceanography,* 37(4), 907-913.

David, M., Drinkwater, L., & Mclsaac, G. (2010). Sources of Nitrate Yields in the Mississippi River Basin. *Journal of Environmental Quality,* 39, 1657-1667.

Frankenberger, J., Kladivko, E., Sands, G., Jaynes, D., Fausey, N., Helmers, M.,…Brown, L. (2007). Questions and Answers about Drainage Water Management for the Midwest, *Purdue Extension Publication WQ-44*. West Lafayette, IN: Purdue Extension.

Gee, G.W., & Or, D. (2002). Particle-size Analysis. In J. Dane and G. Topp (Eds.) *Methods of Soil Analysis, Part 4. Physical Methods,* (2nd ed., Vol. 5, pp 255-294). Madison, WI: ASA and SSSA.

Helmers, M.J., Christianson, R., Brenneman, G., Lockett, D., & Pederson, C. (2012). Water Table, Drainage, and Yield Response to Drainage Water Management in Southeast Iowa. *Journal of Soil and Water Conservation*, 67(6), 485-494.

Jaynes, D.B. (2012). Changes in yield and nitrate losses from using drainage water management in central Iowa, United States. *Journal of Soil and Water Conservation*, 67(6), 495-501.

Jury, W., & Horton, R. (2004). *Soil Physics,* (6th ed.). Hoboken, NJ: Wiley.

Kladivko, E.J., Helmers, M.J., Abendroth, L.J., Herzmann, D., Lal, R., Castellano, M.J.,… Villamil, M.B. (2014). Standardized research transdisciplinary research of climate variation impacts in corn production systems. *Journal of Soil and Water Conservation,* 69(6), 532-542.

Madramootoo, C.A., Dodds, G.T., & Papadopoulos, A. (1993). Agronomic and Environmental Benefits of Water-Table Management. *Journal of Irrigation and Drainage Engineering,* 119(6), 1052-1065.

Ng, H.Y.F., Tan, C.S., Drury, C.F., & Gaynor, J.D. (2002). Controlled drainage and subirrigation influences tile nitrate loss and corn yields in a sandy loam soil in Southwestern Ontario. *Agriculture, Ecosystems & Environment*, 90(1), 81-88.

Pavelis, G.A. (1987). *Farm Drainage in the United States: History Status, and Prospects.* Washington, D.C.: USDA Economic Research Service.

Sands, G.R., Song, I., Busman, L.M., & Hansen, B.J. (2008). The Effects of Subsurface Drainage Depth and Intensity on Nitrate Loads in the Northern Cornbelt. *Transactions of the ASABE,* 51(3), 937-946.

SAS. 2011. *SAS User's Guide*. Ver. 9.3. Cary, N.C.: SAS Institute, Inc.

Skaggs, R.W., & Chescheir III, G.M. (2003). Effects of Subsurface Drain Depth on Nitrogen Losses from Drained Lands. *Transactions of the ASABE,* 46(2), 237-244.

Skaggs, R.W. & van Schilfgaarde, J. (1999). *Agricultural Drainage*. Madison, WI: ASA, CSSA, and SSSA.

Skaggs, R.W., Fausey, N.R., & Evans, R.O. (2012). Drainage Water Management. *Journal of Soil and Water Conservation,* 67(6), 167-172.

Strock, J.S., Sands, G.R., & Helmers, M.J. (2011). Subsurface Drainage Design and Management to Meet Agronomic and Environmental Goals. In . J.L. Hatfield and T.J. Sauer (Eds.) *Soil Management: Building a Stable Base for Agriculture* (pp. 199-208). Madison, WI: ASA, CSSA, and SSSA.

Turner, R.E., & Rabalais, N.N. (1994). Coastal Eutrophication near the Mississippi River Delta. *Nature,* 368(6472), 619-621.

Wang, X., Frankenberger, J.R., & Kladivko, E.J. (2002). Estimating Nitrate-N Losses from Subsurface Drains Using Variable Water Sampling Frequencies. *Transactions of the ASAE,* 46(4), 1033-1040.

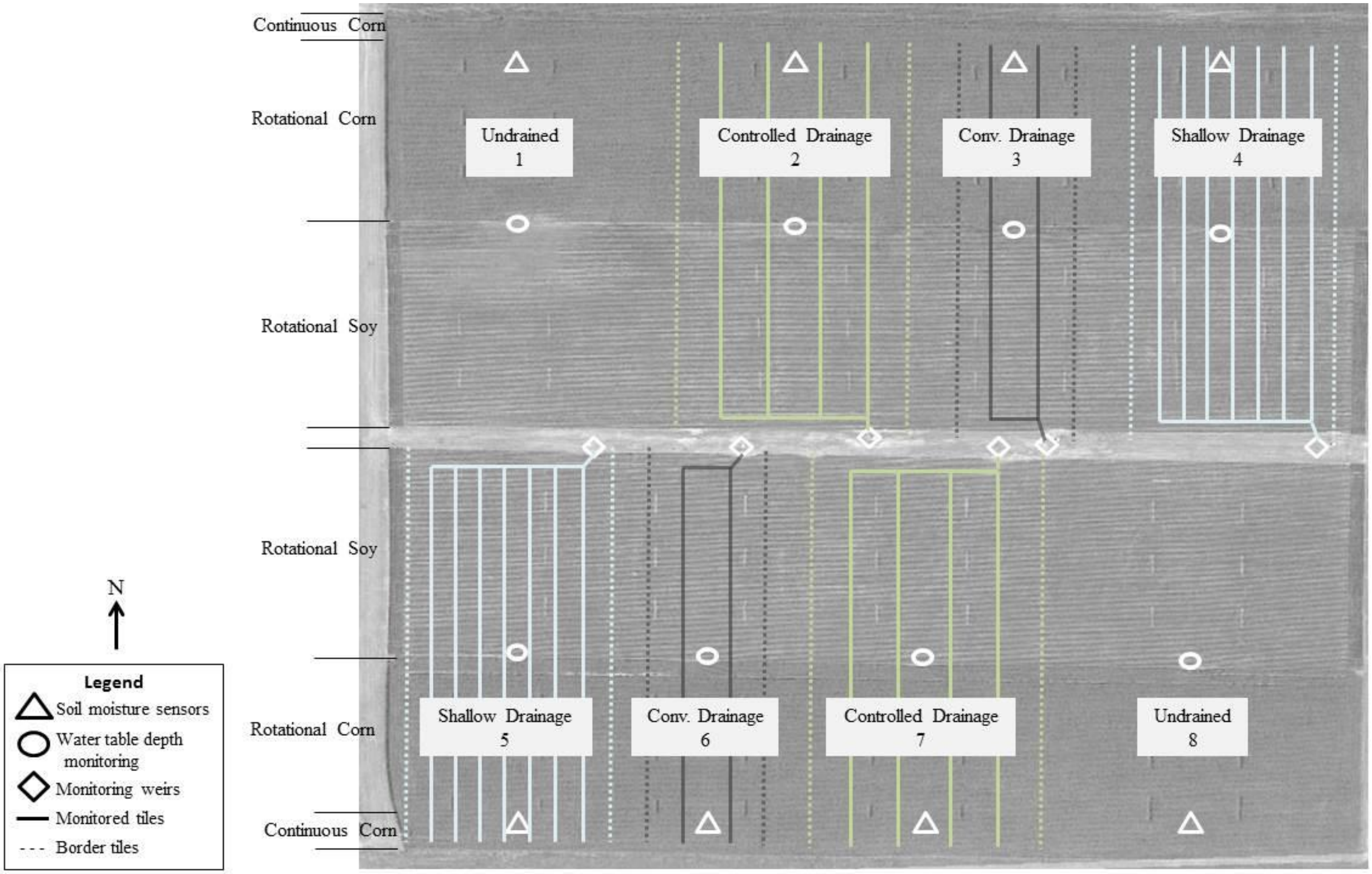

Figure 2.1. Aerial view of drainage plots at SERF in 2011 when 24 rows on the northern and southern side of the field were removed from rotation for continuous corn. The map illustrates data collection locations, drainage layout, and cropping system.

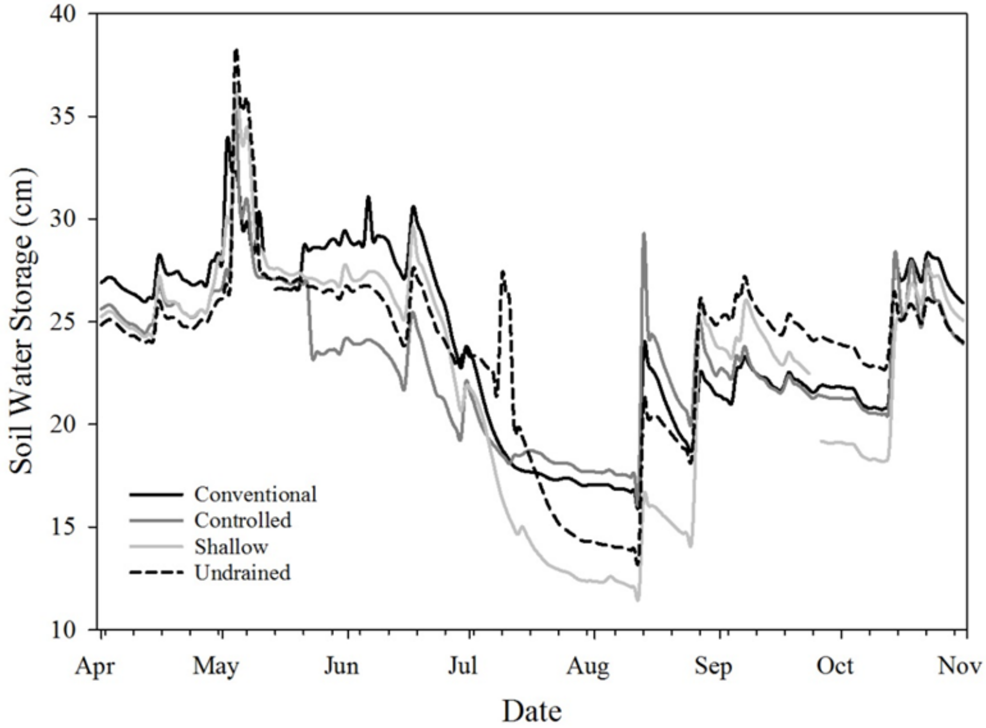

Figure 2.2. Average daily soil water storage (cm) for an 80 cm soil column for the 2012 growing season for all drainage treatments.

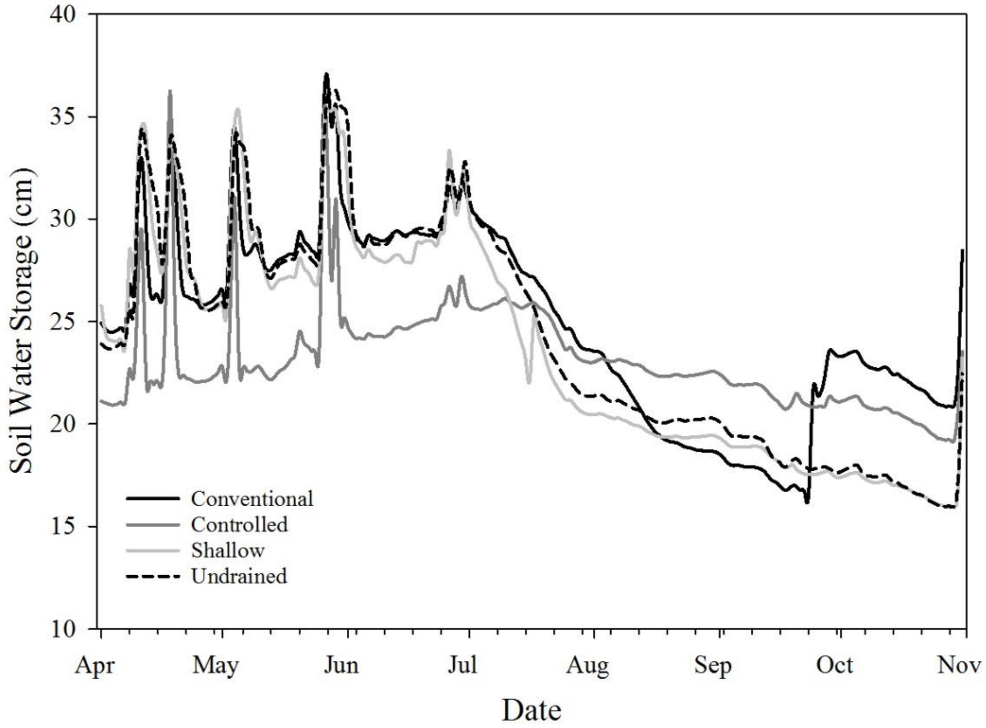

Figure 2.3. Average daily soil water storage (cm) for an 80 cm soil column for the 2013 growing season for all drainage treatments.

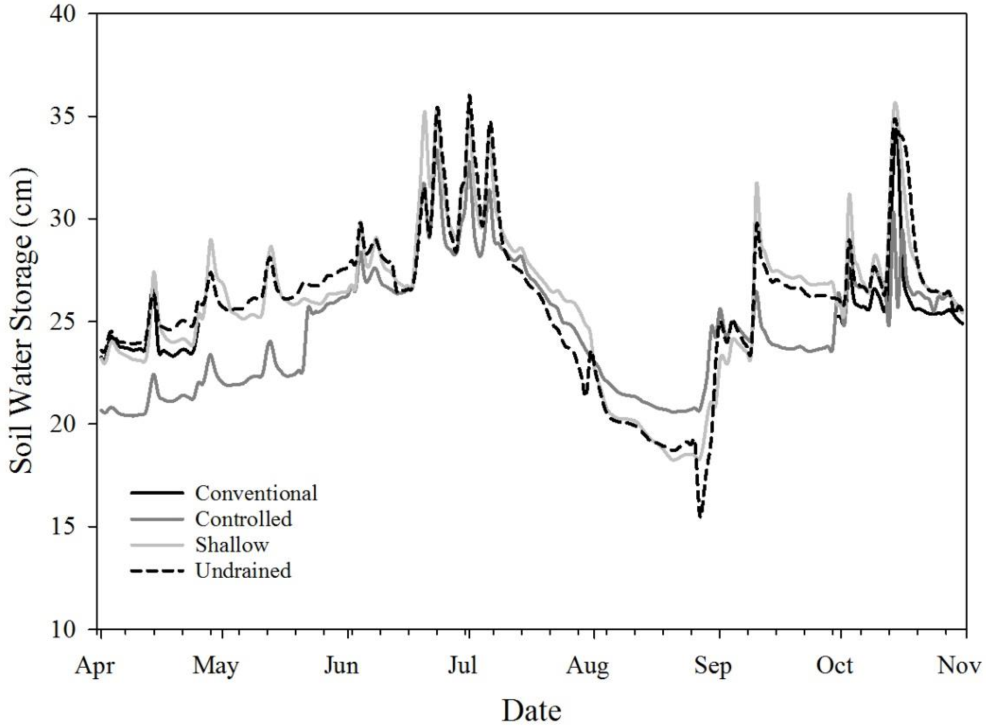

Figure 2.4. Average daily soil water storage (cm) for an 80 cm soil column for the 2014 growing season for all drainage treatments.

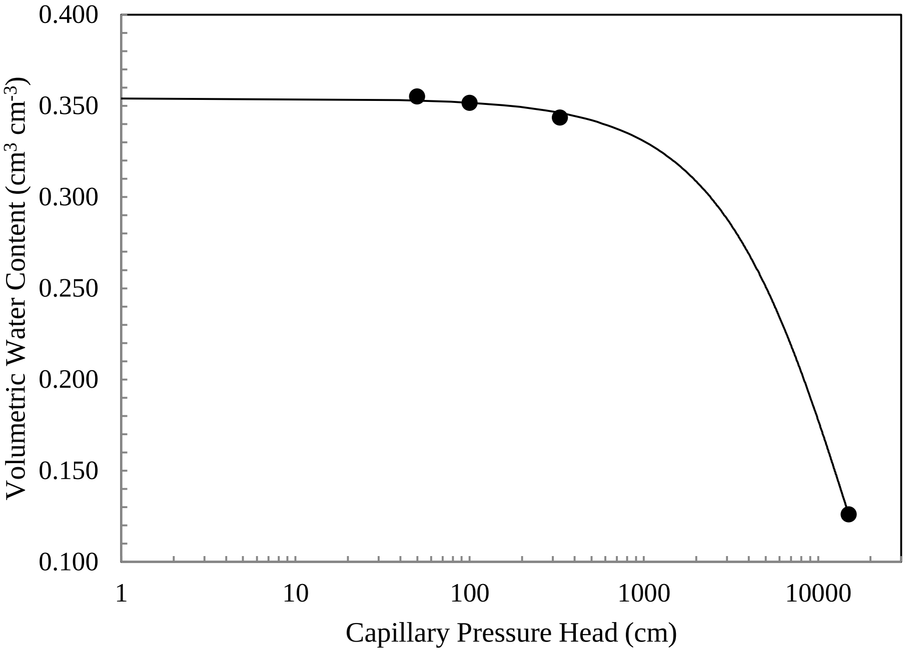

Figure 2.5. Average soil water retention curve for the silty clay loams found at SERF.

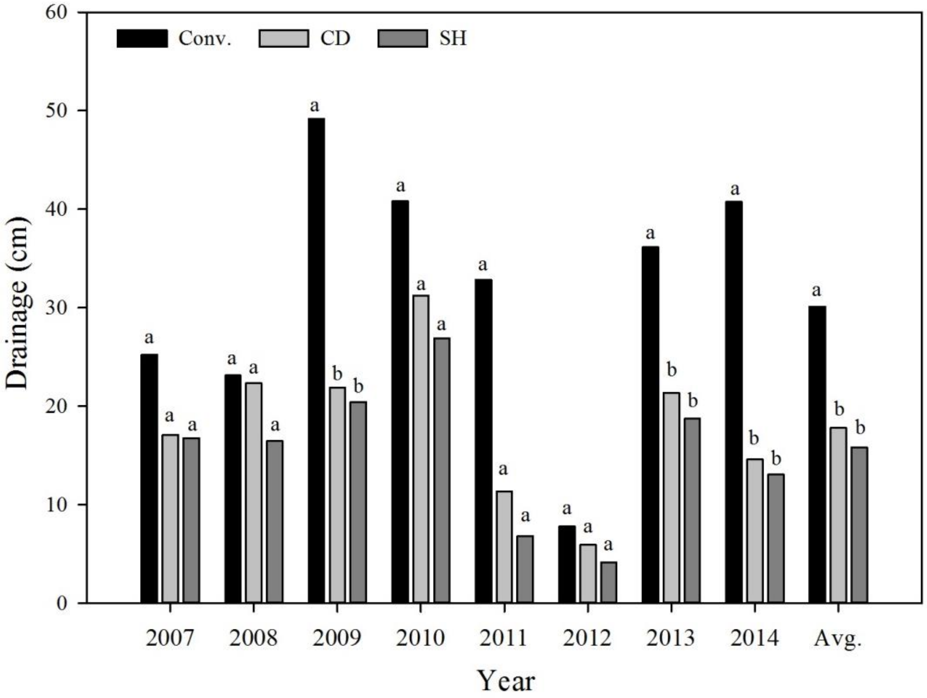

Figure 2.6. Average annual drainage volumes (cm) from the three drainage treatments: conventional drainage (Conv.), controlled drainage (CD), and shallow drainage (SH). Years or the eight year average not connected with the same letter are statistically different (p < 0.05).

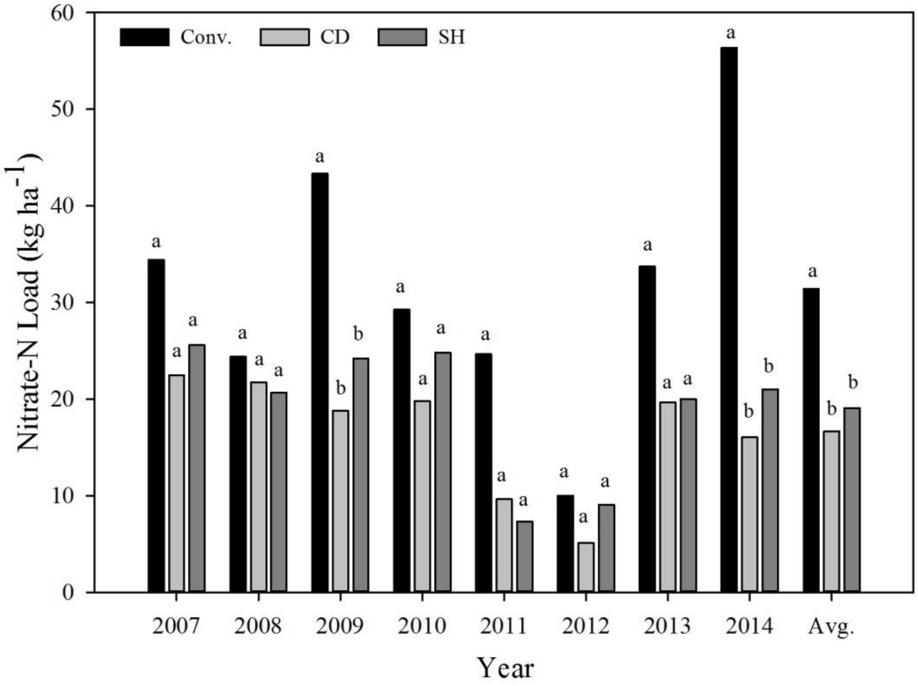

Figure 2.7. Average annual nitrate-N loads (kg ha^{-1}) for the three drainage treatments: conventional drainage (Conv.), controlled drainage (CD), and shallow drainage (SH). Years or the eight- year average not connected with the same letter are statistically different (*p* < 0.05).

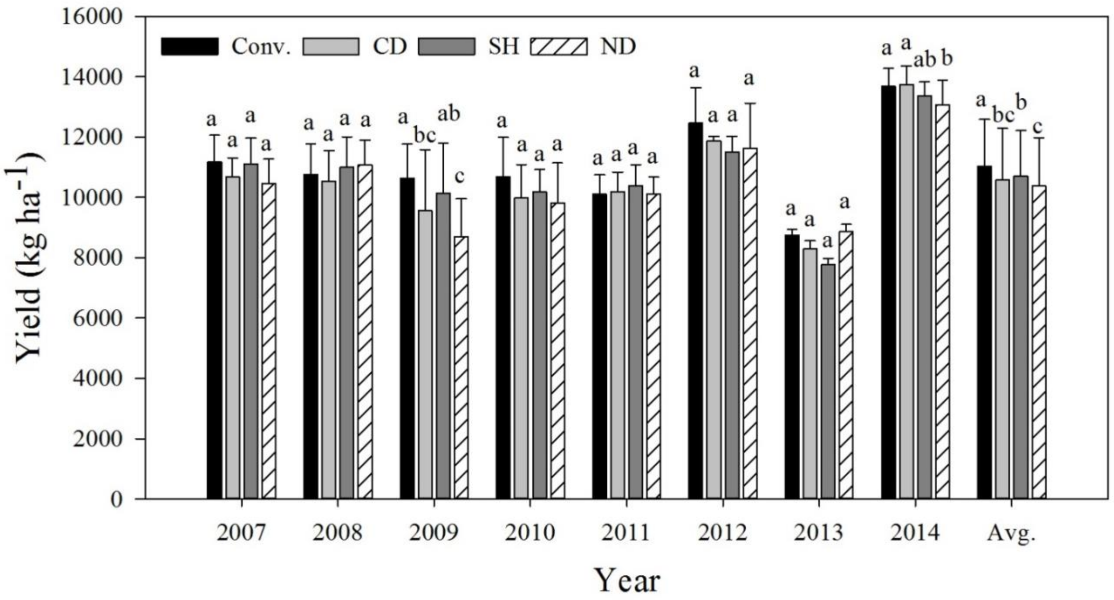

Figure 2.8. Annual and eight-year average corn yields (kg ha^{-1}) for the three drainage treatments: conventional drainage (Conv.), controlled drainage (CD), and shallow drainage (SH). Means within years or the eight-year average with a different letter are significantly different ($p<0.05$). Error bars show standard deviation.

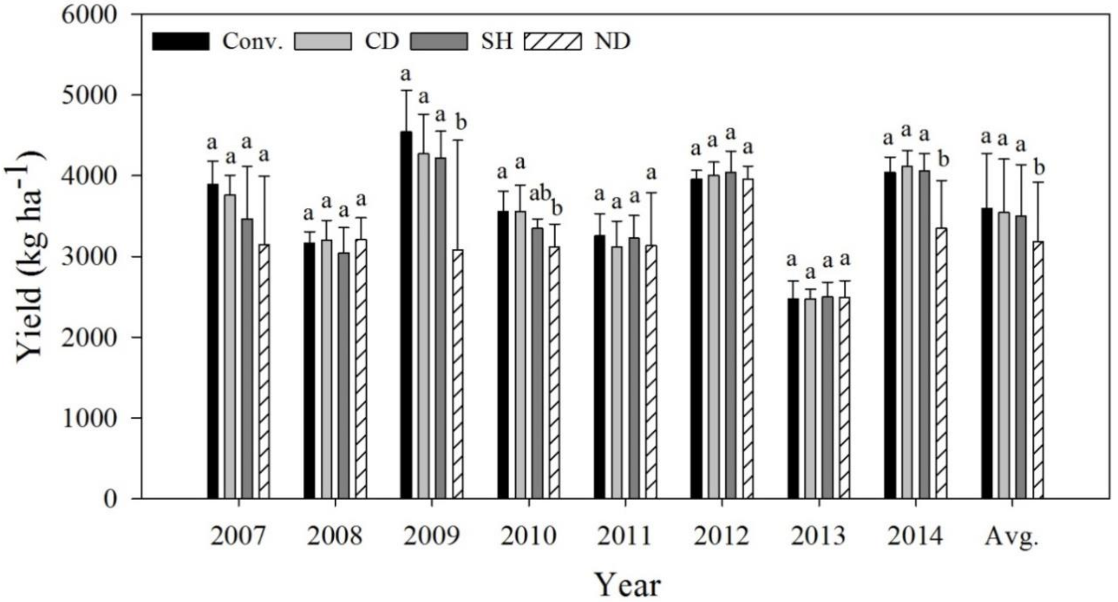

Figure 2.9. Annual and eight-year average soybean yields (kg ha^{-1}) for the three drainage treatments: conventional drainage (Conv.), controlled drainage (CD), and shallow drainage (SH). Means within years or the eight-year average with a different letter are significantly different ($p<0.05$). Error bars show standard deviation.

Table 2.1. Field activities from 2007-2014, including control dates for controlled drainage plots. An open control structure indicates the drainage depth is 1.2 m. In the spring, a closed control structure indicates drainage depth is 0.76 m. In the fall, if a date is given, the drainage depth is 0.30 m. If a date is not provided, the drainage depth is the spring closed depth through the winter.

	Corn		Soybean		Spring control		Fall control
Year	planting	Harvest	planting	Harvest	Open	Close	Close
2007	May 8	Oct. 16	late May	Oct. 25	Apr. 30	June 2	Jan. 7, 2008
2008	May 9	Nov. 4	June 2	Oct. 11	Apr. 14	June 5	Nov. 19
2009	Apr. 17 to 18	Oct. 7, Oct. 12 to 13	May 22	Oct. 20	Apr. 15	May 29	Nov. 5
2010	Apr. 15	Sept. 30, Oct. 12	May 28	Oct. 1 to 2	Apr. 15	June 24	Oct. 18
2011	May 3	Sept. 29	May 11	Oct. 3	Apr. 25	June 1	
2012	Apr. 18	Sept. 24	May 15	Oct. 24	Apr. 5	June 14	
2013	May 17	Oct. 4	June 12	Oct. 2			
2014	May 19	Nov. 7	June 9	Oct. 10			

Table 2.2. Seasonal monthly rainfall (mm) at SERF from 2007-2014, including a long-term average at Mount Pleasant, approximately 15 km away.

	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Season
2007	121	128	140	202	124	234	51	86	1085
2008	23	136	136	159	85	97	207	60	903
2009	108	98	111	219	123	248	35	182	1123
2010	69	110	156	321	100	125	207	26	1114
2011	46	96	144	208	33	26	45	15	612
2012	29	70	159	89	13	121	69	89	638
2013	60	189	259	103	29	2	44	111	798
2014	4	83	46	270	63	72	122	118	778
50 yr Avg.	63	92	118	120	112	108	110	76	798

Table 2.3. Soil characteristics (0-60 cm in depth) of the four treatments: conventional drainage (Conv.), controlled drainage (CD), shallow drainage (SH), and no drainage (ND).

Drainage	Sand (%)	Silt (%)	Clay (%)	TC (kg ha^{-1})	TN (kg ha^{-1})	ρ_b, g cm^{-3}
Conv.	13.3	47.2	39.5	12981	876	1.35
CD	13.3	47.6	39.1	13488	910	1.35
SD	13.2	48.3	38.5	13075	863	1.38
ND	13.3	47.1	39.6	13191	912	1.37

Table 2.4. Average monthly depth to water table (m) from 2009-2014 for the four treatments: conventional drainage (Conv.), controlled drainage (CD), shallow drainage (SH), and no drainage (ND). Dashes indicate unavailable data.

	2009				2010				2011			
	Conv.	CD	SH	ND	Conv.	CD	SH	ND	Conv.	CD	SH	ND
Jan.	—	—	—	—	1.3a	1.25a	1.24a	0.67b	1.44ab	1.47ab	1.53a	1.09b
Feb.	—	—	—	—	1.41a	1.39a	1.37a	0.44b	1.36ab	1.42a	1.45a	1.02b
Mar.	—	—	—	—	1.19a	1.09a	1.14a	0.60b	1.35a	1.21a	1.19a	0.53b
Apr.	—	—	—	—	1.29a	1.22a	1.16a	0.52b	1.35a	1.25a	1.19a	0.63b
May	1.32a	1.26a	0.99a	0.64b	1.27a	1.20a	1.04a	0.37b	1.31a	1.27a	1.17a	0.49b
June	1.15a	0.88b	0.82b	0.16c	1.16a	1.07a	0.93a	0.27b	1.26a	1.22a	1.06a	0.52b
July	1.26a	1.10a	1.03a	0.37b	1.38a	1.33a	1.33a	0.57b	1.43a	1.45a	1.36ab	1.01b
Aug.	1.31a	1.27a	1.35a	0.55b	1.39a	1.42a	1.46a	0.78b	1.86	1.89	1.69	1.38
Sept.	1.37a	1.34a	1.32a	0.54b	1.31a	1.27a	1.26a	0.67b	1.93	1.98	1.70	1.73
Oct.	1.18a	1.07a	1.01a	0.43b	1.38a	1.38a	1.42a	0.64b	1.82	2.02	1.70	1.78
Nov.	1.26a	1.08a	1.06a	—	1.42a	1.49a	1.58a	0.91b	1.76	1.99	1.70	1.74
Dec.	1.29a	1.22a	1.28a	0.55b	1.41a	1.48a	1.58a	1.04b	1.76	1.94	1.70	1.74

	2012				2013				2014			
	Conv.	CD	SH	ND	Conv.	CD	SH	ND	Conv.	CD	SH	ND
Jan.	1.79	2.01	1.75	1.80	1.73	1.85	1.71	1.62	—	—	—	—
Feb.	1.78	1.92	1.75	1.77	1.62	1.56	1.51	1.19	—	—	—	—
Mar.	1.78	1.92	1.74	1.73	1.37a	1.17ab	1.06ab	0.69b	—	—	—	—
Apr.	1.80	1.89	1.71	1.53	1.21a	0.99ab	0.77ab	0.47b	1.74	1.89	1.74	1.64
May	1.30a	1.11ab	0.96ab	0.66b	1.24a	1.09ab	0.82ab	0.61b	1.80	1.89	1.68	1.46
June	1.47	1.34	1.18	1.00	1.49a	1.27ab	0.97ab	0.84b	1.58a	1.50a	1.22ab	1.00b
July	1.78	1.74	1.65	1.43	1.65a	1.35ab	1.19ab	1.13b	1.54a	1.20ab	1.07a	0.85a
Aug.	1.89	2.05	1.73	1.83	1.93	1.80	1.66	1.53	1.80	1.69	1.60	1.40
Sept.	1.88	2.05	1.73	1.66	2.10a	1.88a	1.77ab	1.32b	1.68a	1.61ab	1.5ab	1.20b
Oct.	1.87	1.89	1.73	1.74	2.10a	1.88ab	1.76ab	1.37b	1.31a	1.14ab	0.97ab	0.71b
Nov.	1.90	1.92	1.74	1.73	2.15a	1.88ab	1.76ab	1.54b	1.42	1.29	1.11	1.05
Dec.	1.78	1.92	1.73	1.69	2.16a	1.88ab	1.76ab	1.62b	1.41	1.31	1.01	1.08

Note: Monthly means within years with a different letter are significantly different ($p<0.05$). Only months where there were significant differences have letters included.

Table 2.5. Number of hours water table is within 30 or 60 cm of the ground surface during the growing season (April- October) from 2010-2014 for the four treatments: conventional drainage (Conv.), controlled drainage (CD), shallow drainage (SH), and no drainage (ND).

	30 cm				60 cm			
	Conv.	CD	SH	ND	Conv.	CD	SH	ND
2010	36b	5b	0b	874a	55b	94b	115b	1824a
2011	4b	0b	0b	60a	35b	0b	18b	1459a
2012	20b	23b	33b	152a	14	35	75	131
2013	7b	25b	182ab	524a	123	121	361	464
2014	0b	3b	73b	291a	34b	70b	214ab	413a
Avg.	13b	11b	57b	380a	52b	64b	156b	858a

Note: Number of hours within years with a different letter are significantly different (p<0.05). Only months where there were significant differences have letters included.

Table 2.6. Average monthly volumetric water content (cm^3 cm^{-3}) at 10 cm depth from 2012-2014 for the four treatments: conventional drainage (Conv.), controlled drainage (CD), shallow drainage (SH), and no drainage (ND).

	2012				2013				2014			
	Conv.	CD	SH	ND	Conv.	CD	SH	ND	Conv.	CD	SH	ND
Apr.	0.28	0.28	0.26	0.28	0.29	0.27	0.28	0.31	0.28	0.22	0.26	0.29
May	0.31	0.29	0.29	0.30	0.33	0.29	0.32	0.34	0.29	0.24	0.27	0.31
June	0.29	0.27	0.24	0.27	0.32	0.29	0.30	0.35	0.31	0.30	0.30	0.33
July	0.23	0.20	0.17	0.17	0.27	0.25	0.26	0.27	0.30	0.30	0.29	0.30
Aug.	0.24	0.21	0.19	0.19	0.20	0.21	0.22	0.22	0.25	0.26	0.25	0.24
Sept.	0.28	0.29	0.24	0.26	0.16	0.18	0.19	0.18	0.30	0.27	0.30	0.30
Oct.	0.28	0.30	0.24	0.25	0.16	0.20	0.18	0.18	0.30	0.29	0.29	0.30

Note: Monthly means within years with a different letter are significantly different ($p<0.05$). Only months where there were significant differences have letters included.

Table 2.7. Average monthly volumetric water content (cm^3 cm^{-3}) at 20 cm depth from 2012-2014 for the four treatments: conventional drainage (Conv.), controlled drainage (CD), shallow drainage (SH), and no drainage (ND).

	2012				2013				2014			
	Conv.	CD	SH	ND	Conv.	CD	SH	ND	Conv.	CD	SH	ND
Apr.	0.35a	0.33ab	0.28b	0.30ab	0.34	0.33	0.29	0.33	0.32a	0.31a	0.21b	0.32a
May	0.38	0.36	0.32	0.35	0.38	0.36	0.31	0.38	0.34a	0.33a	0.22b	0.34a
June	0.32	0.31	0.28	0.30	0.39a	0.37a	0.28b	0.39a	0.38a	0.36a	0.26b	0.37a
July	0.21	0.24	0.20	0.17	0.33a	0.30a	0.18b	0.30a	0.37a	0.32ab	0.24b	0.33a
Aug.	0.25	0.26	0.21	0.18	0.27a	0.27a	0.15b	0.25a	0.30a	0.27a	0.16b	0.22ab
Sept.	0.33	0.31	0.27	0.30	0.26a	0.25a	0.13b	0.22a	0.35a	0.32a	0.22b	0.34a
Oct.	0.34	0.31	0.31	0.30	0.32a	0.23b	0.12c	0.19bc	0.35a	0.31ab	0.25b	0.35a

Note: Monthly means within years with a different letter are significantly different ($p<0.05$). Only months where there were significant differences have letters included.

Table 2.8. Average monthly volumetric water content (cm^3 cm^{-3}) at 40 cm depth from 2012-2014 for the four treatments: conventional drainage (Conv.), controlled drainage (CD), shallow drainage (SH), and no drainage (ND). Dashes indicate unavailable data.

	2012				2013				2014			
	Conv.	CD	SH	ND	Conv.	CD	SH	ND	Conv.	CD	SH	ND
Apr.	0.36	0.36	0.33	0.34	0.35	0.35	0.36	0.36	0.31	0.33	0.36	0.33
May	0.39	0.39	0.38	0.39	0.38	0.38	0.38	0.40	0.34	0.36	0.38	0.35
June	0.37	0.38	0.36	0.35	0.39	0.40	0.37	0.40	—	0.39	0.42	0.40
July	0.27	0.30	0.24	0.25	0.35	0.36	0.33	0.36	—	0.38	0.41	0.39
Aug.	0.29	0.30	0.22	0.24	0.27	0.31	0.27	0.29	—	0.32	0.31	0.26
Sept.	0.32	0.31	0.32	0.35	0.25	0.30	0.26	0.27	0.34	0.36	0.38	0.35
Oct.	0.34	0.33	0.32	0.34	0.24	0.28	0.24	0.25	0.36	0.36	0.39	0.37

Note: Monthly means within years with a different letter are significantly different ($p<0.05$). Only months where there were significant differences have letters included.

Table 2.9. Average monthly volumetric water content (cm^3 cm^{-3}) at 60 cm depth from 2012-2014 for the four treatments: conventional drainage (Conv.), controlled drainage (CD), shallow drainage (SH), and no drainage (ND).

	2012				2013				2014			
	Conv.	CD	SH	ND	Conv.	CD	SH	ND	Conv.	CD	SH	ND
Apr.	0.34	0.31	0.36	0.31	0.35b	0.31b	0.41a	0.37ab	0.32	0.30	0.34	0.30
May	0.37ab	0.34b	0.40a	0.37ab	0.38ab	0.34b	0.42a	0.38ab	0.34	0.32	0.37	0.32
June	0.37a	0.30b	0.36a	0.33ab	0.38ab	0.33b	0.43a	0.36b	0.37ab	0.35b	0.42a	0.37ab
July	0.22b	0.22b	0.16c	0.28a	0.37	0.34	0.38	0.34	0.36	0.34	0.40	0.36
Aug.	0.22a	0.23a	0.13b	0.27a	0.26	0.31	0.29	0.26	0.32	0.30	0.26	0.26
Sept.	0.22b	0.22b	0.17b	0.32a	0.21c	0.30a	0.28ab	0.24bc	0.34	0.34	0.36	0.31
Oct.	0.29	0.27	0.27	0.32	0.21b	0.30a	0.25ab	0.22b	0.36	0.35	0.41	0.36

Note: Monthly means within years with a different letter are significantly different ($p<0.05$). Only months where there were significant differences have letters included.

Table 2.10. Average monthly total soil water storage (cm^3 cm^{-3}) for an 80 cm soil column from 2012-2014 for the four treatments: conventional drainage (Conv.), controlled drainage (CD), shallow drainage (SH), and no drainage (ND). Dashes indicate unavailable data

	2012				2013				2014			
	Conv.	CD	SH	ND	Conv.	CD	SH	ND	Conv.	CD	SH	ND
Apr.	27.0	25.5	25.5	24.9	27.0	24.8	28.0	28.0	24.4	23.0	24.5	24.9
May	29.3	27.6	28.7	28.5	29.8	26.3	29.7	30.2	27.0	24.9	26.1	26.5
June	27.6	24.5	26.0	25.4	29.6	26.7	29.2	29.9	—	28.2	29.3	29.4
July	18.5	18.9	16.7	18.6	27.1	25.4	24.0	25.8	—	27.1	28.2	28.2
Aug.	19.5	19.3	17.1	18.5	20.4	22.7	19.7	20.5	—	23.1	21.0	19.8
Sept.	22.0	20.8	23.3	25.0	17.9	21.5	18.3	18.6	26.8	25.9	27.5	26.1
Oct.	24.8	23.8	22.9	24.5	20.9ab	22.1a	17.1b	17.2b	27.9	26.7	28.0	28.0

Note: Monthly means within years with a different letter are significantly different ($p<0.05$). Only months where there were significant differences have letters included.

Table 2.11. Average monthly drainage (cm) from 2007-2014 from the three drainage treatments: conventional drainage (Conv.), controlled drainage (CD), and shallow drainage (SH). Dashes indicate unavailable data.

	2007			2008			2009			2010		
Month	Conv	CD	SH	Conv	CD	SH	Conv	CD	SH	Conv	CD	SH
Jan.	0.0	0.0	0.0	—	0.0	1.1	0.0	0.0	0.4	0.0	0.0	—
Feb.	0.0	0.0	0.0	—	0.0	0.0	0.2a	0.0b	0.0b	0.0	0.0	0.0
Mar.	0.0	0.0	0.0	—	1.3	0.2	—	0.5a	2.2b	5.3	3.8	3.7
Apr.	—	—	—	5.5	7.6	4.2	4.5	2.0	0.8	4.7a	4.1ab	3.3b
May	3.0	5.6	2.8	5.5	5.6	3.2	8.4a	5.8a	2.9b	6.7	5.8	4.0
June	9.8	6.4	8	7.4a	3.2b	3.3b	13.9a	4.3b	5.0b	16.6a	13ab	10.3b
July	0.2	0.2	0.1	1.1a	0.0b	0.0b	6.8a	1.3b	1.6b	0.1a	0.0b	0.0b
Aug.	4.1	2	2.8	0.0	0.0	0.0	4.0	3.0	2.3	0.2a	0.0b	0.0b
Sept.	0.0	0.1	0.0	5.5a	4.6b	4.7ab	0.0	0.0	0.0	6.3	4.5	4.1
Oct.	4.1a	2.8b	3.0b	0.4	0.0	0.1	7.5a	4.9b	4.2b	0.8a	0b	0b
Nov.	0.0	0.0	0.0	0.3	0.0	0.0	2.8a	0.1b	0.8ab	0.0	0.0b	0.0b
Dec.	3.9	0.0	0.0	0.2	0.0	0.1	1.0a	0.0b	0.2ab	0.0	0.0	0.0

	2011			2012			2013			2014		
Month	Conv	CD	SH	Conv	CD	SH	Conv	CD	SH	Conv	CD	SH
Jan.	0.3	0.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Feb.	1.7	0.1	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0
Mar.	3.8	0.0	0.0	0.0	0.0	0.0	4.4	1.7	0.8	0.0	0.0	0.0
Apr.	6.3a	1.9b	0.8b	0.0	0.0	0.0	12.2	7.8	7.9	0.0	0.0	0.6
May	9.3a	4.3b	1.6b	11.1	4.1	5.8	14.2a	10.6b	8.6b	0.0	0.0	0.3
June	11a	4.6b	1.8b	1.3	0.0	0.0	3.8a	1.2b	1.4b	12.3	4.1	5.2
July	0.5	0.0	0.0	0.0	0.0	0.0	1.3	0.0	0.0	13.3a	3.7b	3.9b
Aug.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.1	0.0
Sept.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.2
Oct.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.1a	4.3b	4.4b
Nov.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.8	0.0
Dec.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Notes: Monthly means within years with a different letter are significantly different ($p<0.05$). Only months where there are significant differences have letters included.

Table 2.12. Average annual flow-weighted NO_3-N concentrations (mg L^{-1}) from 2007-2014 for the three drainage treatments: conventional drainage (Conv.), controlled drainage (CD), and shallow drainage (SH).

Year	Conv.	CD	SH
2007	13.7	13.1	15.3
2008	10.6	9.8	12.5
2009	8.8	8.4	11.7
2010	7.2ab	6.4b	9.1a
2011	7.8	8.5	11.3
2012	12.8	12.3	14.2
2013	9.3	9.2	10.6
2014	13.9	12.6	14.2
Avg	10.9b	10.0c	12.4a

Note: Years or the eight-year year average not connected with the same letter are significantly different ($p < 0.05$). Only years where there were significant differences have letters included.

CHAPTER 3. EFFECT OF DRAINAGE WATER MANAGEMENT ON THE PLANTING DATE OF CORN

A paper to be modified for submission to *Journal of Water and Soil Conservation*

Linda R. Schott[2], Ainis Lagzdins, Aaron L. Daigh, Carl Pederson, Greg Brenneman, Matthew J. Helmers

Abstract

In Iowa, when the timeliness of spring field activities are critical to achieve an adequate growing season for high yielding corn, subsurface drainage is necessary to improve trafficability and decrease excess water stress on crops. The objective of this study was to determine the effect of shallow, controlled, conventional and no drainage on depth to water table, volumetric water content, and soil temperature during a 51 day period, from mid-April through May, when corn needs to be planted in Iowa in order to qualify for crop insurance. This research was conducted at the Iowa State University Southeast Research Farm near Crawfordsville, Iowa from 2012 to 2015. The site consists of eight plots with two replicates for each of the four drainage treatments. Each plot had half planted in soybeans (*Glycine max* L. Merr.) and the other half in corn (*Zea mays* L.), and the halves were rotated every year in accordance with a typical corn-soy rotation. During the five year study period, the water table in the undrained treatment was significantly shallower ($p<0.05$) than the conventional and controlled drainage treatments. The soil temperature at 10 cm was also significantly warmer ($p<0.05$) in the undrained and shallow drainage treatments than the conventional and controlled drainage

---

[2] Primary author and researcher

treatment. Drainage treatment did not affect volumetric water content, maximum soil temperature, and minimum soil temperature at 10 or 20 cm as well as average soil temperature at 20 cm. Overall, drainage treatment did not impact planting date with respect to temperature and volumetric water content. Drainage treatment could impact the date of planting with respect to the depth of water table due to a higher risk of excess water stress on the crop.

Introduction

Subsurface drains are used to remove excess water from the soil profile of agricultural land in areas with poor natural drainage. High water tables reduce soil aeration, which in turn can prevent seed germination, cause plant root injury, and reduce plant nutrient uptake thereby reducing grain yields (Evans & Fausey, 1999). Field research conducted by Kanwar et al. (1988) showed that corn yields are impacted the most when excess water stress occurs during crop establishment soon after planting. Evans et al. (1991) used this information when they developed a corn yield model based on soil excess water stress based on a 30 cm water table (SEW_{30}) as well as a factor for crop susceptibility to high water tables at various growth stages.

In Iowa, when the timeliness of spring field activities are critical to achieve an adequate growing season for high yielding corn, subsurface drainage is also necessary to improve trafficability. Campbell and O’Sullivan (1991) defined trafficability as the ability of the soil to provide adequate traction for vehicles while withstanding traffic without excess compaction. Many authors have used a relationship between available water content and soil strength to show that as soil moisture decreases in the upper soil profile, trafficability increases (Earl, 1996; Bornstein & Hedstrom, 1982; Kornecki & Fouss, 2001). Bornstein and Hedstrom (1982) concluded that trafficability developed more rapidly in the spring with drainage than without it by decreasing soil water content below field capacity. Soils cannot be too dry either at the time of planting either; corn seeds must absorb about 30% of their weight in water for germination (Elmore & Al-Kaisi 2013).

Soil temperature at 4 cm needs to be at least 10°C in order for corn to germinate and accumulate 50 to 67 growing degree days °C (GDD) to emerge (Elmore & Al-Kaisi 2013). Historically, subsurface drainage was thought to increase soil temperatures in early spring, which could allow for earlier planting. In their literature review, Steenhuis and Walter (1986) found there were three main reasons for this rationale: evaporation from an undrained field decreases temperature, rainfall increases soil temperature faster in a drained field due to increased infiltration of warm rain water, and more heat is needed to warm a wet field than a dry one due to water's high specific heat. However, their analytical analysis concluded that thermal diffusivity, which is a function of a soil's ability to store and conduct thermal energy, is more important than the volumetric heat capacity, which is a soil's ability to store thermal energy. However, there are very few field studies that support this conclusion. Jin et al (2008) concluded from their field study in Northern Minnesota that subsurface drainage significantly increased spring soil temperature but only at the depth of the subsurface drains.

Although there are benefits to subsurface drainage, there are also negative environmental impacts. Drainage has increased the loss of nitrate-nitrogen from agricultural lands in the Mississippi River Basin contributing to the hypoxia zone in the

Gulf of Mexico (Turner & Rabalais, 1994). David et al. (2010) found that a significant portion of the nitrate-nitrogen export originated from subsurface drainage. One practice being proposed to combat these losses is drainage water management. Drainage water management is designing or managing the subsurface drainage system in order to reduce the drainage volume or to manage the outflow. The drains are either installed at a shallower depth or installed at the conventional depth described earlier with a control structure that regulates the water table outflow height. These two practices are known as shallow and controlled drainage, respectively (Strock et al., 2011).

Drainage water management has been shown to reduce drainage volumes and NO_3-N losses but yields impacts have been mixed. Shallow drainage reduced drainage volume and NO_3-N loss by 46- 20% and 29-18%, respectively, when compared to conventionally drained systems (Helmers et al., 2012; Sands et al. 2008). Using 20 controlled drainage sites across the Midwest and Canada, Skaggs et al. (2012) reported an 18-80% reduction in annual drainage volume and an 18-79% reduction in NO_3-N loads when compared to conventional drainage. However, corn yields ranged from a yield reduction in Iowa to an increase of 19% (Helmers et al., 2012; Skaggs et al. 2012).

Since high yielding corn requires a longer growing season than soybeans, corn is planted first in Iowa. If planting date is delayed, producers may have to change corn hybrids for varieties with less growing degree units necessary for maturity, but these hybrids tend to be lower yielding. In Iowa, in order for producers to qualify for crop insurance, corn must be planted between April 11 and May 31st (Plastina, 2014). The recommended planting window to obtain the highest corn yield potential in Southern Iowa is April 17 to May 8 (Elmore, 2012). Since planting delays and higher water tables can reduce crop yields, it is important to understand the impact of drainage and drainage water management during the spring planting window. The objective of this study was to investigate the impact of drainage and drainage water management practices on volumetric soil water content, soil temperature, and depth to water table in order to evaluate trafficability and crop establishment during the crop insurance planting window for corn in Southern Iowa. Drainage treatment effect on soil volumetric water content and soil temperature were investigated at depths of 10 and 20 cm for this thesis, but realistically, only the 10 cm depth would be pertinent for seed germination.

Materials and Methods

Site location and design

Research was conducted at the Iowa State Southeast Research Farm (SERF) near Crawfordsville, Iowa (41°11'38" N, 91°28'58" W) from 2007 to 2014. The site has eight research plots with two replications for each of the following drainage treatments: undrained, conventional drainage, shallow drainage, and controlled drainage. The plots were blocked into a north and south replication because the site consists of two poorly drained silty clay loam soils. Kalona (silty clay loam, fine, smectitic, mesic Vertic Endoaquolls) is found predominantly in the northern plots while Taintor (silty clay loam, fine, smectitic, mesic Vertic Argiaquolls) is predominantly in the south. The site is relatively flat with less than a five meter elevation change over 17 ha. The plots were designed to have a maximum drainage coefficient of 1.9 cm day^{-1}, and the individual plots range in size from approximately 1.2 to 2.4 ha. The conventional and controlled drainage plots have a drain depth and spacing of 1.2 and 18 m, respectively. The shallow drained plots have drains at a depth of 0.76 m with 12.2 m spacing.

Originally, the plots were split down the middle and cropped east to west with both corn (*Zea mays* L.) and soybeans (*Glycine max* L. Merr.) each year, which were alternated each consecutive year to replicate a typical corn-soybean rotation in Iowa. In 2012, however, 24 rows of continuous corn were added on the north and south edges of the site, so each plot had rotational corn, rotational soybeans, and continuous corn every year. Since corn is generally planted first in Iowa and requires a longer growing season, the rotational corn will be the focus of analysis. Spring field activities included field cultivation, anhydrous ammonia application, planting, and a pre-emergence herbicide application (Table 3.1). All drainage treatments are planted on the same day due to plot layout and the field manager decided when field conditions were suitable for planting. If necessary, all activities for all plots can be completed in one day. At this site, controlled drainage plots were only managed in the spring when necessary for field activities. The gates were typically opened in mid to late April approximately two weeks prior to planting to allow free drainage and closed in late May to early June after planting was completed.

Data collection

Daily rainfall was measured using a manually-read rain gauge located approximately 1 km from the research plots from 2012 to 2015. For both the long-term precipitation average and total rainfall during the planting period, daily manual measurements from 2000 to 2015 were averaged with rainfall amounts at a NOAA station in Mount Pleasant, approximately 15 km away, from 1990 to 2015. Daily average, maximum, and minimum temperatures for the site were compiled using the Iowa State Agclimate Network for 2012 to 2013 and Iowa State University Soil Moisture Network for 2014 to 2015.

In 2009, monitoring wells were installed in the center of each plot where the water table would be the shallowest and between the rotational corn and soybeans to minimize the impact of farming operations. Depth to water table was monitored hourly using Global Water pressure transducers (Global Water, Sacramento, California). Daily average water table depths were calculated as well as the daily minimum depth to water table. The daily minimums were used to calculate the soil excess water stress for 30 cm (SEW_{30}) since crop susceptibility to SEW_{30} is greatest during the early stages of crop establishment and growth (Kanwar et al., 1988; Evans et al., 1999).

$$\mathrm{SEW30} = \sum_{i=1}^{n}(30 - X_i)$$

where

X_i = the water table depth below the ground surface in cm on day i

n = the number of days within the planting window

Bulk density samples were collected in 2011 using a modified Uhland sampler for depth increments of 0-10, 10-20, 20-30, 30-40, 40-50 and 40-60 cm at eight locations transecting each plot across all crops (Kladivko et al., 2014) and were oven dried at 105°C (Blake & Hartge, 1986). ECH_2O 5TM (Decagon, Pullman, Washington) sensors were installed in the center of each plot in the continuous corn in May 2011. The soil volumetric water content (VWC) and temperature were measured at five depths: 10, 20, 40, 60, and 100 cm although only the top two depths were used for this paper since corn is planted at a depth of 4 cm. Data was logged every five minutes using an Em50 logger.

Maximum soil moisture values were capped to individual plot soil porosity at the sensor depth increments. Using the bulk density samples collected in each plot in 2011, soil porosity was calculated for 10 and 20 cm sensors using the corresponding depth bulk density values for 0-10 and 10-20 cm, respectively. Daily average soil moisture and temperature were calculated for the top two depths. Using bulk density samples collected in 2013, the soil water retention curve for soil samples corresponding to 0-10 and 10-20 cm depths were determined using a simultaneous collection system for pressures 50, 100, and 330 cm water (Powers et al., 1999). The permanent wilting point was defined at 15 bar and was determined using a WP4C Water Potential Meter (Decagon, Pullman, Washington). Due to homogeneity, soil water retention curves were averaged to create one soil water retention curve for 0-20 cm representing the entire site. Field capacity is the soil volumetric water content after a rain event when previously saturated soils can no longer drain by gravity. Due to shallow water tables, field capacity at the site was defined at the volumetric water content at 100 cm capillary pressure head.

Data analysis

Statistical analyses were conducted using Statistical Analysis System software (SAS 2011). The generalized linear mixed model (GLIMMIX) procedure was used with two replicates per treatment as repeated measures to determine the statistical significance of treatment effects on the following measurements at 10 and 20 cm: daily average soil volumetric water content, daily average temperature, daily maximum temperature, daily minimum temperature, and daily temperature amplitude. The same procedure was also used to analyze the daily average depth to water table.

Results and Discussion

Climate

During the planting window from April 11 to May 31, average temperatures ranged from 13.6 °C in 2013 to 16.2°C in 2012 (Table 3.2). When compared to the long-term average, the average temperature was 10% warmer in 2012 and 7% cooler in 2013. However, when accumulated growing degree days (GDD) for corn were considered, all four years of the study period were below average. The years of 2012 and 2013 were still the extremes with 24% and 42% fewer GDD than the long-term average. Every year, except 2013, had less than 201.6 mm of rainfall, which was the average for the planting period; 2012 received 3% less rain while 2014 and 2015 received 32% and 16% less, respectively. The planting window during 2013 received 75% more rain than average.

Volumetric water content

Over the four years of planting windows, there were no significant differences ($p=0.90$) between drainage treatments in VWC at 10 cm (Figure 3.1) nor were there significant differences ($p<0.05$) between drainage treatments on any individual day. There was also no significant difference ($p=0.35$) between the northern and southern replications. All treatments tended to have similar responsiveness to rainfall during both wetting and drying for the majority of events. Overall, 2013 had the greatest variation during the planting window for VWC due to the high rainfall with adequate time for drying between events. Both 2014 and 2015 had little variation in VWC because the rainfall events were smaller and closer together.

Similarly to the VWC at 10 cm, over the four years of planting windows, there were no significant differences ($p=0.53$) in VWC at 20 cm between the drainage treatments nor were there significant differences ($p<0.05$) between drainage treatments on any individual day. There was also no significant difference ($p=0.24$) between the northern and southern replications. The VWC at 20 cm tended to be wetter than at 10 cm. During large rain events, like in 2012 and 2013, the peaks were nearly the same, but the VWC at 20 cm appeared to dry slower (Figure 3.2).

In all four years, corn was planted when VWC at 10 cm was between 0.25 and 0.30. The VWC at 20 cm were more variable at the time of planting than the VWC at 10 cm, ranging from 0.25 to 0.35. The VWC in both cases would be at or below field capacity, defined as 100 cm of capillary head, for this soil type. Since corn was never planted with VWC above field capacity, these results are consistent with the conclusion reached by Earl (1997) that as VWC decreases below field capacity trafficability increases. VWC in all drainage treatments never remained above field capacity after a large rain event for more than a few days.

Soil temperature

There were significant differences in soil temperatures at 10 cm ($p=0.05$) between drainage treatments. In the last three weeks of the planting window in 2012, when the average temperatures were the highest over the entire study period, the shallow drainage treatment had significantly higher ($p<0.05$) temperature than the controlled drainage treatment (Figure 3.3). During the second to last week, the undrained treatment was also significantly warmer ($p<0.05$) than the controlled drainage treatment. For the last few days in April in 2013, when the average temperature drastically increased, the undrained and shallow drainage treatments were significantly warmer ($p<0.05$) than the controlled drainage treatment, and during the middle of May in the same year, the undrained treatment was also significantly warmer ($p<0.05$) than the controlled drainage treatment. There were no significant differences ($p<0.05$) in temperature in the other two years. The soil temperature at 10 cm was, on average, 2°C warmer in the shallow drainage and undrained treatments than in the controlled and conventionally drained treatments. In 2012, when average air temperatures were the highest, corn was planted the earliest of all four years; the average soil temperature for all treatments was 15°C. In contrast, on the latest corn planting date in 2013, the average soil temperature was 21°C. There was no significant difference ($p=0.14$) between the northern and southern replications. While the increase in average temperature could allow for earlier planting, the differences occurred later in the planting window when soil temperatures were already above 10°C. These results are not intuitive, and the reason for why the shallow drainage and undrained treatments are warmer is unknown.

Unlike the temperature differences between drainage treatments at 10 cm, there was no significant difference ($p=0.71$) in temperature at 20 cm between drainage treatments. There were also no significant differences ($p<0.05$) between drainage treatments on individual days within the planting windows. The average soil temperature at 20 cm was slightly cooler than at 10 cm for this part of the year. The average temperatures during planting at 20 cm varied from 13°C in 2015 to 18°C in 2013 (Figure 3.4). There was also no significant difference ($p=0.89$) between the northern and southern replications, like average soil temperature at 10 cm.

Overall, there was no significant difference ($p=0.32$) in daily maximum soil temperatures at 10 cm between drainage treatments, but there were some notable daily differences ($p<0.05$). In 2012 and 2013, the maximum daily soil temperature at 10 cm was the warmest in the shallow and undrained treatments and coolest in the controlled and conventional (Figure 3.5). There were sporadic days throughout both years where the maximum temperature at 10 cm in the undrained treatment was significantly warmer ($p<0.05$) than the controlled drainage treatment. There were also a few instances in both years when the maximum temperature at 10 cm in the shallow drained treatment was also significantly warmer ($p<0.05$) than the controlled drainage treatment. These differences tended to occur when the soil temperature was increasing rapidly, like the end of 2012 and mid-2013. The maximum soil temperature at 10 cm was between 3°C and 5°C warmer in the shallow drainage and undrained treatments, but just like the differences in average soil temperature at 10 cm, they tended to occur later in the planting window when soil temperatures were already warm. Like 2014, the undrained treatment tended to have the highest maximums, but a few times during the end of the planting window, the undrained treatment was significantly warmer ($p<0.05$) than the shallow drainage treatment. There were no clear differences in 2015. There was also no significant difference ($p=0.46$) between the northern and southern replications.

Like the average soil temperatures at 20 cm, the daily maximum temperatures at the same depth (Figure 3.6) showed fewer differences between treatments. There was no significant difference ($p=0.83$) between drainage treatments in daily maximum temperature at 20 cm. The daily maximum temperatures at 20 cm were cooler than the daily maximum temperatures at 10 cm. There was also no significant difference ($p=0.93$) between the northern and southern replications.

There were no differences ($p=0.49$) between the daily minimum soil temperatures at 10 cm between drainage treatments during the four planting windows. There were only two instances when there were daily differences ($p<0.05$) between drainage treatments. During the first week of May in 2012, the daily minimum soil temperature at 10 cm in the conventional drainage treatment changed from significantly warmer than the other three treatments to significantly cooler than the others (Figure 3.7). Then, in early May 2013, the undrained and shallow drainage treatments had significantly warmer minimum temperatures than the conventionally drained treatment for a couple of days. In 2012 and 2014, the shallow drainage treatment had warmer minimum temperatures than the other three drainage treatments, and the undrained drainage treatment had the coolest daily minimums in the early part of both those years. There were no clear patterns between the other treatments in those years. In all four years, corn was planted when the daily minimum soil temperatures at 10 cm were above the 10°C necessary for seed germination; although in 2012 when corn was planted the earliest, soil minimum temperatures at 10 cm fell below 10°C. The daily minimum temperature at 10 cm in the northern and southern replications were also not different ($p=0.73$).

Unlike the other temperature parameters, the daily minimum temperatures at 20 cm were warmer than the daily minimum temperatures at 10 cm. However, like the other temperature parameters at 20 cm, there are no clear relationships between drainage treatments in the daily minimum temperatures ($p=0.10$), and there was also no difference between the replications ($p=0.31$). There were only two notable instances when there were significant daily differences ($p<0.05$) between drainage treatments. During the week of May in 2012, the daily minimum soil temperature at 20 cm in the conventional drainage treatment changed from significantly warmer than the other three treatments to significantly cooler than the others (Figure 3.8). The second instance was during late

April 2014 when the daily minimum temperature at 20 cm for conventional drainage was significantly cooler than the other three.

Water table

There were significant differences ($p=0.05$) in depths to water tables between drainage treatments. In all four years, the water table in the undrained treatment was the shallowest followed by the shallow drainage treatment (Figure 3.9). In 2012, 2013, and 2015, the water table in the conventional treatment was the deepest, but in 2014 the controlled drainage treatment was slightly deeper. Low rainfall at the end of 2013 and inadequate rainfall in early 2014 kept the water tables deeper when compared to the other years. The water tables were the shallowest in 2013 compared to the other three years due to above average rainfall in the spring. Water tables were the shallowest at planting in 2013 and 2015 when both the undrained and shallow drained treatments were approximately one meter from the surface. Unlike VWC and temperature, there was a significant difference ($p=0.04$) between the northern and southern replications. The northern replication tended to have shallower water tables than the southern one.

In 2012, prior to the large rain event in early May, the undrained treatment had a significantly shallower ($p<0.05$) water table than the deepest water table, which was the controlled drainage treatment. During the week of rainfall at the end of April through early May, there were no significant differences ($p<0.05$) between treatments. Immediately following the rainfall event, nearly all treatments were significantly different ($p<0.05$) from one another. At the end of 2012, only the undrained treatment was significantly shallower ($p<0.05$) than the controlled and conventional drainage treatments. In 2013, the water table in the undrained treatment was significantly shallower ($p<0.05$) than the other three treatments for most of the year. Since the boards in the controlled drainage treatment were maintained at 0.76 m during 2013, the other three treatments only significantly differed ($p<0.05$) from each other immediately following a big rain event. The undrained treatment was also significantly shallower ($p<0.05$) than the controlled and conventional drainage treatments for most of 2014. During 2015, the shallow and undrained treatments had a significantly shallower ($p<0.05$) water table than the other two treatments.

In most years, there was little difference between the controlled and conventional drainage treatments, which is expected since this is the period of time when there is no water table management in the controlled drainage treatment. In 2013, when the water table control boards were maintained at 0.76 m, and there was substantial rainfall during the planting window, the water table in the controlled drainage treatment was shallower than the conventional treatment but deeper than the shallow drainage treatment. There were also several instances in 2012, 2013, and 2015 when the water table in the undrained treatment was at the surface, which likely reduced trafficability and would negatively impact crop establishment due to reduced soil aeration. The water tables in the other three drainage treatments also rose near the surface in 2012 and 2013 but receded faster. The water table wells were located in the center of each plot between two tile lines where the water table would be the shallowest. The wells in the undrained plots were also placed in the center of each plot and not necessarily where the water table would be the shallowest. Therefore, the water tables in the undrained plots could be much shallower than the data available.

Initial logic would indicate that since there were significant differences in the depth to water table between drainage treatments, there would also be significant differences between VWC. Theoretically, the VWC in the undrained and shallow drainage treatments would be higher than the VWC in the controlled and conventionally drained treatments (Skaggs and Chescheir, 2003). However, this is not the case. This inconsistency can be explained with the soil water retention curve for this soil type (Figure 3.10). There is little difference between VWC between 50 and 330 cm of capillary pressure.

The undrained treatment had the greatest SEW_{30} in every year followed by the shallow drainage treatment except 2015 (Table 3.3). In that year, the water table pressure transducer malfunctioned in the northern replication, which is typically has the shallowest water tables. In 2012, the conventionally drained treatment had a greater SEW_{30} than the controlled, but in the following year, the relationship switched. Over all four years, SEW_{30} was 2200% greater in the undrained plots than the conventional drainage treatment and 517% greater in the shallow drainage treatment. The conventional and controlled drainage plots were approximately equal.

Results for SEW_{30} after planting were similar to those for SEW_{30} during the whole planting window (Table 3.4). In 2012, when corn was planted the earliest of all four years, all SEW_{30} occurred after planting. However, the same thing occurred in 2015 when corn was planted two weeks later. In 2013 when corn was planted the latest of all four years, all treatments had less SEW_{30} after planting than in the entire planting window; the shallow and controlled drainage treatments had nearly half SEW_{30} after planting than in the entire planting window. Since Iowa receives much of its rainfall in April through

June, planting date is heavily dependent on the timing of rainfall. Crop susceptibility to SEW_{30} is greatest during the early stages of crop establishment and growth (Kanwar et al., 1988; Evans et al., 1999). Interestingly, 2014, which had no SEW_{30} during the planting window, was the only year of this analysis that had corn yield reductions. In this year, the corn yields in the undrained treatment were 17% less than the yields in the conventional drainage treatment. Although yields do not seem to be associated with SEW_{30} during this time period, the years investigated were not wet years. Yields could also be driven by excess water stress or water deficit stress later in the season.

Drainage effect on planting date

When each plot had a VWC at 10 cm depth below field capacity (Earl, 1997), average soil temperature at 10 cm above 10 °C (Elmore & Al-Kaisi, 2013), and a water table deeper than 30 cm (Kanwar et al., 1988; Evans et al., 1999), the plot was deemed suitable for planting. Using the first day when both drainage plots within a treatment would be suitable for planting, a theoretical planting date was determined. For the years 2012, 2014, and 2015, the theoretical planting dates for all treatments would have been April 11th or 12th. In 2013, the conventionally drained and shallow drainage treatments would have been suitable for planting on the 14th or 15th of April. However, the undrained treatment was not suitable for planting until the 26th of April due to shallow water tables.

All of the theoretical dates of planting are well before the actual date of planting each year. Even though only one day of field work was allotted because all planting activities can be completed in one day, the field manager would probably want a larger window. The water table in the undrained plots may also be shallower than the data available due to the location of the water table elevation wells, which could delay planting. Producers may also be hesitant to plant on the first day of the planting window due to high risk of additional cold weather.

Conclusions

Overall, drainage treatment did not affect VWC, maximum daily soil temperature, and minimum daily soil temperature at 10 and 20 cm depth as well as average soil temperature at 20 cm. Drainage treatment did affect depth to water table and average soil temperature at 10 cm though. The water table in the undrained was the shallowest followed by the water table in the shallow drained treatment. In most years, there was little difference between the controlled and conventional drainage treatments, which is expected since this is the period of time when there is no water table management in the controlled drainage treatment. The average soil temperature at 10 cm tended to be warmest in the undrained and shallow drainage treatments and coolest in the conventional and controlled drainage treatments, but the reasons for this is unknown since it is not an intuitive relationship. These temperature differences also occurred later in the planting window when average soil temperatures were already above 10°C.

The field manager used his judgement not the measurements analyzed for this paper to determine adequate conditions for planting. Using the metrics discussed in this paper, corn could have theoretically been planted much earlier in every year than when it was actually planted. In all four years, corn was planted when VWC at 10 cm was between 0.25 and 0.30. The VWC at 20 cm were more variable at the time of planting than the VWC at 10 cm, ranging from 0.25 to 0.35. The VWC in both cases would be at or below field capacity for this soil type. This is consistent with the conclusion reached by Earl (1997) that as VWC decreases below field capacity trafficability increases. At the time of planting every year, average soil temperatures in all treatments were well above the 10°C necessary for germination although in 2012, when corn was planted the earliest, average soil temperatures fell below 10°C after planting. Water tables were the shallowest during planting in 2013 and 2015 when both the undrained and shallow drained treatments were approximately one meter from the surface, but the undrained treatment could have been shallower. The relationship between SEW_{30} and crop yields from 2012-2014 was not very strong at this field site, so there are likely other more important factors.

Overall, drainage treatment did not impact the planting date of corn with respect to temperature and VWC since little soil temperature differences exist in the early part of the planting window, and there were no differences in VWC between treatments. However, drainage treatment does impact the date of planting with respect to the depth of water table. From the analyses discussed, the undrained treatment would have been delayed in planting in one year. When water tables were high after rain events, like in 2012 and 2013, water tables in all three drainage treatments receded back to drain depth in a couple of days, which is the same time period that the VWC were above field capacity. More investigation is necessary to determine if drainage treatment effects yields in terms of SEW_{30}, especially during wet years.

Acknowledgements

This research is part of a regional collaborative project supported by the USDA-NIFA, Award No. 2011-68002-30190, “Cropping Systems Coordinated Agricultural

Project: Climate Change, Mitigation, and Adaptation in Corn-based Cropping Systems." Project Web site: sustainablecorn.org. Research data and supporting metadata are stored in the team's centralized Climate and Cropping Systems database.

References

Blake, G.R., & Hartge, K.H. (1986). Bulk Density. In A. Klute (Ed.), *Methods of Soil Analysis, Part 1. Physical and Mineralogical Methods* (2nd ed., Vol. 5, pp 363-375). Madison, WI: ASA and SSSA.

Bornstein, J., & Hedstrom, W.E. (1982). Trafficability Factor in a Silty Clay Loam Soil. *Transactions of the ASAE*, 1240-1244.

Campbell, D.J., & O'Sullivan, M.F. (1991). The Cone Penetrometer in Relation to Trafficability, Compaction, and Tillage. In K.A. Smith and C.E. Mullins (Eds.), *Soil Analysis: Physical Methods* (pp. 399-429). New York, NY: Marcel Dekker.

David, M., Drinkwater, L., & Mclsaac, G. (2010). Sources of Nitrate Yields in the Mississippi River Basin. *Journal of Environmental Quality,* 39, 1657-1667.

Earl, R. (1997). Prediction of Trafficability and Workability from Soil Moisture Deficit. *Soil and Tillage Research*, 40, 155-168.

Elmore, R. (2012). Best Corn Planting Dates for Iowa. *Integrated Crop Management News.* Retrieved from http://www.extension.iastate.edu\CropNews\2012\0327elmore2.htm

Elmore, R., & Al-Kaisi, M. (2013). Corn Seeding Depth: Back to Basics. *Integrated Crop Management News.* Retrieved from http:\\ www.extension.iastate.edu\CropNews\2013\0303elmore2.htm

Evans, R.O, Skaggs, R.W., & Sneed, R.E. (1991). Stress Day Index Models to Predict Corn and Soybean Relative Yield under High Water Table Conditions. *American Society of Agricultural Engineers*, 34(5), 1997-2005.

Evans, R.O., & Fausey, N.R. (1999). Effects of Inadequate Drainage on Crop Growth and Yield. In Skaggs, R.W. and J. van Schilfgaarde (Eds.), *Agricultural Drainage* (pp. 13-54). Madison, WI: ASA, CSSA, and SSSA.

Helmers, M.J., Christianson, R., Brenneman, G., Lockett, D., & Pederson, C. (2012). Water Table, Drainage, and Yield Response to Drainage Water Management in Southeast Iowa. *Journal of Soil and Water Conservation*, 67(6), 495-501.

Jin, C.X., Sands, G.R., Kandel, H.J., Wiersma, J.H., & Hansen, B.J. (2008). Influence of Subsurface Drainage on Soil Temperature in a Cold Climate. *Journal of Irrigation and Drainage Engineering*, 134(1), 83-88.

Kanwar, R.S., Baker, J.L., & Mukhtar, S. (1988). Excessive Soil Water Effects at Various Stages of Development on the Growth and Yield of Corn. *Transactions of the ASAE*, 31(1), 133-141.

Kladivko, E.J., Helmers, M.J., Abendroth, L.J., Herzmann, D., Lal, R., Castellano, M.J.,… Villamil, M.B. (2014). Standardized research transdisciplinary research of climate variation impacts in corn production systems. *Journal of Soil and Water Conservation,* 69(6), 532-542.

Kornecki, T.S. & Fouss, J.L. (2001). Quantifying Soil Trafficability Improvements Provided by Subsurface Drainage for Field Crop Operations in Louisiana. *Applied Engineering in Agriculture*, 17(6), 777-781.

Powers, W.L, House, M.L., Tejral, R.D., & Eisenhauer, D.E. (1999). A simultaneous data collection system for several soil water release curves. *Applied Engineering in Agriculture*, 15(5), 477-481.

Plastina, A. (2014). Current Crop Insurance Policies. *Ag Decision Maker.* Retrieved from https://www.extension.iastate.edu/agdm/crops/pdf/a1-48.pdf

Sands, G.R., Song, I., Busman, L.M., & Hansen, B.J. (2008). The Effects of Subsurface Drainage Depth and Intensity on Nitrate Loads in the Northern Cornbelt. *Transactions of the ASABE,* 51(3), 937-946.

SAS. 2011. *SAS User's Guide*. Ver. 9.3. Cary, N.C.: SAS Institute, Inc.

Skaggs, R.W., Fausey, N.R., & Evans, R.O. (2012). Drainage Water Management. *Journal of Soil and Water Conservation*, 67(6), 167-172.

Skaggs, R.W., & Chescheir III, G.M. (2003). Effects of Subsurface Drain Depth on Nitrogen Losses from Drained Lands. *Transactions of the ASABE,* 46(2), 237-244.

Steenhuis, T.S., & Walter, M.F. (1986). Will Drainage Increase Spring Soil Temperatures in Cool and Humid Climates? *Transactions of the ASAE*, 29(6), 1641-1645.

Strock, J.S., Sands, G.R., & Helmers, M.J. (2011). Subsurface Drainage Design and Management to Meet Agronomic and Environmental Goals. In . J.L. Hatfield and T.J. Sauer (Eds.) *Soil Management: Building a Stable Base for Agriculture* (pp. 199-208). Madison, WI: ASA, CSSA, and SSSA.

Turner, R.E., & Rabalais, N.N. (1994). Coastal Eutrophication near the Mississippi River Delta. *Nature*, 368(6472), 619-621.

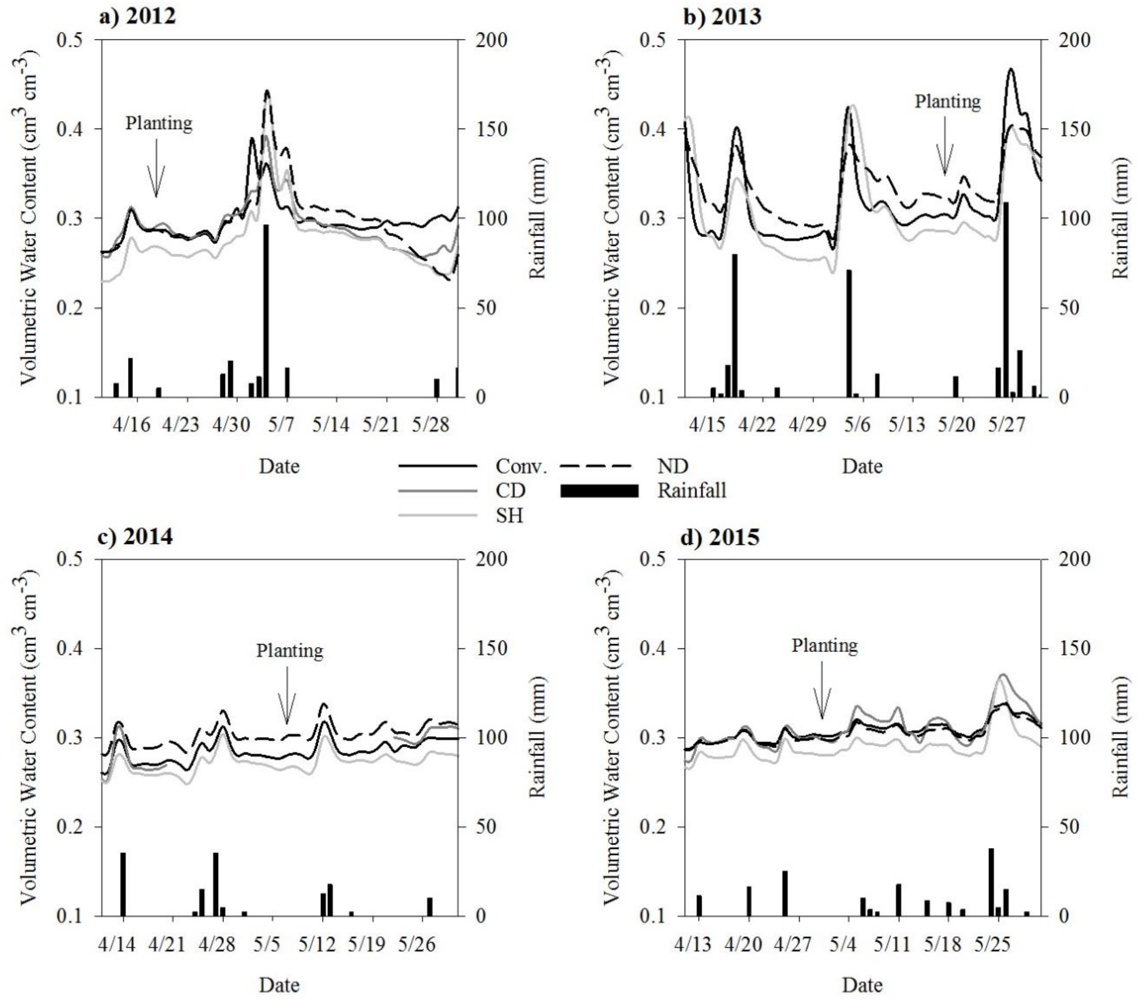

Figure 3.1. Average daily volumetric water content (cm^3 cm^{-3}) at 10 cm depth and daily rainfall amounts (mm) with the date of planting indicated for the planting windows in a) 2012, b) 2013, c) 2014, d) 2015 for all drainage treatments: conventional drainage (Conv.), controlled drainage (CD), shallow drainage (SH), and no drainage (ND).

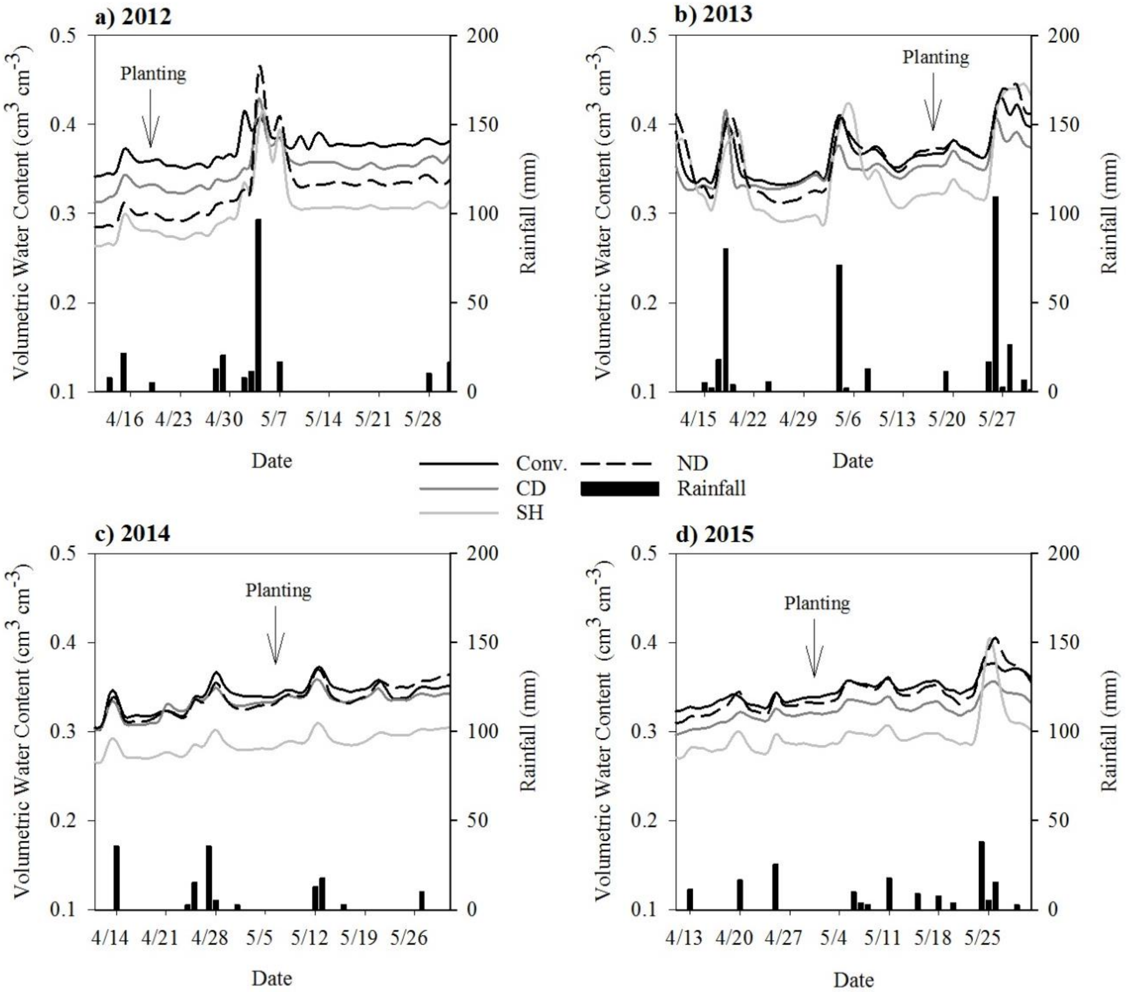

Figure 3.2. Average daily volumetric water content (cm^3 cm^{-3}) at 20 cm depth and daily rainfall amounts (mm) with the date of planting indicated for the planting windows in a) 2012, b) 2013, c) 2014, d) 2015 for all drainage treatments: conventional drainage (Conv.), controlled drainage (CD), shallow drainage (SH), and no drainage (ND).

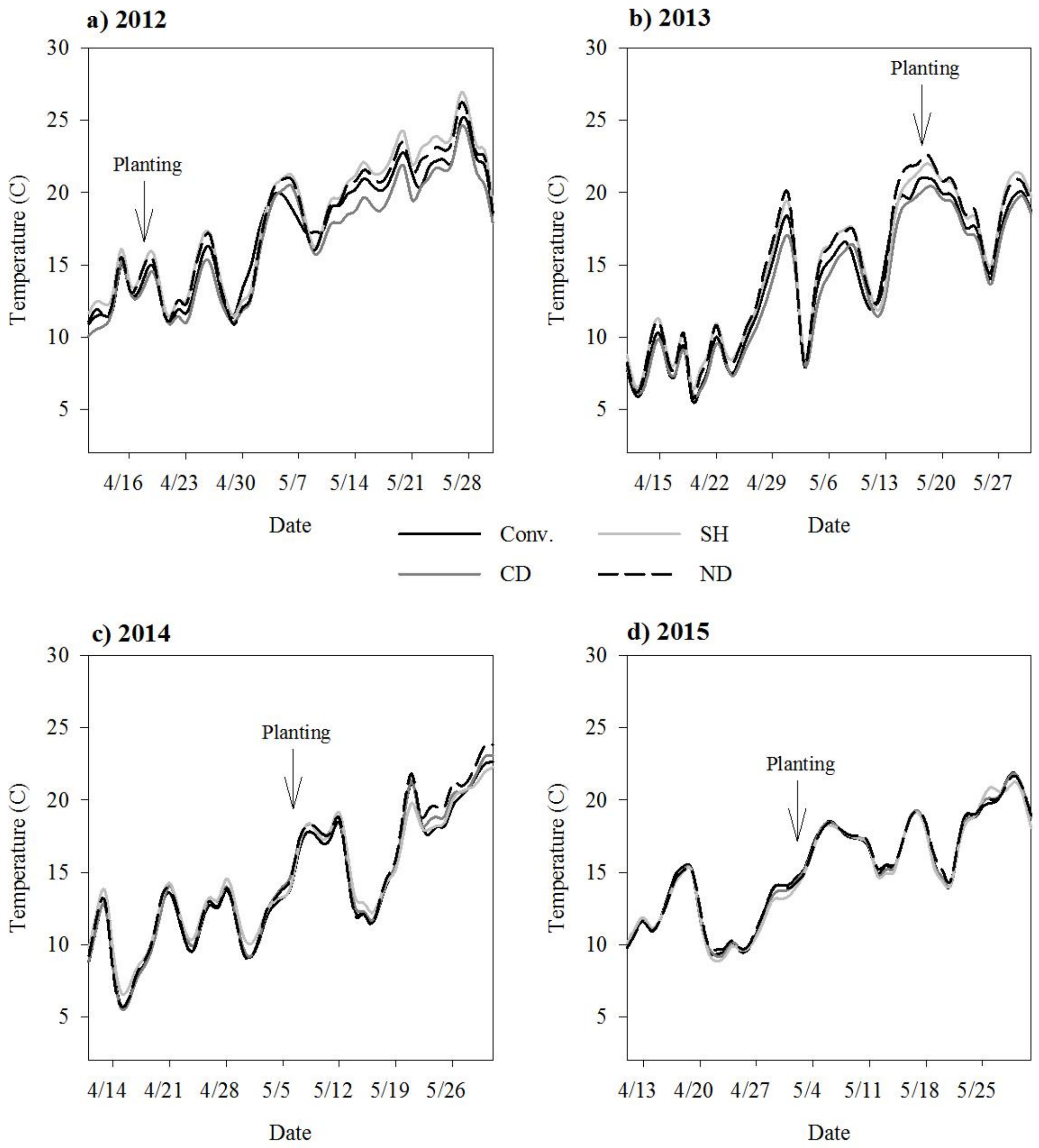

Figure 3.3. Average daily soil temperature (°C) at 10 cm depth with the date of planting indicated for the planting windows in a) 2012, b) 2013, c) 2014, d) 2015 for all drainage treatments: conventional drainage (Conv.), controlled drainage (CD), shallow drainage (SH), and no drainage (ND).

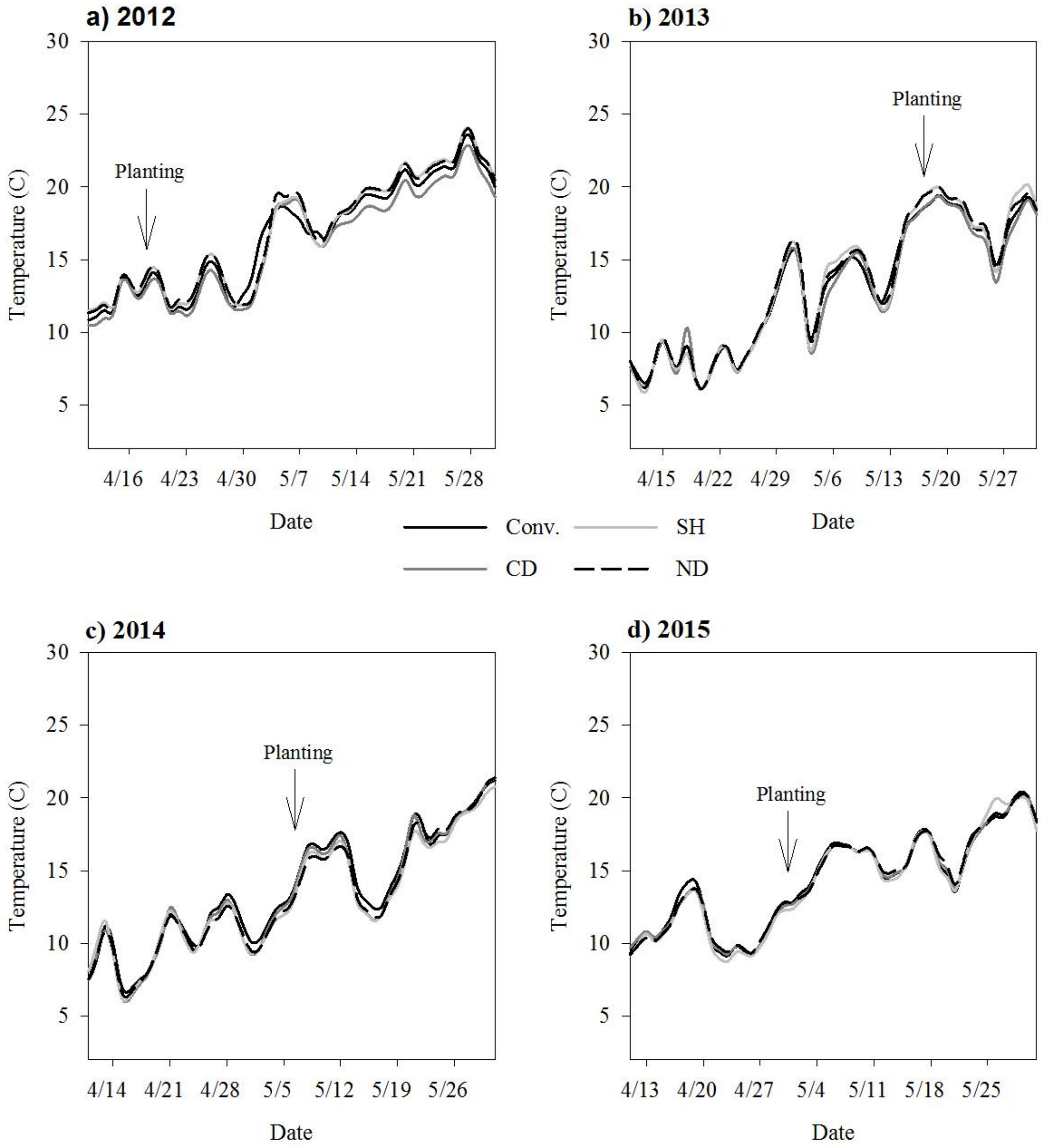

Figure 3.4. Average daily soil temperature (°C) at 20 cm depth with the date of planting indicated for the planting windows in a) 2012, b) 2013, c) 2014, d) 2015 for all drainage treatments: conventional drainage (Conv.), controlled drainage (CD), shallow drainage (SH), and no drainage (ND).

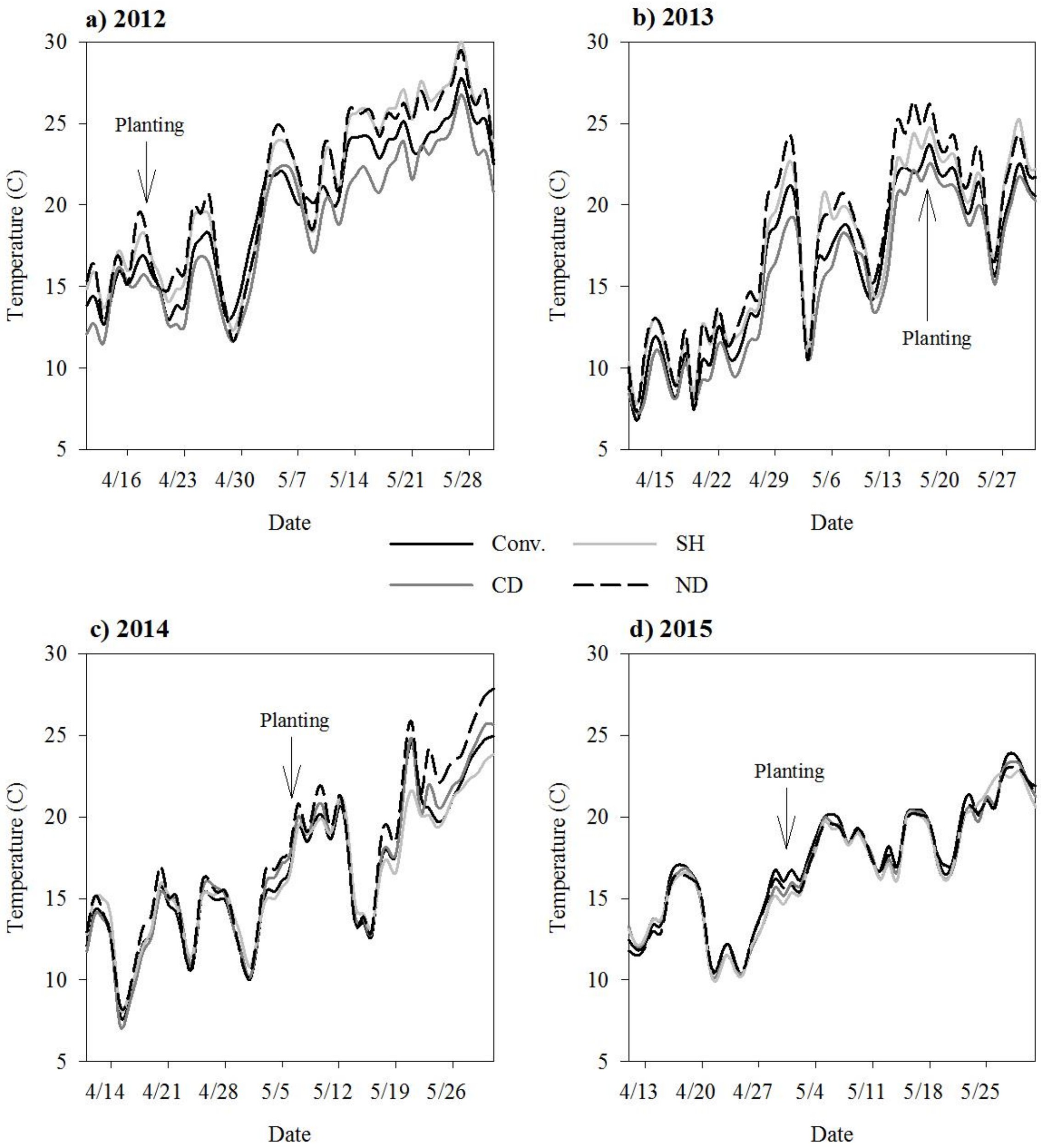

Figure 3.5. Maximum daily soil temperature (°C) at 10 cm depth with the date of planting indicated for the planting windows in a) 2012, b) 2013, c) 2014, d) 2015 for all drainage treatments: conventional drainage (Conv.), controlled drainage (CD), shallow drainage (SH), and no drainage (ND).

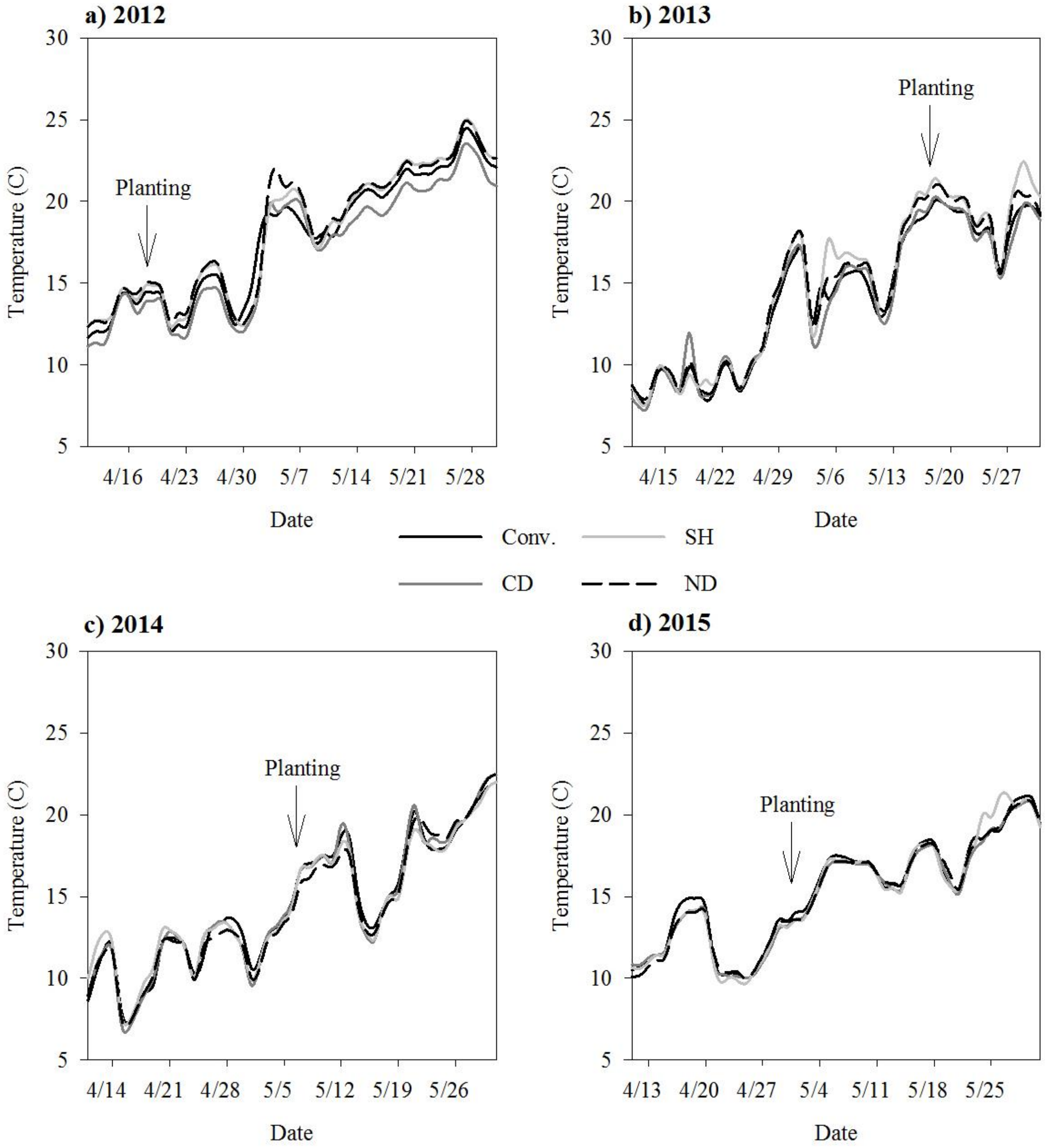

Figure 3.6. Maximum daily soil temperature (°C) at 20 cm depth with the date of planting indicated for the planting windows in a) 2012, b) 2013, c) 2014, d) 2015 for all drainage treatments: conventional drainage (Conv.), controlled drainage (CD), shallow drainage (SH), and no drainage (ND).

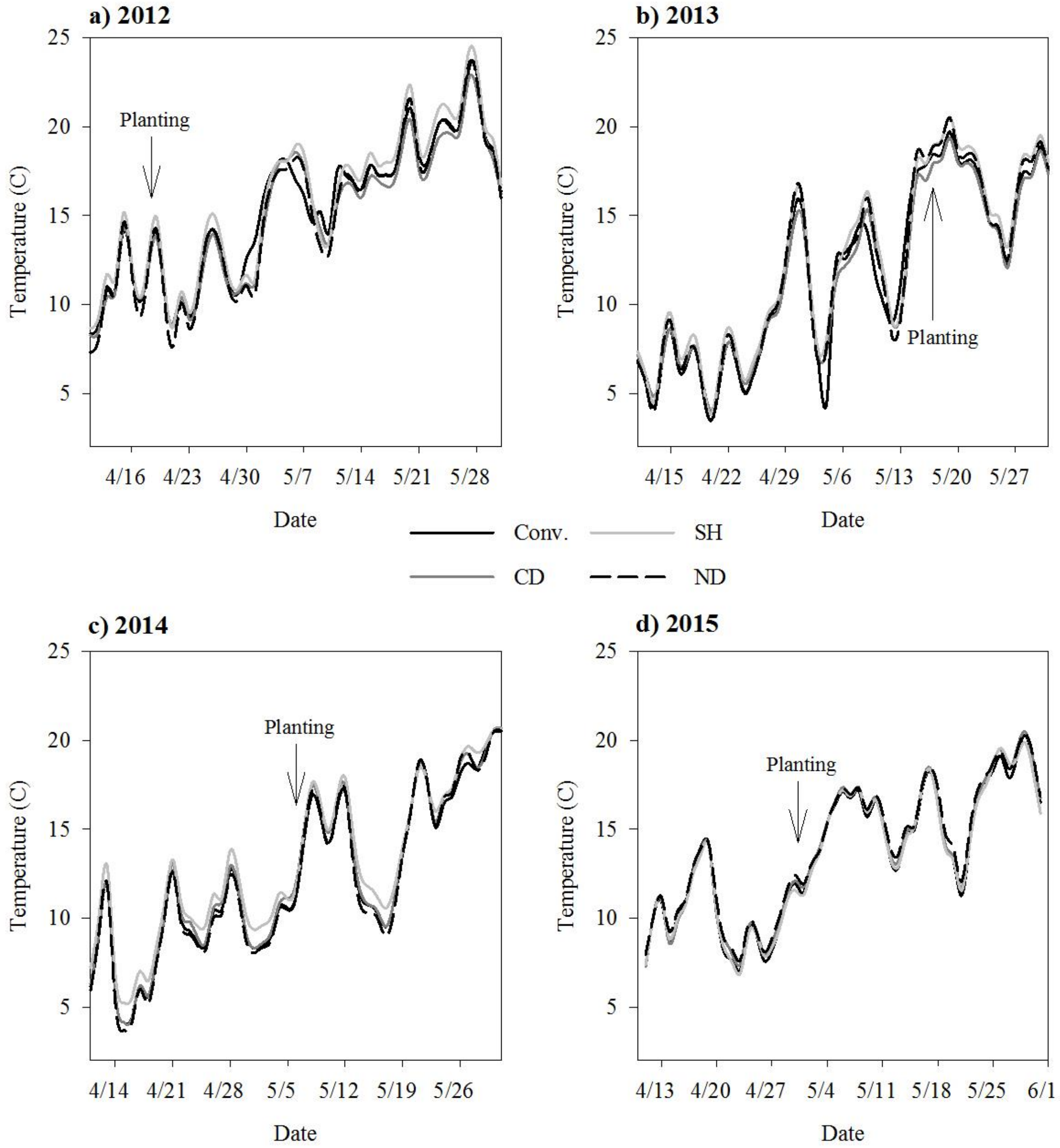

Figure 3.7. Minimum daily soil temperature (°C) at 10 cm depth with the date of planting indicated for the planting windows in a) 2012, b) 2013, c) 2014, d) 2015 for all drainage treatments: conventional drainage (Conv.), controlled drainage (CD), shallow drainage (SH), and no drainage (ND).

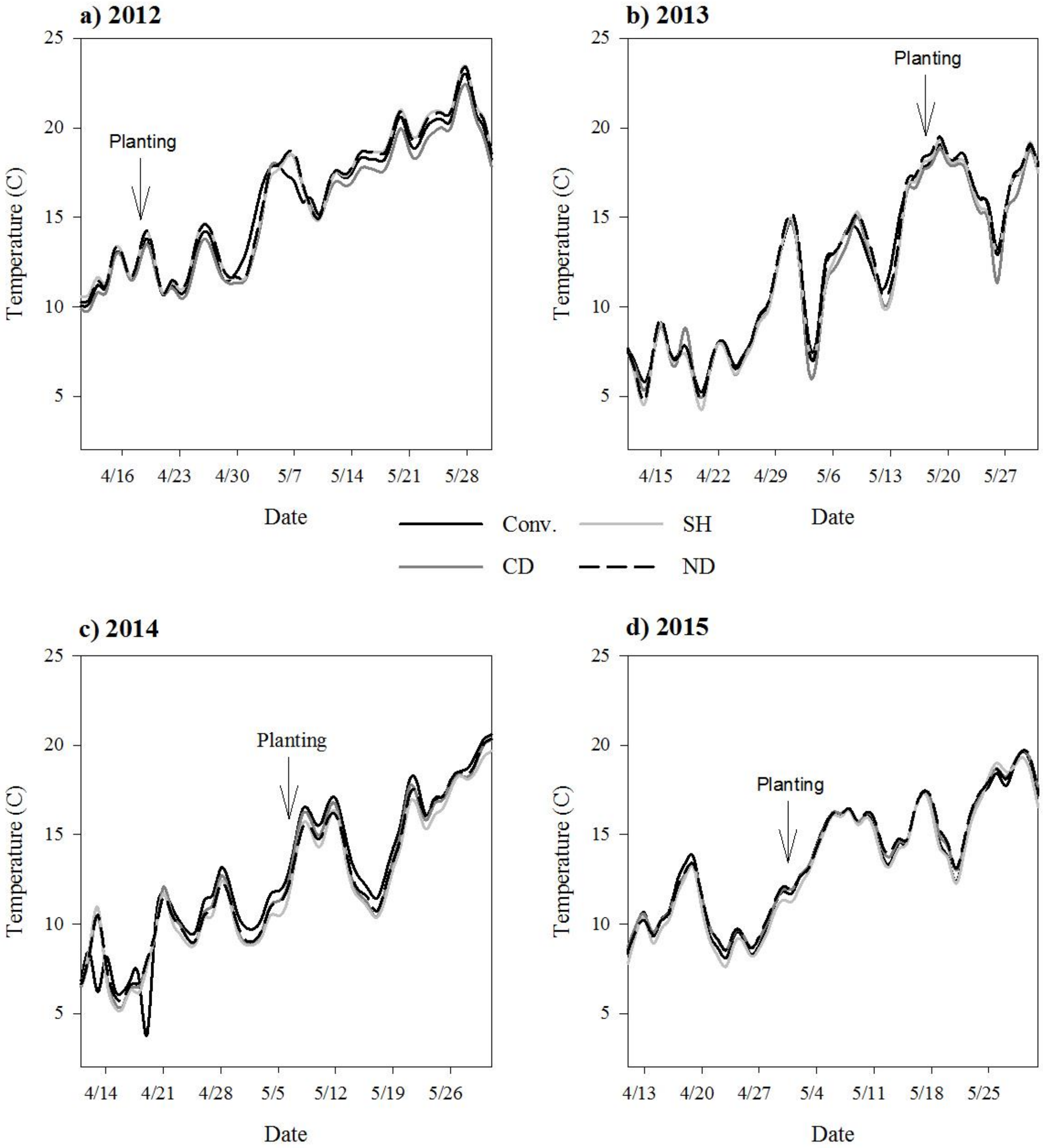

Figure 3.8. Minimum daily soil temperature (°C) at 20 cm depth with the date of planting indicated for the planting windows in a) 2012, b) 2013, c) 2014, d) 2015 for all drainage treatments: conventional drainage (Conv.), controlled drainage (CD), shallow drainage (SH), and no drainage (ND).

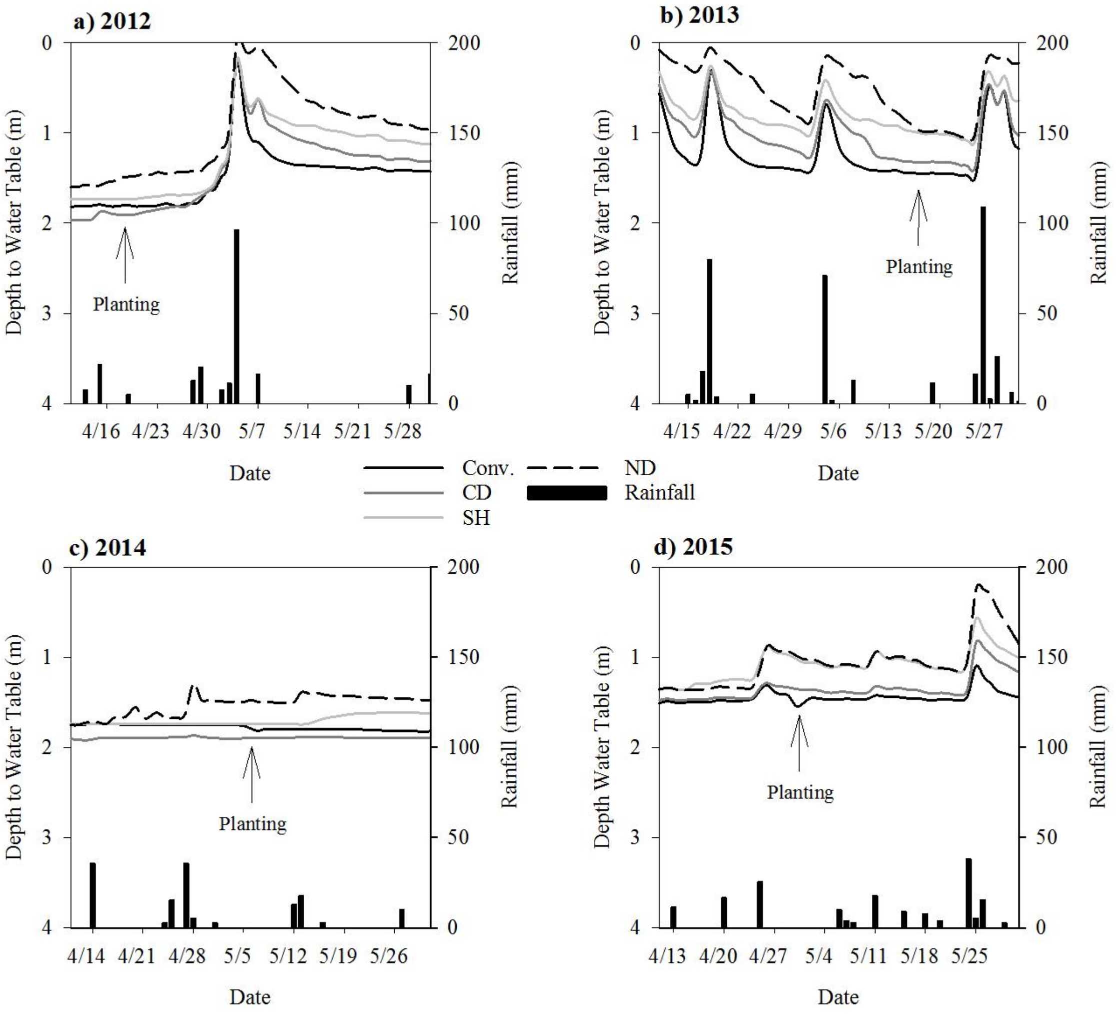

Figure 3.9. Average daily depth to water table (m) and daily rainfall amounts (mm) with the date of planting indicated for the planting windows in a) 2012, b) 2013, c) 2014, d) 2015 for all drainage treatments: conventional drainage (Conv.), controlled drainage (CD), shallow drainage (SH), and no drainage (ND).

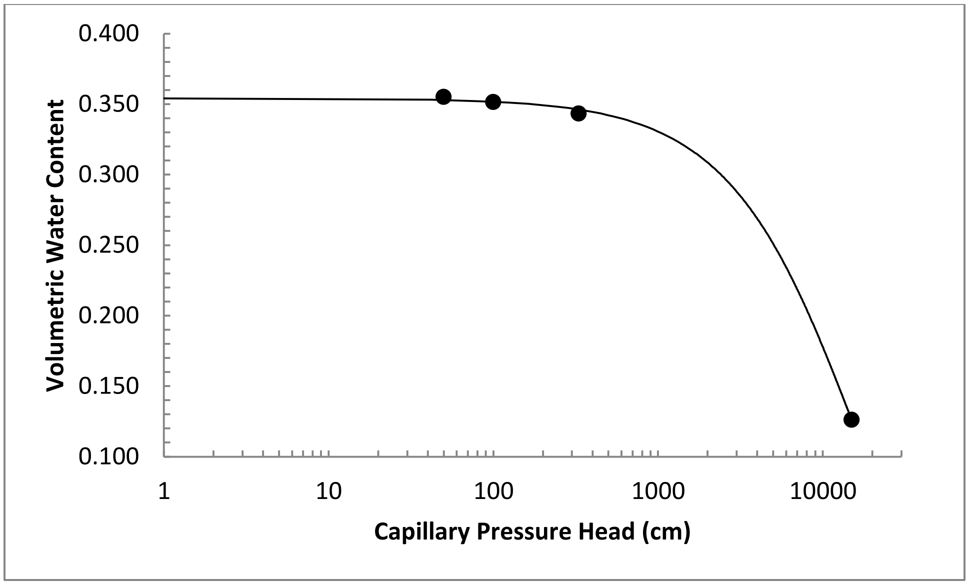

Figure 3.10. Average soil water retention curve for the silty clay loam soils found at SERF. Field capacity is defined as the volumetric water content at 100 cm of pressure.

Table 3.1. Spring field activities for the corn rotation from 2012-2015 including control dates for controlled drainage plots. An open control structure indicates the drainage depth is 1.2 m. In the spring, a closed control structure indicates drainage depth is 0.76 m. If a date is not provided, the drainage depth is the spring closed depth.

	Fertilizer	Tillage		Herbicide	Spring control	
Year	Anhydrous	Field Cultivate	Planting	Pre-emerge	Open	Close
2012	Mar. 28	Apr. 11	Apr. 18	Apr. 25	Apr. 5	June 14
2013	May 2	May 17	May 17	May 17		
2014	Apr. 23	May 6	May 6	May 19		
2015	Apr. 17	Apr. 29	Apr. 30		Mar. 31	May 22

Table 3.2. Average temperature (°C), accumulated growing degree days (GDD) for a 10 °C baseline temperature, and rainfall (mm) at SERF during the planting window for 2012-2015, including a long-term average.

Year	Temp (°C)	GDD	Rainfall (mm)
2012	16.2	333	196.5
2013	13.6	254	351.8
2014	15.1	299	137.3
2015	15.6	304	168.3
25 yr Avg.	14.7	436	201.6

Table 3.3. SEW_{30} during planting window from 2012-2015 for all drainage treatments: conventional drainage (Conv.), controlled drainage (CD), shallow drainage (SH), and no drainage (ND).

Year	Conv.	CD	SH	ND
2012	23	14	41	221
2013	2	13	94	332
2014	0	0	0	0
2015	0	0	13	1
Avg.	6	7	37	138

Table 3.4. SEW_{30} after planting was completed from 2012-2015 for all drainage treatments: conventional drainage (Conv.), controlled drainage (CD), shallow drainage (SH), and no drainage (ND).

Year	Conv.	CD	SH	ND
2012	23	14	41	221
2013	0	10	42	95
2014	0	0	0	0
2015	0	0	13	1
Avg.	6	6	24	79

CHAPTER 4. EFFECT OF DRAINAGE WATER MANAGEMENT ON PEAK DRAINAGE AND WATER TABLE RECESSION

Linda R. Schott

Abstract

The effects of drainage water management practices on peak drainage and water table recession time are important for understanding the impact of nitrate-N transport within watersheds but has not been widely investigated. The objective of this study was to determine the effect of shallow and controlled drainage on time to peak drainage discharge, peak drainage discharge, and water table recession. This research was conducted at the Iowa State University Southeast Research Farm near Crawfordsville, Iowa from 2010 to 2015. This research focuses on six plots with two replicates of shallow drainage, controlled drainage, and conventional drainage. Each plot had half planted in soybeans (*Glycine max* L. Merr.) and the other half in corn (*Zea mays* L.), and the halves were rotated every year in accordance with a typical corn-soy rotation. There were no statistical differences in time to peak discharge between drainage treatments. The shallow drainage treatment had significantly greater ($p<0.05$) peak discharge than the conventional system in two of the four events, which could be due to a higher coefficient of drainage than what the system was designed for. The controlled drainage treatment also had a significantly greater ($p<0.05$) peak discharge than the conventional system in one event, which could be due to a shallower water table prior to the event. There were no differences between treatments in water table recession time.

Introduction

Subsurface drainage removes excess water from agricultural fields in order to facilitate earlier planting in the spring. By removing this excess water, more soil pore space is available for infiltration by rainwater. The effect of subsurface drainage on hydrology is likely dependent upon a number of factors like soil type, rainfall pattern, antecedent moisture conditions, depth and spacing of drains, and topography (Robinson & Rycroft, 1999). The same authors concluded that soil type is the biggest factor impacting subsurface drainage hydrology; peak drainage discharge is likely to increase on tile drained compared to non-tile drained land on loamy soils but decrease on tile drained land with slowly permeable clayey soils.

Subsurface drainage contribution to stream flow is important because drainage has increased the loss of nitrate-nitrogen from agricultural lands in the Mississippi River Basin contributing to the hypoxia zone in the Gulf of Mexico (Turner & Rabalais, 1994). David et al. (2010) found that a significant portion of the nitrate-nitrogen export originated from subsurface drainage. Schilling and Helmers (2008) found that tile drainage increased stream base flow and identified that the separation of stream base flow originating from groundwater seepage from groundwater removed by tile drainage is important to understanding nitrate-N fate and transport.

One practice being proposed to combat nitrate-N losses is drainage water management. Drainage water management is designing or managing the subsurface drainage system in order to reduce the drainage volume or to manage the outflow. The drains are either installed at a shallower depth or installed at the conventional depth described earlier with a control structure that regulates the water table outflow height.

These two practices are known as shallow and controlled drainage, respectively (Strock et al., 2011). Helmers et al. (2012) cited slower water table recession as a hypothesis for why crop yields were reduced in controlled drainage plots. The effects of drainage water management practices on peak drainage and water table recession time are important for understanding the impact of nitrate-N transport within watersheds but has not been widely investigated. The objective of this paper is to investigate the impact of drainage water management practices on time to peak drainage discharge, peak drainage discharge, and water table recession at a field site near Crawfordsville, Iowa.

Materials and Methods

Site location and design

Research was conducted at the Iowa State Southeast Research Farm (SERF) near Crawfordsville, Iowa (41°11'38" N, 91°28'58" W) from 2007 to 2014. The site has eight research plots with two replications for each of the following drainage treatments: undrained, conventional drainage, shallow drainage, and controlled drainage (Figure 4.1). The plots were blocked into a north and south replication because the site consists of two poorly drained silty clay loam soils. Kalona (silty clay loam, fine, smectitic, mesic Vertic Endoaquolls) is found predominantly in the northern plots while Taintor (silty clay loam, fine, smectitic, mesic Vertic Argiaquolls) is predominantly in the south. The site is relatively flat with less than a five meter elevation change over 17 ha. The individual plots range in size from approximately 1.2 to 2.4 ha. Each drainage treatment was designed to have a coefficient of drainage of approximately 1.27 cm day^{-1}. Therefore, the conventional and controlled drainage plots have a drain depth and spacing of 1.2 and 18 m, respectively. The shallow drained plots have drains at a depth of 0.76 m with 12.2 m spacing. At this site, controlled drainage plots were only managed when necessary for field activities (Table 4.1). The gates were opened in mid to late April approximately two weeks prior to planting to allow free drainage and closed in late May to early June after planting was completed. Management for harvest in the fall was typically not required at this site due to low water table conditions.

Data collection

Daily rainfall was measured using a manually-read rain gauge located approximately 1 km from the research plots from 2007 to 2014. At the end of December 2013, a weather station, part of the Iowa State University Soil Moisture Network, containing a non-heated tipping bucket was installed adjacent to the research plots, which provided higher resolution rainfall data. As a result, beginning in 2014, the two rainfall data sets were averaged.

Tile lines for all plots were laid out in a north-south orientation. The interior tiles were continuously monitored for flow rate with a 13 cm tall 45° V-notch weir and a Global Water pressure transducer (Global Water, Sacramento, California) logging in 5 to 30 minute intervals. To account for differences in plot size, flow was converted to a depth basis for comparison. Border tiles were installed in each plot to hydraulically isolate the treatments but were not monitored. On the controlled drainage plots, the border tiles also had water table control structures. In 2009, monitoring wells were installed in the center of each plot where the water table would be the shallowest. Depth to water table was monitored hourly using Global Water pressure transducers (Global Water, Sacramento, California).

Event definition

The drainage main was designed to have a maximum drainage coefficient of 1.9 cm day^{-1}, which is 50% larger than necessary based on treatment design. However, following large rain events, it is evident that the actual drainage rate is higher than the design maximum (Figure 4.2). Therefore, only drainage events where the rate of drainage was below the maximum drainage coefficient were used. Events were also chosen where all three drainage treatments had drainage. An event was excluded if two consecutive events could not be distinguished from each other, such as when rainfall occurred soon after discharge had peaked. The start of the event was defined as the time when discharge began in one of the conventional plots, and the time of water table recession was defined as when the water table peaked to when it receded either below 30 or 60 cm in an individual plot.

Data analysis

Statistical analyses were conducted using Statistical Analysis System software (SAS 2011). The general linear model (GLM) procedure was used with two replicates per treatment to determine the statistical significance of treatment effects on peak discharge and time to peak discharge. The mean values for time to peak and peak drainage were separated using a least significance difference (LSD) test at $p = 0.05$ ($\text{LSD}_{0.05}$).

Results and Discussion

Event description

Four events were identified for analysis (Table 4.2). The rainfall for event 1 was the greatest of all four events, but rainfall began three days prior to the start of the event.

Event 2 had the lowest rainfall amount, but rainfall had not occurred for over a week. For both events 3 and 4, at least one of the conventionally drained plots was still flowing from a previous event, so the start of the event was defined as the time when the hydrograph began to rise again. The only event when the controlled drainage plots were freely draining was during event 2. During event 1, the water table depth for the controlled drainage treatment was set to 0.3 m from the surface.

Time to peak discharge

Overall, there were no events where there were statistical differences ($p<0.05$) between drainage treatments in the time to peak drainage discharge (Table 4.3). Time to peak drainage seems to be tied to rainfall amount. The larger the rainfall amount leading up to the event, the longer the time to peak drainage. Events 1 and 4 had the highest rainfall amounts and shortest average time to peak drainage discharge whereas event 2 had the least rainfall and the longest average time to peak drainage discharge.

Peak discharge

The shallow drainage treatment had the greatest discharges for events 3 and 4 (Table 4.4). For event 3, the shallow drainage treatment had a significantly greater peak discharge than the other two treatments, but for event 4, both the controlled and shallow drainage treatments had significantly greater ($p<0.05$) peak discharge than the conventional drainage treatment. If the saturated hydraulic conductivity is higher than what was used to design the drainage systems, the shallow drainage system could have a higher drainage coefficient than the conventional drainage system. If this is the case, the significant differences in the peak discharge between the drainage treatments for events 3 and 4 can be explained from the depth to the water table prior to the events. For event 3, when only the peak discharge for the shallow drainage treatment was higher than the other two treatments, the initial depth of the water table was shallower in the shallow drainage treatment than the other two. For event 4, when both the controlled and shallow drainage treatment had higher peak discharges than conventional drainage, the water tables for both the controlled and shallow drainage treatments were shallower prior to the event than the conventional drainage system.

Water table recession time

For the small events analyzed, the water tables in the conventionally drained treatment never peaked within 30 cm of the surface (Table 4.5). The controlled drainage treatment did peak shallower than 30 cm during event 1, but this was also when the water table control gate was at a depth of 30 cm from the surface. The controlled drainage treatment did not peak within 30 cm of the ground surface when the water table control gate was at 0.76 m, however. During events 3 and 4, the water table in the shallow drainage treatment did peak within 30 cm of the ground surface. However, it was only one replication, which was in the north side. Previous analysis completed indicates that the northern replication has shallower water tables, on average, than the southern one.

Conclusions

In general, the two drainage water management practices, shallow and controlled drainage, impacted the hydrology of small drainage events. At this research site, large drainage events could not be analyzed due to undersized drainage tile mains. There were no statistical differences between drainage treatments for the time to peak discharge. The shallow drainage treatment had greater peak discharges for events 3 and 4 than the conventional drainage treatment while the controlled drainage treatment had a greater peak discharge than the conventional treatment for event 4. This is probably due to a higher drainage coefficient in the shallow drainage treatment due to a higher saturated hydraulic conductivity in all drainage treatments than the conductivity used in designing the systems and shallower water tables in the two drainage water management systems prior to event 4.

Overall, the drainage events that were capable of being analyzed were not large enough for the water table to peak closer than 30 cm from the ground surface. There were two events when the water table in the northern replication of the shallow drainage treatment peaked at less than 30 cm of the ground surface. Previous work indicated that the water tables in the northern replication, on average, were shallower than the water tables in the southern replication. Other than first event, when the water table control gate was set at 30 cm from the ground surface, the water tables in the controlled drainage treatment did not come within 30 cm of the ground surface. From the analysis of these small events, it is unlikely that the time of water table recession during the summer is greater in the controlled drainage treatment causing yield reductions cited by Helmers et al. (2012). Additional hydrograph and water table recession analyses should be completed using the larger drainage events should be completed to attempt to separate the influence of plot location on overloaded drains from the impact of drainage design.

Acknowledgements

This research is part of a regional collaborative project supported by the USDA-NIFA, Award No. 2011-68002-30190, “Cropping Systems Coordinated Agricultural

Project: Climate Change, Mitigation, and Adaptation in Corn-based Cropping Systems." Project Web site: sustainablecorn.org. Research data and supporting metadata are stored in the team's centralized Climate and Cropping Systems database.

References

Burchell II, M.R., Skaggs, R.W., Chescheir, G.M, Gilliam, J.W., & Arnold, L.A. (2005). Shallow Subsurface Drains to Reduce Nitrate Losses from Drained Agricultural Lands. *Transactions of the ASAE*, 48(3), 1079-1089.

David, M., Drinkwater, L., & Mclsaac, G. (2010). Sources of Nitrate Yields in the Mississippi River Basin. *Journal of Environmental Quality,* 39, 1657-1667.

Helmers, M.J., Christianson, R., Brenneman, G., Lockett, D., & Pederson, C. (2012). Water Table, Drainage, and Yield Response to Drainage Water Management in Southeast Iowa. *Journal of Soil and Water Conservation*, 67(6), 495-501.

Poole, C.A., Chescheir, G.M., Skaggs, R.W., & Burchell, M.R. (2010). Effects of Drain Depth on Nitrate-N and Phosphorous Losses from Drained Agricultural Lands Receiving Nitrogen and Phosphorous from Organic Sources. CSBE Paper No. 100224. St. Joseph, Mich.: ASABE.

Robinson, M., & Rycroft, D.W. (1999). The Impact of Drainage on Streamflow. In Skaggs, R.W. and J. van Schilfgaarde (Eds.), *Agricultural Drainage* (pp. 767-800). Madison, WI: ASA, CSSA, and SSSA.

SAS. 2011. SAS User's Guide. Version 9.3. Cary, NC: SAS Institute, Inc.

Schilling, K.E., & Helmers, M.J. (2008). Effects of Subsurface Drainage Tiles on Streamflow in Iowa Agricultural Watersheds: Exploratory Hydrograph Analysis. *Hydrological Processes,* 22, 4497-4506.

Strock, J.S., Sands, G.R., & Helmers, M.J. (2011). Subsurface Drainage Design and Management to Meet Agronomic and Environmental Goals. In . J.L. Hatfield and T.J. Sauer (Eds.) *Soil Management: Building a Stable Base for Agriculture* (pp. 199-208). Madison, WI: ASA, CSSA, and SSSA.

Turner, R.E., & Rabalais, N.N. (1994). Coastal Eutrophication near the Mississippi River Delta. *Nature,* 368(6472), 619-621.

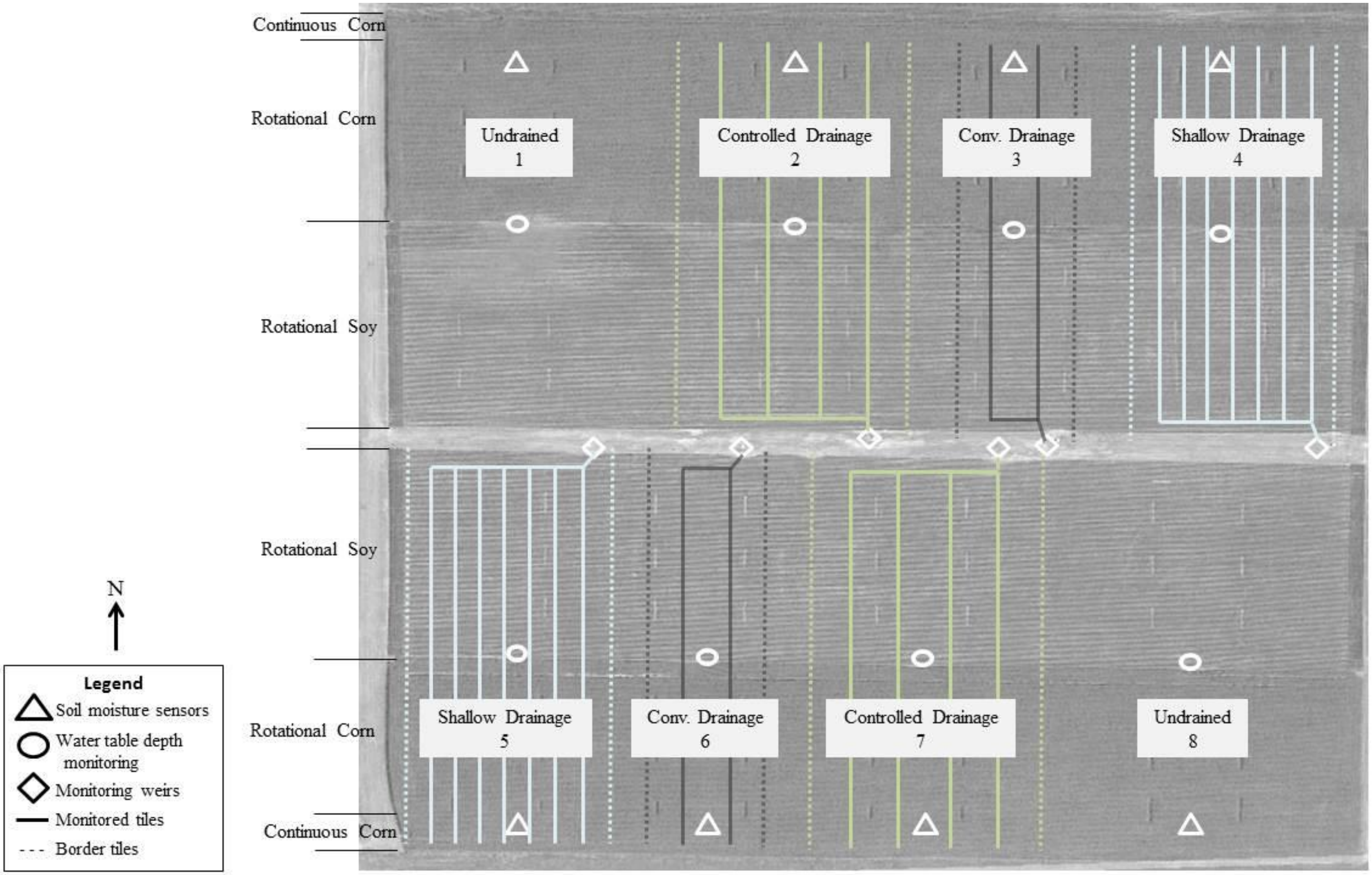

Figure 4.1. Aerial view of drainage plots at SERF illustrating data collection locations and drainage layout.

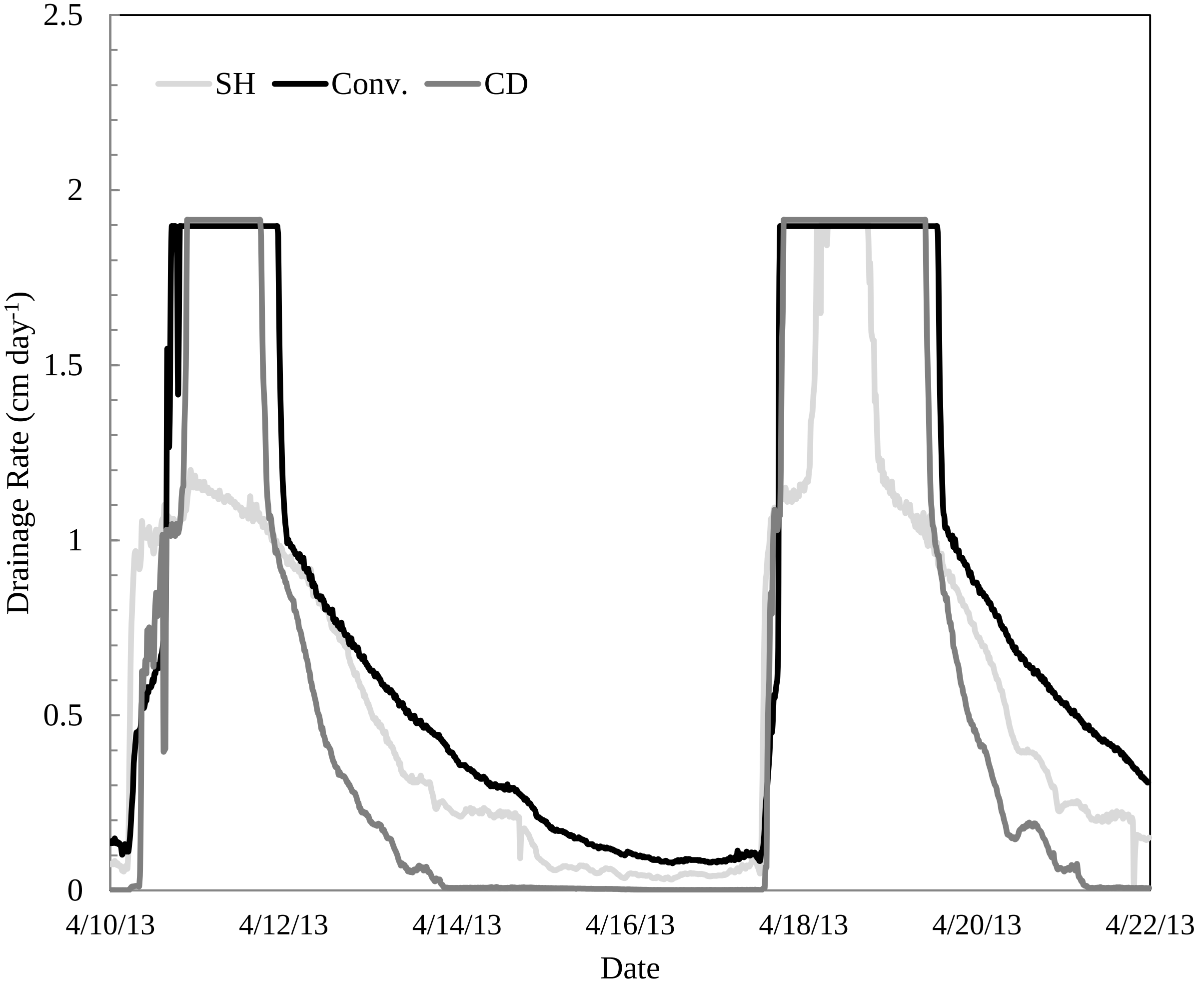

Figure 4.2. Example of overloading of drainage main for plots 5, 6, and 2, corresponding to shallow (SH), conventional (Conv.), and controlled drainage (CD) systems, respectively. Due to location, drainage water from plot 5 is the first to enter the drainage main, followed by plot 6 then 2.

Table 4.1. Field activities from 2010-2015, including control dates for controlled drainage plots. An open control structure indicates the drainage depth is 1.2 m. In the spring, a closed control structure indicates drainage depth is 0.76 m. In the fall, if a date is given, the drainage depth is 0.30 m. If a date is not provided, the drainage depth is the spring closed depth.

	Spring control		Fall control
Year	Open	Close	Close
2010	Apr. 15	June 24	Oct. 18
2011	Apr. 25	June 1	
2012	Apr. 5	June 14	
2013			
2014			

Table 4.2. Description of drainage events that have a maximum drainage rate less than 1.9 cm day^{-1}.

Event	Year	Date	Rainfall, mm
1	2011	Apr. 19	41
2	2011	May 14	18
3	2013	June 25	23
4	2014	July 5	36

Table 4.3. Time to peak drainage discharge (hr) for each drainage event for the three drainage treatments: conventional drainage (Conv.), controlled drainage (CD), and shallow drainage (SH).

Event	Conv.	CD	SH
1	10	11	6
2	24	28	24
3	14	15	13
4	6	10	8

Note: Years or average not connected by the same letter are statistically different ($p<0.05$). Only years where there were significant differences have letters included.

Table 4.4. Peak drainage discharge (10^{-2} m^3) for each drainage event for the three drainage treatments: conventional drainage (Conv.), controlled drainage (CD), and shallow drainage (SH).

Event	Conv.	CD	SH
1	6.7	7.4	6.7
2	8.8	6.9	6.1
3	4.2b	5.3b	11.1a
4	8.8b	13.2a	15.1a

Note: Years or average not connected by the same letter are statistically different ($p<0.05$). Only years where there were significant differences have letters included.

Table 4.5. Time for water table to recede below 30 cm from peak water table depth (hr) for each drainage event for the three drainage treatments: conventional drainage (Conv.), controlled drainage (CD), and shallow drainage (SH).

Event	Conv.	CD	SH
1	0	7	0
2	0	0	0
3	0	0	8
4	0	0	13

CHAPTER 5. CONCLUSIONS

General Discussion

For off-field impacts, the second chapter of this thesis found that drainage water management practices were effective at reducing nitrate-N and drainage losses downstream when compared to conventional drainage, which is consistent with other studies (Skaggs et al. 2012). The fourth chapter found that shallow and controlled drainage increased peak drainage discharge while there were no differences in the time to peak drainage discharge.

On-field impacts of drainage water management were also investigated. The second chapter showed both controlled and shallow drainage did not increase crop yields and in some years, corn yields were reduced. The second and third chapters also illustrated that drainage did not impact soil volumetric water content. The third chapter of this thesis found that drainage water management did not impact date of planting, but the soil temperature in the shallow drainage treatment was warmer in the late spring than controlled and conventional drainage systems, which is conflicting with results from Jin et al. (2008), who concluded that drainage did not impact soil temperatures near the surface. The fourth chapter was inconclusive in investigating the impact of drainage water management on water table recession due to the small events analyzed.

In relationship to the USDA-NIFA project, drainage water management practices, such as shallow and controlled drainage, have been shown to significantly reduce off-field nitrogen losses that contribute to water pollution by reducing drainage volumes.

Recommendations for Future Research

The research presented previously in this thesis also highlighted the need for additional research relative to drainage water management:

1. Future work should focus on how to manage controlled drainage fields more effectively during wet years to mitigate yield losses from high water tables.
2. Drainage water management impact on planting date should be investigated on other fields with different soil types in order to determine if there are differences in volumetric water content that could impact trafficability.
3. Since there were differences in soil temperature between drainage systems, which conflicts with some previous research, more research should be completed at other locations within the Midwest to determine if drainage impacts average and maximum soil temperatures throughout the year and whether or not this impacts crop production.
4. More work also needs to be done to determine the effect of drainage water management practices on peak drainage discharge, time to peak discharge, and the time for water table recession when the water table in controlled drainage is managed in order to better understand drainage water management impact on streamflow and crop excess water stress from high water tables.

References

Jin, C.X., Sands, G.R., Kandel, H.J., Wiersma, J.H., & Hansen, B.J. (2008). Influence of Subsurface Drainage on Soil Temperature in a Cold Climate. *Journal of Irrigation and Drainage Engineering*, 134(1), 83-88.

Skaggs, R.W., Fausey, N.R., & Evans, R.O. (2012). Drainage Water Management. *Journal of Soil and Water Conservation*, 67(6), 167-172.