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Soil Hydraulic Property Impacts of Incorporating Prairie Vegetation within a Row Crop Production Area

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Soil hydraulic property impacts of incorporating prairie vegetation within a row crop production area

by

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A thesis submitted to the graduate faculty

in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Co-Majors: Agricultural Engineering (Environmental Stewardship Engineering); Civil Engineering (Environmental Engineering)

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ABSTRACT

Vegetative filter strips (VFS) and buffers have long been recognized as a viable option for managing land and water quality in regions where erosion is prevalent. Many studies have been conducted to evaluate the extent to which introduction of VFS reduces runoff, limits soil loss, and influences soil properties. These studies have compared the use of various vegetation as well as various in-field management styles such as conventional tillage, reduced tillage, and no tillage. However, there are still many questions as to the overall effectiveness of VFS dependent upon size, location, vegetation, existing soil characteristics, and age of the strips. Though many studies have been conducted there is still a need for investigating the use of alternative vegetation forms such as native prairie vegetation in filter strips. This research explores the use of native prairie vegetation within the filter strips which have been strategically located within an agricultural field managed under a no tillage corn-soybean rotation. The first objective was to determine if incorporation of native prairie vegetation within an agriculture system will have an effect on soil physical properties specifically hydraulic conductivity and soil bulk density. The second objective was to determine if slope position also had an effect on soil physical properties.

Small experimental watersheds at the Neal Smith National Wildlife Refuge (NSNWR) in Jasper County, Iowa were used. In the watersheds soil hydraulic properties under the cropped area were directly compared to the soil properties within the VFS to determine if the soil properties in the filter strips had changed significantly. Unsaturated and field saturated hydraulic conductivity were obtained *in situ* using tension infiltrometers near the same locations where soil cores were extracted for lab analysis of saturated hydraulic conductivity and bulk density.

Changes in soil properties varied greatly among the three watersheds and the two experimental years. Most results lacked significant differences in treatment and position. Results showed that VFS generally had a greater overall number of pores than row crop. *In situ* analysis showed conductivity of row crop to be greater, though not significant, than VFS and restored prairie at field saturation, K(0) and most other tensions. However laboratory determination of saturated hydraulic conductivity, K_{sat} was the opposite and showed greater K_{sat} in the VFS followed by the restored prairie with the lowest measured K_{sat} in the row crop. Position results varied greatly depending on analysis and year though only the upslope position in 2011 had significantly greater hydraulic conductivity than the foot slope position.

The results indicate that land cover and land position had little effect on soil hydraulic properties. Some of the watersheds showed a response from implementation of VFS treatments in a short amount of time while others may require more time. There is some indication that large amounts of prairie vegetation may potentially produce temporal negative impacts on some soil processes such as infiltration rate, which could be due to roots occupying vital pore space. However, temporal effects were not a part of this study; this is an aspect that warrants further investigation. In summary, while there is some evidence of improved soil hydraulic properties in VFS compared to row crop generally the results were not statistically significant. Thus, the study should be repeated again after more time has passed to determine if significant differences have developed and more conclusive results obtained.

Key Words:

hydraulic conductivity, soil hydraulic properties, tension infiltrometer, prairie, buffer, no-till corn-soybean rotation

CHAPTER 1.GENERAL INTRODUCTION

1.1 INTRODUCTION

In the 1800's and 1900's Iowa's landscape drastically changed. As the population increased so too did the removal or permanent vegetation. What were once forests, prairies, and wetlands was converted to agricultural production (Figure 1.1). Today approximately 86% of Iowa is classified as farmland of which just over 77% is harvested cropland (non-irrigated) (US Census Bureau, 2000; Census of Agriculture, 2007). These changes can easily be seen across the Iowa landscape. Over the years due to continued population growth along with new demands for grains and biomass for such industries as biofuels producers are attempting to produce even more crop. In order to keep up with demand producers essentially have two options; increase crop intensity on lands currently in production and/or bring new land into production by removing yet even more perennial vegetation. What we are seeing is that the increase demand for corn is affecting re-sign up for conservation programs such as the conservation reserve program (CRP). Statistics on CRP enrollment from the Farm Service Agency has shown a decrease in re-enrollment over the last couple of years (http://www.fsa.usda.gov). Producers are deciding not to keep land in conservation programs but are instead returning it to production. The decades of tile draining in combination with acre upon acre of native perennial vegetation removal for row crop production continue to change the soil characteristics and hydrology characteristics both on site and off site (Dinnes et al., 2002). The current practices may not be sustainable, and it may soon begin to be difficult to maintain the current rate of productivity (Matson et al., 1997).

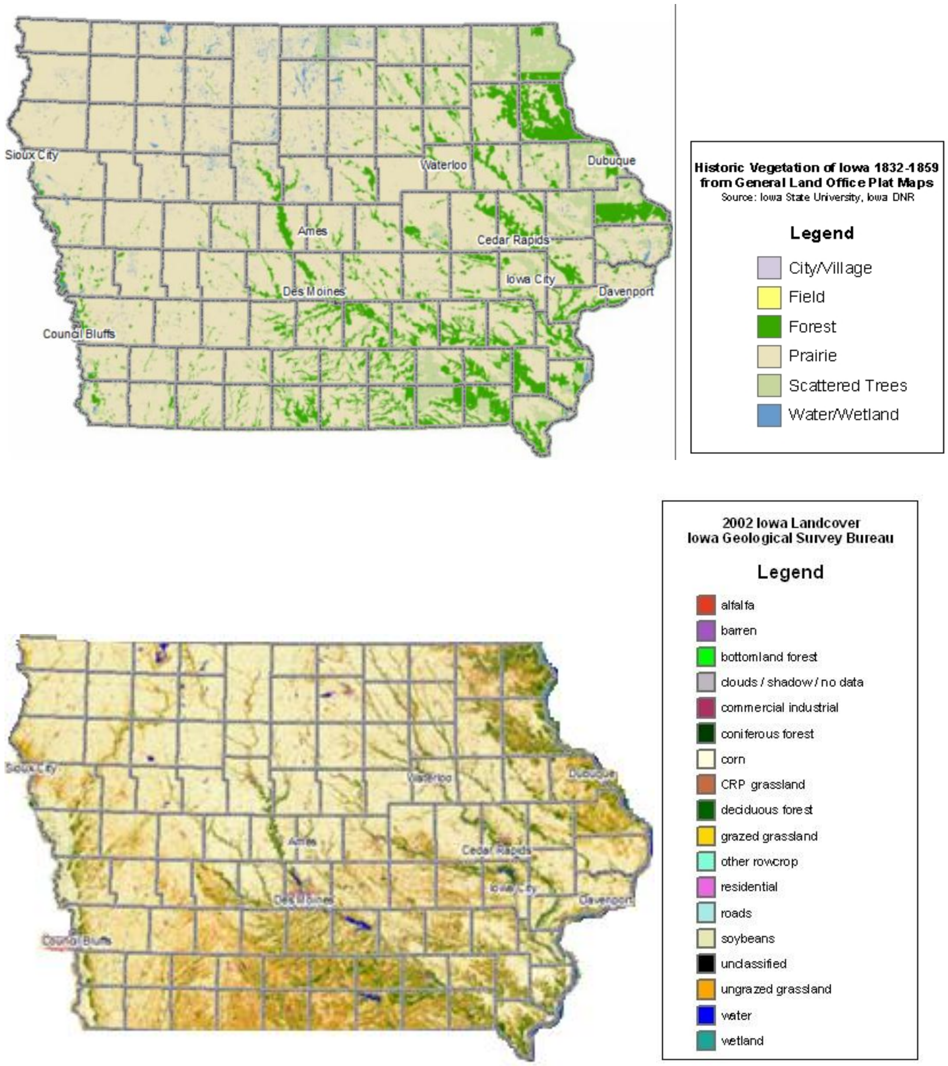

Figure 1.1 1800's and 2002 Iowa land cover

Source: Iowa State University Geographic Information System Support & Research Facility; Iowa Geographic Map Server (http:ortho.gis.iastate.edu)

Agriculture in the Corn Belt region contributes to the transport of sediment and sediment bound nutrients to streams and rivers (Zaimes et al., 2004). Agriculture has also been attributed to increased contributions to surface runoff, increased base flow and significantly reduced time to stream peak flow which can result in flash flooding (Zhou et al., 2010). The increased contributions of water, sediment, and nutrients to streams and rivers have resulted in negative effects on the quality of both soil in the field and surrounding hydrologic systems (Lovell and Sullivan, 2006; Zaimes and Schultz, 2011). There is concern about the effect these changes from permanent land cover to annual crop will have on nutrient, sediment, and water movement all of which can have an effect on water quality.

In order to determine the environmental impacts of producing corn investigations into the impact of reintegrating prairie vegetation into systems either coming out of CRP or still in row crop production are needed. A study was started; it is the overall project from which the research in this thesis is a small portion of.

The objective of the overall project is to investigate the effect integration of strategically placed perennial vegetation in the form of native prairie into annual cropping system would have on water and nutrients storage, cycling, and output as well as plant and animal diversity.

The overall experiment was established fall 2006 into spring 2007 at the Neal Smith National Wildlife Refuge. CRP land at three sites located within the refuge that had been in bromegrass cover for over 10 years were mulch tilled and a total of twelve small watersheds were created. At each site at least one watershed contained one of three treatments; 0%, 10%, and 20% perennial vegetative. Preliminary results of the study show that the watersheds with perennial vegetation incorporated had less runoff and sediment loss than those that were 100% annual crop. The research presented in this thesis stems from the desire to provide an explanation of how the treatments with perennial reduced runoff and sediment. Are there differences in physical soil properties between the perennial vegetation and the row crop areas that can explain the reduction in runoff and sedimentation?

A soil's quality is measured by its ability to carry out essential functions; these functions are primarily physical support for buildings and field equipment as well as stability for plants, productivity, water/solute regulation and nutrient cycling. Soil quality cannot be directly measured, so it is measured by several indicators and each indicator provides insight into soil functionality. The research conducted for this project concentrates on several of the physical indicators of soil quality. The physical indicators are strongly connected to soil hydrological characteristics and thus also play an important role in mediating crop production effects on water quality as well as soil quality. The physical indicators investigated are infiltration, hydraulic conductivity, and bulk density.

Infiltration is important for water movement from the soil surface into the soil profile within the field. If the rate at which water accumulates at the soil surface is greater than the rate of infiltration it can lead to surface runoff. Water runoff instead of water percolation results in 1) lack of water replenishment within the soil profile, 2) increased nonpoint source pollution to water bodies, and 3) decreased soil quality and infield productivity due to potential soil loss. Infiltration is the process of water transfer from the atmosphere to the soil at the soil-atmosphere interface. The infiltration rate is defined as the time rate at which water percolates into the soil or quantitatively as the volume of water entering the soil per unit area in time. (Ghildyal and Tripathi, 1987). The rate of infiltration is affected by many different characteristics of both water and the soil. The properties of water that affect infiltration are water temperature and viscosity. The properties of water are not of concern in this study because they not affected by any land management practices occurring on site. The characteristics that are of interest in this study are those that can be influenced the most by agriculture production. Agriculturally affected characteristics of infiltration rate are those related to surface features such as land cover or lack thereof, entry of water at the surface via surface pores, movement of water away from the surface, and water storage capacity. These characteristics are more specifically soil compaction, soil texture, porosity, and root activity.

Hydraulic conductivity is a measure of the ability of the soil to conduct water when a hydraulic gradient exists. It is dependent upon properties of both the soil and water. The physical property of water important to conductivity is the viscosity of the fluid however once again that is not of concern in this study. Agriculturally affected properties important to hydraulic conductivity are porosity, pore connectivity, tortuosity and particle size distribution. Hydraulic conductivity is important because of its close relation with infiltration. In order for there to be infiltration once water has passed the soil surface it must be carried away from the surface in order for water to continue to infiltrate. Thus infiltration is restricted by rate of transmission (hydraulic conductivity) of water away from the soil surface.

Soil water retention is the ability of a soil to retain water within soil pores when exposed to various pressure and/or suction that occur within the soil profile. It can be used to determine which sizes pores are present within a soil profile. Soils must have a mixture of pores sizes [macropores ($d > 1000 \mu m$), mesopores ($d = 10\text{-}1000 \mu m$), and micropores ($d < 10 \mu m$)] which are interconnected to effectively regulate water and nutrient movement and storage. Soils with larger pores are easily drained by gravity or under lower pressure/suction while progressively smaller pores require greater pressure/suction to drain. In those soils dominated by large pores water can leave the crop root zone too quickly before plants have had a chance to utilize it and can transport nutrients along with it finding their way into nearby water bodies. This can result is soils with abundant amounts of soil air and little soil water. While on the other hand in soil profiles dominated by small pores the soil can retain greater quantities of water in the soil profile and consequently will not transport nutrients from the field leaving it available for plant usage. This results in soil with abundant amounts of water however plants may have difficulty extracting the water from the soil due to the greater force required to extract it. Plants may not have the energy required to pull water up against the suction forces holding water in the soil profile. Additionally, because the majority of soil air is usually in the larger soil pores except for that air which is trapped in pore spaces, soils dominated by small pores could have poor soil aeration and lack oxygen required for roots and microorganisms.

Bulk density is the mass of soil particles (dry weight) occupied in a known total volume. The total volume includes particle volume, inter-particle void volume and internal pore volume. It is commonly used as indication of a soil's compaction. It is affected by the soil texture, structure, porosity, and organic matter. It is altered by agricultural practices which affect organic matter, land cover, soil structure and porosity. Bulk density is very important to plant growth. Soils with high bulk density restrict seed emergence, due to the soil being too difficult to emerge through, and root growth, due to the soil being too difficult to push through restricting rooting depth and plant nutrient uptake, which ultimately impacts plant growth and yield. Not only can bulk density affect plant growth but it can also affect soil water movement. Generally, there is an inverse relationship between bulk density and porosity, if a soil's bulk density increases then its porosity decreases thus restricting soil water movement.

Due to a growing awareness over time, by farmers and non-farmers alike, of the large environmental effects agriculture has had on soil and water quality, techniques called best management practices have been introduced to reduce the impact agriculture has on the environment. Best management practices (BMP) are conservation practices or systems of practices and management measures that control soil loss and reduce water quality degradation caused by nutrients, animal wastes, toxins, and sediment (Maryland Department of Natural Resources Critical Areas Commission). Some BMPs include nutrient application management, controlled drainage, reduced and conservation tillage, terraces, contour strip farming, grassed waterways, riparian buffers, vegetated filter strips, and ponds (Al-Kaisi et al., 2003; MD, DNR). The implementation of BMPs can result in benefits to the farmer as well as the environment. For example conventional tillage results in significant soil loss (Zheng et al., 2004) which causes the deterioration of soil physical and chemical properties thus reducing field productivity and impairing water quality. Conversely, when the field is switched to a reduced tillage practice in which some residue remains on the field, soil physical and chemical properties improve and runoff reduces (Al-Kaisi and Hanna, 2009). To assist in the alleviation of environmental strain caused by farming, federal, state, and regional programs were started to encourage and assist farmers in implementing BMPs on their farms. The Conservation Reserve Program (CRP) is one of those programs. CRP provides incentive to farmers to remove entire fields or portions of fields from production and replace these areas with permanent vegetative cover for several years (Cowan, 2010).

Over the last 25 years alone there has been a combined 43% decrease in erosion from water and wind on land including both cropland and CRP accompanied by an increase in CRP land and decrease in cropland (USDA-NRCS NRI Annual Report 2007; USDA-NRCS RCA Appraisal 2011). With increased demand for agricultural products there is concern that instead of continued progress relative to conservation we will begin to move backward

(Secchi et al., 2008). Due to the increased prices for rent of farm land and increasing commodity prices there is strong reason to believe that farmers will began to remove BMPs like field borders and filter strips, as well as land from programs like the CRP program to plant as much crop as possible for higher profit. This means years of work towards improved soil and water quality could soon return to the condition of past days. Gilley et al. (1997) used rainfall simulations to test CRP land returned to production and found that infiltration rates under wet conditions after tillage and a fallow period was significantly reduced compared to undisturbed CRP dependent on the soil type. They also determined that soil loss initially after tillage was similar to CRP but became higher after 1-2 years. Thus the positive soil affect achieved from the CRP program could be erased shortly after conversion. The goal of the work within is to assess former CRP land soil hydraulic properties in a row crop production area and in vegetative filter strips containing native prairie vegetation.

1.2 OBJECTIVES AND HYPOTHESES

Two experiments were conducted one in the lab and the other in-situ both with essentially the same objectives to determine whether differences in soil hydraulic properties that are important to the transport of water from the surface into the soil profile and through the soil profile exist under different land covers and landscape position.

The in-*situ* use of a tension infiltrometer allowed for the benefit of determination of soil hydraulic properties at both saturated and unsaturated conditions of soil under field conditions (e.g. non-disturbed, field moisture content, and intact pore connectivity). It allowed for the determination of the objectives as well as the potential to address others including the dependence of soil hydraulic properties on soil structure, living roots, and macropores.

The laboratory use of standard procedures on relatively undisturbed soil samples to determine soil hydraulic properties under saturated condition also addressed the objectives. Results give an overall idea of the differences in soil hydraulic properties under the various land covers and landscape positions. However laboratory analysis only allowed for determination at the saturated condition and at the saturated condition gravity and preferential flow can have an influence on soil hydraulic properties as well as the soil pores thus that is why both in-situ and laboratory are used.

The overall research hypothesis is that the soil hydraulic properties in a vegetative filter strip will be improved (e.g., higher infiltration, water retention, and lower bulk density) compared to that in row crop. Thus, converting a portion of the field to permanent vegetation will hopefully provide environmental benefits when compared to a field completely in crop production.

Specifically the first hypothesis is that the vegetative buffer strip will develop significantly different soil hydraulic properties than that of the surrounding row crop. The significant difference in hydraulic properties of the vegetative buffer will be due to improvement is soil quality (e.g., higher conductivity, greater soil water retention, and lower bulk density) through little to no soil disturbance by field machinery and reduced soil exposure to the elements.

The second hypothesis is that soil hydraulic properties of vegetative filter strips will be the same (no significant difference) as soil hydraulic properties of the adjacent prairie which has been established for nearly two decades. Previous results from simulated runoff showed old grass (~25 yrs.) to have no significant difference than new grass (~ 2.1 yr) in as short a time as the third growing season (Dosskey et al., 2007).

The final hypothesis is that soil hydraulic properties will be better at the foot slope position over that of the upslope shoulder position. This will be due to the significantly reduced slope at the foot slope over that of the upslope. Thus at the foot slope the top layers of soil in which greater infiltration and saturated hydraulic conductivity, and reduced bulk density is expected to occur have not been eroded away leaving the poor less hydraulically conductive layers of soil at the surface. In addition it will be due to the deposition of coarser materials from the upslope position over time which are more conducive to high conductivity.

1.3 THESIS ORGANIZATION

This thesis contains two papers on land cover and landscape position differences on soil hydraulic properties including unsaturated hydraulic conductivity (K(h)), saturated hydraulic conductivity (K_s), pore size distribution, and bulk density (ρ_b) of a field formerly under CRP at the Neal Smith National Wildlife Refuge (NSNWR). Both papers attempt to address the objectives and hypotheses previously stated. Both papers are to be submitted for publication. The first paper (Chapter 2) entitled “Impact of incorporating prairie vegetation within row crop production on soil hydraulic properties” was written for submission to Transactions of the ASABE. It describes the experiment which consisted of field measured soil hydraulic properties under five sequentially applied tensions to determine differences in unsaturated hydraulic conductivity and pore size distribution for land cover and slope position. The second paper (Chapter 3) entitled “Lab measured soil hydraulic properties of restored prairie, row crop agriculture, and prairie filter strips” will also be published in a journal which has yet to be determined. It describes the experiment of lab measured soil hydraulic properties using standard lab procedures to determine differences in land cover and slope position. Both papers are organized into an abstract, introduction, materials and methods, results and discussion, conclusion and references.

This thesis also includes an abstract and general introduction which precedes the papers followed by an overall conclusion from the research.

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CHAPTER 2. IMPACTS OF INCORPORATING PRAIRIE VEGETATION WITHIN ROW CROP PRODUCTION ON SOIL HYDRAULIC PROPERTIES

2.1 ABSTRACT

Runoff from agricultural land is a concern for downstream water quality. Certain soil physical properties have a profound influence on soil hydraulic properties which influence surface runoff and, as a result, downstream water quality. Implementation of vegetative filter strips (VFS) has the potential to reduce downstream pollutant loading by changing the soil physical properties which encourage water infiltration rather than runoff. In addition, VFS have the potential to slow overland flow velocities, which allows particulates to settle out, as well as allowing for infiltration. Since soil hydraulic properties influence infiltration there is a need to evaluate the impacts VFS have on physical properties of the soil, which will allow for a better understanding of the mechanisms by which VFS provide benefits. The objective of this study was to determine through in-situ measurement whether differences in soil hydraulic properties of unsaturated hydraulic conductivity and pore size distribution exist under recently established row crop, recently established VFS, and restored prairie (~15 yrs. old) at various landscape positions.

Unsaturated hydraulic conductivity at the soil surface between VFS, restored prairie, and agriculture row crop areas were determined utilizing tension infiltrometers at the upslope and foot slope positions under various land cover in three small watersheds at the Neal Smith Wildlife National Refuge (NSNWR) near Prairie City, IA. Results did not show many statistically significant differences in treatment at the tensions tested. There were significant differences in conductivity between the land cover and the two landscape positions however they were found only at the highest tension except in one analysis from the second year where landscape position was significantly different at zero tension. Conductivity at the upslope row crop and filter strip were greater than the down slope filter strip. It is possible that the lack of significant differences is a result of dense root growth in the restored prairie and filter strips at the time of experimental. Further investigation into the effectiveness of prairie vegetation on improving soil physical properties is warranted.

Keywords. tension infiltrometer, hydraulic conductivity, vegetative filter strips, restored native prairie

2.2 INTRODUCTION

Cereal grain production is very important in the U.S. especially in the Corn Belt region, where a reported 81.5 million acres (33 million ha) of cropland is harvested each year (USDA, 2007). Increasing demand for cereal grains (primarily corn and soybeans) due to emerging markets such as biofuels as well as feed markets is making increased production economically feasible to producers (Zhou et al., 2010). There are several methods in which a producer can increase production; one method is by returning land once in Conservation Reserve Program (CRP) and other such programs back into production (Hart, 2006; Secchi et al., 2008; Zhou et al., 2010). While these practices increase grain production and are economically feasible to the producer they have also come with increases in non-point source pollution impacts (Zhou et al., 2010).

The conversion of permanent vegetation to row crop production over time along with certain management practices alter subsurface soil properties as well as soil surface properties resulting in increased runoff from agricultural lands during rainfall events (Harper et al., 2008). Heavy farm equipment causes compaction and reduced land coverage by residue of vegetation leaves the soil surface vulnerable to raindrop impact. Compaction and rain impact cause reduction in soil infiltration due to reduced pore size and surface crusting via particle detachment and deposition both of which affect pore size distribution (Grismer, 1986). Infiltration depends greatly on pore size distribution and the migration towards smaller pore sizes under row crop production has reduced infiltrability (Grismer, 1986). Grismer (1986) reported that pore size distributions skewed towards smaller pores causes a greater resistance to water flow thus reducing infiltration.

Poor infiltration causes soil and nutrient loss by increasing erosion. Ultimately, the loss of highly productive surface soil due to erosion leads to reduced field productivity for producers (Haghighi et al., 2010). Changes in land use and management practices may have the ability to reverse the changes in soil physical properties that have resulted from row crop production (Schilling and Spooner, 2006).

Incorporation of the appropriate mixture of perennial vegetation as filter strips has the potential to increase infiltration, increase water storage, and create greater pore size distribution than is generally found in agricultural fields. The root systems of vegetative filter strips (VFS) create pores which serve as pathways for increased infiltration. Dense year round cover protects the soil from surface crusting and also provides runoff protection by slowing overland flow which provides the opportunity for deposition of soil particles carried from upslope fields and increased infiltration (Dosskey et al., 2005; Jiao et al., 2011). Anderson et al. (2009) found that agroforestry buffers used more water during the growing season; thus there was more room available for water storage. The increased infiltration they measured was a result of increased water storage capacity which is important in preventing runoff. Also due to the plant mixture in the filter strips, root development created a variety of pore sizes, greater pore connectivity, and soil aggregate stability (Unger, 2001) which can also positively impact infiltration.

Permanent vegetation—specifically restored native permanent vegetation–has the potential to benefit both surface and subsurface water quality as delivered to a stream (Dabney et al., 2006). Schilling and Spooner (2006) found that converting row crop to grass reduced nitrate concentrations over time but when the reverse was done and grassland was converted back to row crop nitrate concentration rose quickly. VFS within row crop production provides a compromise to converting an entire field to perennial vegetation and has the potential to provide some of the benefits in water quality protection that would be provided by an entire field in permanent vegetation.

Few of the studies done have been done in Iowa on Iowa soils and none have be done utilizing native tall grass prairie vegetation for the filter strips. Because Iowa is such as leader in corn production and a lot of new corn production area will come at the expense of Iowa conservation land a study on former conservation land remove and placed back to production or into prairie vegetation needs to be conducted.

A study on the environmental impacts of removing land from CRP to produce corn was established fall 2006 into spring 2007. Preliminary results of the study of twelve small watersheds with perennial vegetation in the form of vegetative buffers/filter strips within row crop showed that the watershed with perennial vegetation incorporated had less runoff and sediment loss than those that were 100% annual crop (Helmers et al., in review).

This study is one of two smaller studies created to explain how the treatments with perennial reduced runoff and sediment.

The objective of this study was to compare the no-till row crop area to areas with restored native prairie and vegetative filter strips at varied landscape positions to determine *i*) if hydraulic conductivity differed by cover and position and *ii*) if pore size distribution differed by cover and position.

2.3 MATERIALS AND METHODS

SITE DESCRIPTION

The study was conducted at the Neal Smith National Wildlife Refuge (NSNWR) in Jasper County, IA managed by the U.S. National Fish and Wildlife Service (Figure 2.1). Within the refuge there are areas of conservation reserve program (CRP), several reestablished areas containing native perennials, and there is farmland that is leased while it awaits restoration. Prior to the start of the overall experiment which began in 2006 all of the chosen experimental areas were under CRP brome grass for at least 10 years prior to this time. In August 2006, a total of twelve small research watersheds were established over three different locations (Basswood (6), Interim (3), Orbweaver (3)) (Orbweaver from here on referred to as Weaver) within the refuge. The watersheds were tilled in preparation for the experiment fall of 2006 and spring of 2007. In the spring of 2007, row crop areas of the watersheds were planted to soybeans (*Glycine max.* (L)Merr). The small watersheds have since been managed under a no-till corn (*Zea mays* L.) - soybean (*Glycine max.* (L)Merr.) rotation. Each watershed contains 0%, 10%, or 20% perennial vegetation area planted with a native prairie mixture. In watersheds containing filter strips, the strip areas were seeded on July 7, 2007 using broadcast seeder with a mixture of native prairie forbs and grasses.

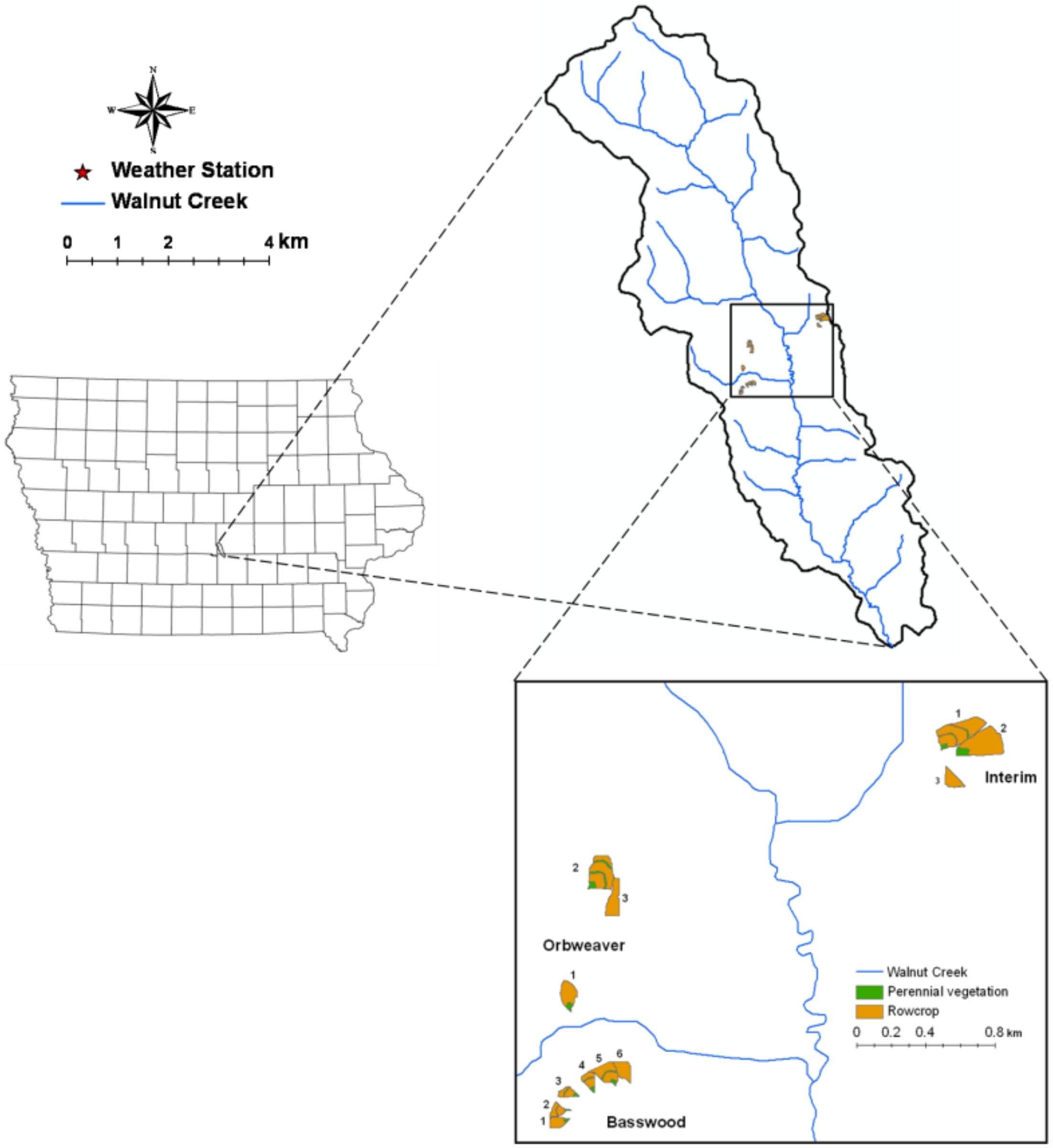

Figure 2.1 Research watersheds at the Neal Smith National Wildlife Refuge (NSNWR) Latitude 41.57654, Longitude -93.27264

Figure 2.2 Aerial view of the three experimental watersheds and restored prairie

For this experiment three of the twelve watersheds were used. The watersheds used in 2010 were Basswood-4, Interim-1, and Weaver-2 (Figure 2.1 and 2.2). Along with the three watersheds in 2010 restored native prairie (unnamed) next to Interim-1 was used. In 2011, restored native prairie (Interim-4) just south of Interim-1was added to the experiment. The three agroecosystem sites chosen range in size from 0.55 ha to 3.0 ha. Each agroecosystem used in the experiment contained at least 2 vegetative filter strips within the row crop, one located upslope at the shoulder position and the other located down slope at the foot slope position (Table 2.1). Soil series at the research sites consist of primarily Ladoga (silt loam, Mollic Hapludalf) or Otley (silty clay loam, Oxyaquic Argiudolls) soils with slopes ranging from 5 – 14 %. Soil samples were obtained from each of the study positions and sent to Ward Laboratories, Inc. Kearney, Nebraska for particle size analysis obtained using hydrometer method. Soil texture information by position and depth are provided in Table 2.2.

Table 2.1 Watershed and vegetative filter strip area

Location	Watershed Area (ha)	No. of filters in watershed	% of watershed in Filter Strip	Filter Strip Area (ha)
Basswood–4	**0.55**	**2**	**20**	**0.11**
Interim–1	**3.00**	**3**	**10**	**0.30**
Weaver–2	**2.40**	**3**	**10**	**0.24**

Table 2.2 Watershed soil texture

Location	Slope Position	Depth (cm)	Soil Particle Size Distribution (%)		
			Sand	Silt	Clay
Basswood-4	**Upslope**	**0-15**	10.5	52.8	36.7
		15-30	9.7	53.8	36.5
		30-60	8.2	56.5	35.3
	Foot slope	**0-15**	11.7	58.2	30.2
		15-30	11.3	58.7	30.0
		30-60	11.0	54.8	34.2
Interim-1	**Upslope**	**0-15**	15.6	50.8	33.6
		15-30	15.0	50.6	34.4
		30-60	14.3	53.1	32.6
	Foot slope	**0-15**	27.1	42.8	30.1
		15-30	25.0	44.1	30.9
		30-60	21.1	45.8	33.1
Weaver-2	**Upslope**	**0-15**	10.3	55.3	34.3
		15-30	10.5	53.5	36.0
		30-60	10.5	53.3	36.2
	Foot slope	**0-15**	11.2	57.2	31.7
		15-30	12.5	57.8	29.7
		30-60	11.2	56.5	32.3
Prairie*	**Upslope**	**0-15**	12.0	51.0	37.0
		15-30	12.8	53.8	33.5
		30-60	16.0	52.8	31.3
	Foot slope	**0-15**	31.5	39.3	29.3
		15-30	29.3	40.5	30.3
		30-60	25.8	42.0	32.2

Soil texture information is from 2010 soil samples only.

****Only the unnamed prairie adjacent to Interim-1 was soil sampled in 2010, Interim-4 prairie was not soil sampled.***

TENSION INFILTROMETER EXPERIMENT

Tension infiltrometer testing began in mid-July 2010 due to wet soil conditions from the high amount of rainfall during the early portion of the season and was completed in October 2010. Experiments in 2011 were conducted May 2011 through August 2011.

Tension infiltrometers with 0.20 m diameter tension discs (Figure 2.4 and 2.5) were used to determine unsaturated surface infiltration rates within restored native prairie, VFS and row crop at the upslope and foot slope position of each watershed (Figure 2.3). Sixteen total locations in each watershed, four at each treatment-position combination (4 x filter strip upslope, 4 x row crop upslope, 4 x filter strip foot slope, 4 x row crop foot slope) as shown in figure 2.3, where soil sampled for utilization in lab analysis than marked for In-situ analysis. At each of the four treatment-position sample locations two of the four locations were used for tension infiltrometer tests. For example at the Basswood site locations BRC1S, BRC3S, BFS1S, BFS3S, BRC1F, BRC3F, BFS1F, and BFS3F shown in Figure 2.3 are where the tension infiltrometer experiments were conducted in both 2010 and 2011. The tests were conducted in triplicate (three tension infiltrometers running simultaneously unless equipment issues prevented) at each location for a total of six replicates for each treatment- position combination. Tensions were chosen to remain close to or somewhat consistent with published literature (Lin et al., 1997; Zhou et al., 2008; Holden, 2009). As such, there were six tensions (0, -1, -2, -5 and -11cm H_2O) tested at all locations.

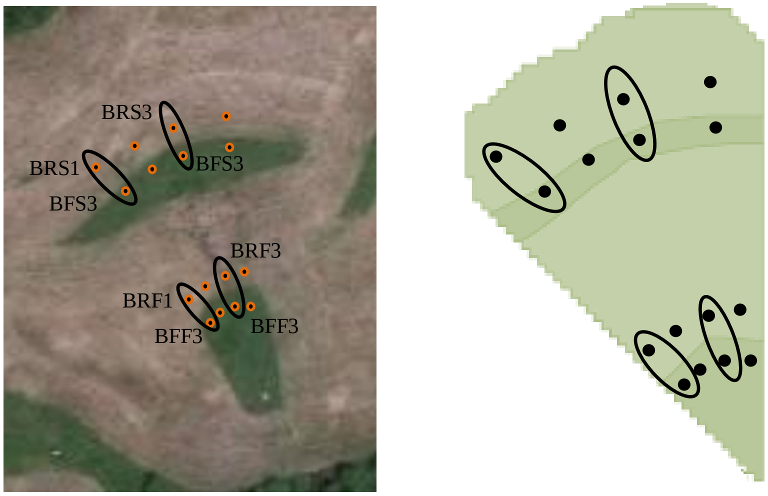

Figure 2.3 Aerial and drawing of Basswood-4 experiment sampling sites

Circled dots represent the two locations used out of the four locations marked and sampled
Abbreviation: basswood row crop shoulder 1(BRS1), basswood row crop shoulder 3(BRS3), basswood filter strip shoulder 1(BFS1), basswood filter strip shoulder 3(BFS3), basswood row crop foot 1(BRF1), basswood row crop foot 3(BRF3), basswood filter strip foot 1(BFF1), basswood filter strip foot 3(BFF3)

Infiltration was measured approximately 3.66 m (12 feet) from the interface between the row crop and VFS. The row crop measurement was 3.66 m upslope of the interface in a non-trafficked inter-row and the VFS measurement was 3.66 m into the strip directly down slope of the row crop measurement. The experimental set up was conducted using the tension infiltrometer operating instructions by Soil Moisture Equipment Corporation (2008); modifications to the protocol were done as needed to suit existing field characteristics. The modifications were, 1) in areas of extreme slope or unlevel soil sometime more than 2-3 cm of soil surface needed to be removed to level the surface and 2) the metal rings were not removed at the start of the test they were left in place for the entirety of the experiment. In 2010 all measurements were collected manually using a cm/mm scale attached to the reservoir of the infiltrometer and a stopwatch. Water levels were read for each infiltrometer at each tension every 0.5 min, 1 min, 1-2 min, 2 min, 4 min for a total of 15 min, 15 min, 20 min, 25-30 min, 40 min at tensions 0, -1, -2, -5 and -11 respectively. Time intervals were adjusted as needed depending on the rate of infiltration. For example if infiltration was occurring quickly at tension -1 the time interval may be decreased to every 0.5 min instead of every 1 min so that at the end of the experiment there would be more data points to use for calculations. In 2011, at the beginning of the season measurements were collected every ten seconds using an Omega PX26-005DV pressure transducer (Omega Engineering, Stamford, CT) along with a Campbell CR10X datalogger (Campbell Scientific, Inc., Logan, UT). By the end of the season measurements were taken manually as they were in 2010 due to equipment problems. In the row crop area surface residue was brushed away and in the VFS the vegetation was removed by clipping it at the soil surface. A metal ring was placed where the vegetation and residue was removed. A piece of cheese cloth was place over the metal ring and moistened using a spray bottle filled with water. Afterwards a thin layer of fine silica sand was placed on the cheese cloth in the ring and leveled to help create good hydraulic contact between the soil and the tension infiltrometer disc and ensure the entire cross sectional area contributed to water movement. The tension disc with the membrane was then placed on the sand, and the tests were run sequentially from -11 cm H_2O to 0 cm H_2O. Each experiment started at the lowest tension (-11 cm) and was run until quasi steady state was reached, indicated by a consecutive equal change in water level over a specific time period, before moving on to the next tension. Tests at each location lasted approximately two and a half hours. Tests for paired locations (e.g., VFS upslope location and row crop upslope location) within the same watershed were completed on the same day so that all conditions were the same or as similar as possible so a direct comparison of the sites could be done statistically.

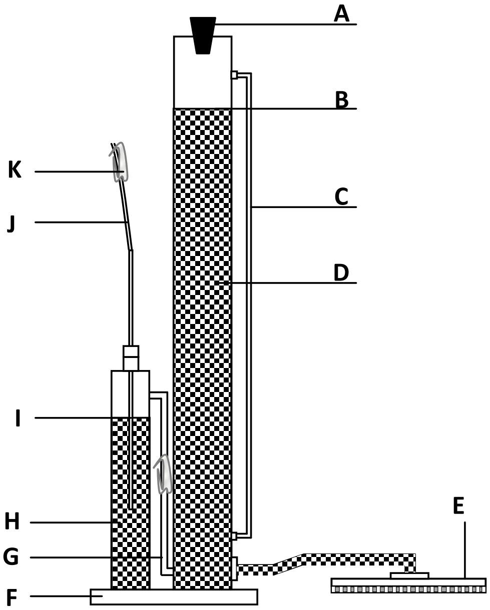

Figure 2.4 Schematic of Tension Infiltrometer

a)Rubber stopper, b)Water level, c)Tygon tubing for pressure transducer, not used in 2010, d)Reservoir, e)Infiltration disc, f)Base, g)Air bubbling tube, h)Air bubble tower, i) Water level, j) Air entry tube, and k) hose clamp

Figure 2.5 Tension Infiltrometer and equipment used

DATA ANALYSIS

Data collected from the experiments were used to determine hydraulic conductivity, pore radii, and pore size distribution.

Unsaturated Hydraulic conductivity, K(ψ)

Infiltration rates were determined by manually measuring change in water level, Δh in the infiltrometer reservoir over time, t, in 2010 and with a pressure transducer and datalogger in 2011. In both cases the infiltration rates were graphed then translated into an infiltration flux, Q ($cm^3\ hr^{-1}$). The calculated infiltration fluxes were used in the Wooding (1968) equation [Eq. 1] for infiltration of water from a circular source. Multiple water potentials were used and Equation 1 for the potentials were used to solved for α [Eq. 2] (Reynolds and Elrick, 1991; Hussen and Warrick, 1993). Once K_{sat} ($cm\ hr^{-1}$) and α (cm^{-1}) were determined hydraulic conductivities, K(ψ) (cm hr^{-1}) were calculated using Gardner (1958) exponential hydraulic equation [Eq.3]

$$\mathbf{Q}(\boldsymbol{\psi}_i) = \boldsymbol{\pi}\mathbf{r}^2\mathbf{K}_{\mathbf{sat}}\mathbf{e}^{\boldsymbol{\alpha\psi}}\left[1 + \frac{4}{\pi r\alpha}\right] \qquad (1)$$

$$\boldsymbol{\alpha} = \frac{\ln\left[Q(\psi_i)/Q(\psi_i+1)\right]}{\psi_i - \psi_{i+1}} \qquad (2)$$

$$\mathbf{K}(\boldsymbol{\psi}) = \mathbf{K}_{\mathbf{sat}}\mathbf{e}^{\boldsymbol{\alpha}\mathbf{h}} \qquad (3)$$

where Q(ψ) (cm^3hr^{-1}) is the steady infiltrating flux at a given water potential ψ (cm), r (cm) is the radius of the infiltration disc, K_{sat} (cm hr^{-1}) is the field saturated hydraulic conductivity, and α (cm^{-1}) is an empirical fitting parameter.

Number of pores per square area, N(r)

Macropore flow can be a major factor in infiltration. Luxmoore (1981) defined macropores as pores at which drain at <3 cm H_2O tension and mesopores as those that drain between 3 and 300 cm H_2O tension. Data obtained for the tension infiltration experiments were used to calculate the number of macropores per square area within the watersheds to determine if macropore flow is present and whether different locations or land uses have different numbers of macropores. The number of macropores per area was calculated using the method by Watson and Luxmoore (1986).

$$\mathbf{r} = \frac{-2\,\sigma\,\cos\beta}{\rho g h} \qquad (4)$$

$$\mathbf{N}(\mathbf{r}) = \frac{8\mu K_m}{\pi\rho g r^4} \qquad (5)$$

where for Equation 4, r (cm) is the pore radius, σ (g s^{-2}) is the surface tension, β(°) is the contact angle (assumed to be zero), ρ(g cm^{-3}) is the density of water, g(cm s^{-2}) is gravity, and h (cm) is the applied tension. For equation 5, N(r) is the number of macropores per area, μ (g

$cm^{-1}s^{-1}$) is the dynamic viscosity, and K_m (cm s^{-1}) is the difference in conductivities between tensions.

Statistical Analysis

The same analysis was done for both experimental years. Each year two separate analyses were conducted. First, a block design with paired data was used for analysis of treatment and position at all the sites this analysis excluded all restored prairie. The second, a single block design also with paired data, was used for the analysis of treatment and position at only the Interim site this analysis included all restored prairie. The analysis was done in this manner due to the Interim site having restored native prairie vegetation located directly adjacent to the watershed that could be included as part of the block being tested whereas Basswood-4 and Weaver-2 did not.

Statistical analyses were conducted using Statistical Analysis Systems (SAS) software (SAS Institute Inc., Cary, NC). Data was log transformed to facilitate statistical analysis. The Proc GLIMMIX procedure was utilized for determination of significance between treatment effects (block, land use, and position) as well as their interactions.

2.4 RESULTS AND DISCUSSION

HYDRAULIC CONDUCTIVITY

All watersheds (short term treatment effects-row crop vs vegetative filter strips)

In the 2010 analysis of the row crop compared to the VFS, the only significant difference between the two treatments was at tension, $\psi = -5$ cm H_2O (Table 2.3 & 2.4). In the 2011 analysis of the row crop compared to the VFS results showed no significant differences between the two treatments at any tensions (Table 2.3 & 2.4). The difference at $\psi = -5$ in 2010 did not carry over into the following year, so it highly probable that the significant difference at the -5 tension is due to high soil variability and not due to any overall significant changes in soil properties. The overall relative lack of significant differences in hydraulic conductivity is likely due to age of the treatments. Schwartz et al. (2003) found that conductivities were similar between 10 year old CRP and no-till suggesting that longer than 10 years is needed for changing soil properties. However it could also be in part due to the experiments being conducted late in the season during a time in which the vegetation was quite mature on all the treatments so the root systems were occupying vital pore space. Zhou et al. (2008) found that the time of year measurements were taken had the greatest impact on measured hydraulic conductivity; late season values averaged lower conductivity than early season.

There was a significant difference between landscape position at the ψ = -5 and -11cm tensions in 2010 (Table 2.3 & 2.4). The hydraulic conductivity at the foot slope was significantly greater than the upslope position. The larger conductivity at the foot slope position is likely a result of higher clay content present at the upslope position for the surface (0-15 cm depth) within all the watersheds (Table 2.2) due to erosion and deposition of the more conductive sand and silt at the foot slope from the upslope position which too can be seen in the surface (0-15 cm) particle size analysis (Table 2.2). After one large storm event in particular, sediment deposition at the foot slope position within the VFS was very noticeable. In 2011 only at ψ = 0 cm was the hydraulic conductivity significantly different. The upslope position was greater than the foot slope position.

Overall, there were little significant differences in the hydraulic conductivity between the VFS and the row crop. The row crop showed some evidence of greater K_{sat} than VFS at saturation (e.g., ψ = 0 cm); however, VFS K_{sat} was not significantly smaller (Table 2.4). At this time K_{sat} seems to vary more greatly due to landscape position than land use. Individual watersheds varied greatly in 2010, Basswood and Interim showed that the conductivity was larger in the VFS at some if not all tensions while Weaver showed the opposite (Figure 2.6a-f). In 2011, the opposite occurred in two watersheds where row crop conductivity was greater than VFS while in the other watershed at zero tension VFS and row crop were almost the same. Many different vegetation types have been employed to positively influence field soil hydraulic properties on vastly different soil types. As such the effect of VFS influence on infiltration has been shown to vary greatly. Some researchers have found that permanent vegetation's effect on soil hydraulic properties increases soil hydraulic properties (Rachman et al. 2004)others have found that vegetation reduces some soil hydraulic properties (Gish and Jury, 1983), and others have found no significant differences (Anderson et al., 2009). Overall our results tend to be consistent with Anderson et al. 2009 in that saturated conductivity was not significantly different between treatments and more time is needed for significant differences to develop.

Table 2.3 Analysis of variance saturated hydraulic conductivity measured from tension infiltrometers at 0, -1, -2, -5, and -11 cm tension in all watersheds showing effect of block, land use, position, and position*land use.*

			$\psi = 0$		$\psi = -1$		$\psi = -2$		$\psi = -5$		$\psi = -11$	
Year	**Analysis**	**Effect**	**F**	***p***	**F**	***p***	**F**	***p***	**F**	***p***	**F**	***p***
2010	**All watersheds**											
		Block	**6.41**	**0.03****	**4.54**	**0.06***	**3.25**	**0.11**	**0.10**	**0.90**	**0.96**	**0.44**
		Land use	**1.33**	**0.29**	**0.00**	**0.96**	**0.84**	**0.39**	**3.89**	**0.09***	**0.19**	**0.68**
		Position	**0.88**	**0.38**	**1.57**	**0.26**	**2.23**	**0.19**	**7.77**	**0.03****	**12.87**	**0.01****
		Position* Land use	**0.55**	**0.55**	**0.31**	**0.60**	**0.00**	**0.98**	**0.58**	**0.47**	**0.23**	**0.65**
	Interim Only											
		Land use	**3.16**	**0.24**	**2.39**	**0.30**	**1.45**	**0.41**	**0.98**	**0.50**	**0.19**	**0.84**
		Position	**0.15**	**0.73**	**0.36**	**0.61**	**0.01**	**0.93**	**0.20**	**0.70**	**0.03**	**0.89**
2011	**All watersheds**											
		Block	**10.40**	**0.01****	**10.80**	**0.01****	**11.39**	**0.01****	**1.61**	**0.28**	**0.79**	**0.50**
		Land use	**0.54**	**0.49**	**0.00**	**0.99**	**0.11**	**0.75**	**1.09**	**0.34**	**0.06**	**0.81**
		Position	**7.51**	**0.03****	**3.49**	**0.11**	**0.86**	**0.39**	**0.33**	**0.58**	**0.29**	**0.61**
		Position* Land use	**1.08**	**0.34**	**0.90**	**0.38**	**0.92**	**0.38**	**0.55**	**0.49**	**1.87**	**0.22**
	Interim Only											
		Land use	**1.16**	**0.40**	**1.00**	**0.44**	**0.04**	**0.96**	**0.88**	**0.48**	**2.92**	**0.17**
		Position	**0.00**	**0.97**	**0.00**	**0.98**	**0.06**	**0.82**	**0.06**	**0.81**	**0.77**	**0.43**

Significance only determined within effect and tension applied
***Asterisks imply different significant levels for *p* value. (**$p<0.05$, *$p<0.1$). The all watershed analysis excludes the prairie.**

Table 2.4 Saturated hydraulic conductivity, K(ψ) (cm hr^{-1}) for treatment and slope position in all watersheds at tensions of 0, -1, -2, -5, and -11 cm.*

Year	Effect		K(0)	K(-1)	K(-2)	K(-5)	K(-11)
2010	**Treatment**						
		Row Crop	**17.55a**	**6.44a**	**2.19a**	**0.39a**	**0.14a**
		Filter Strip	**12.43a**	**6.32a**	**3.03a**	**0.64b**	**0.16a**
	Position						
		Upslope	**12.84a**	**5.04a**	**1.97a**	**0.36a**	**0.09a**
		Down slope	**17.00a**	**8.06a**	**3.36a**	**0.71b**	**0.24b**
	Treatment*Position						
		Row Crop Upslope	**13.65a**	**4.59a**	**1.68a**	**0.31a**	**0.09a**
		Row Crop Down slope	**22.57a**	**9.02a**	**2.84a**	**0.51a**	**0.21b**
		Filter Strip Upslope	**12.07a**	**5.54a**	**2.31a**	**0.41a**	**0.09a**
		Filter Strip Down slope	**12.82a**	**7.20a**	**3.97a**	**0.99b**	**0.27b**
2011	**Treatment**						
		Row Crop	**28.91a**	**10.68a**	**3.52a**	**0.71a**	**0.13a**
		Filter Strip	**23.60a**	**10.70a**	**3.93a**	**1.12a**	**0.13a**
	Position						
		Upslope	**38.13a**	**14.96a**	**4.32a**	**1.01a**	**0.12a**
		Down slope	**17.89b**	**7.63a**	**3.20a**	**0.78a**	**0.14a**
	Treatment*Position						
		Row Crop Upslope	**36.54a**	**12.60ab**	**3.50a**	**0.68a**	**0.11a**
		Row Crop Down slope	**22.90ab**	**9.05ab**	**3.54a**	**0.73a**	**0.16a**
		Filter Strip Upslope	**39.79a**	**17.76a**	**5.33a**	**1.49a**	**0.14a**
		Filter Strip Down slope	**14.72b**	**6.45b**	**2.89a**	**0.84a**	**0.12a**

Letters only hold for pressure and specific aspect being studied (i.e. year, position, and pressure).

*** Values with corresponding letters next to them indicate a lack of significant difference at the $p<0.10$ level.**

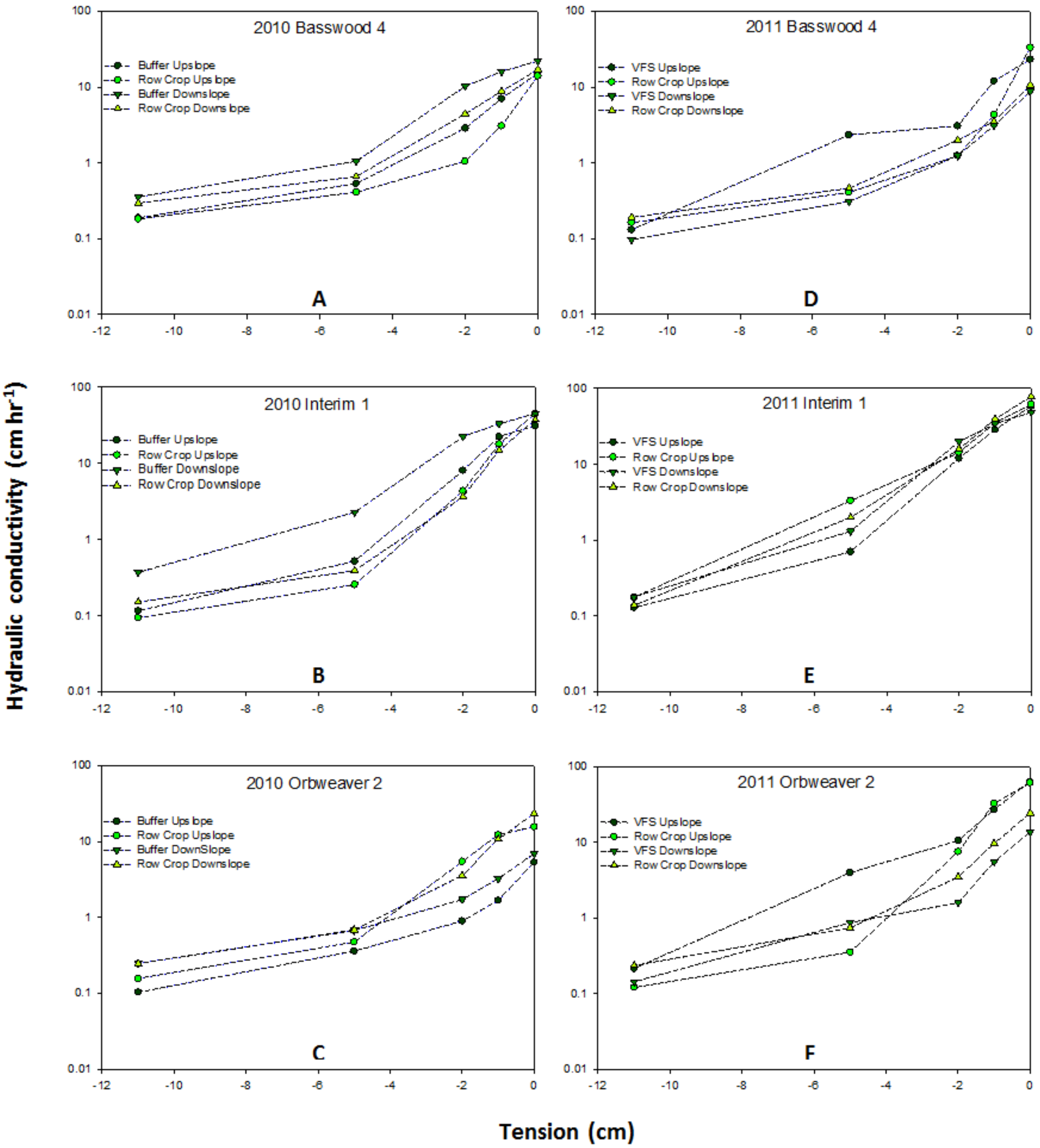

Figure 2.6 Mean hydraulic conductivity of each watershed and position

a) 2010 Basswood K(ψ) b) 2010 Interim K(ψ) c) 2010 Weaver K(ψ) d) 2011 Basswood K(ψ) e) 2011 Interim K(ψ) f) 2011 Weaver K(ψ)

Interim-1 and restored native prairie (Long term treatment effects- Row crop, VFS, and restored prairie)

There were no significant differences found between treatments in 2010 for all tensions in the Interim only analysis (Table 2.5). Closer to the saturated conditions the lack of significant differences could have been due to the large surface cracks through which water could easily infiltration regardless of vegetation type. At the higher tension, which correspond to drier soil conditions, the lack of significance is possibly due to vegetation in the restored prairie being well established and very dense by the time testing started. Thus an explanation for the lack of significant differences as well as the lower conductivities observed in the restored prairie could be that the roots were actively growing and utilizing pore space that would have been available for profile transmission thus limiting water movement (Gish and Jury, 1983; Rachman et al., 2004). In 2011the only significant difference was at the -11 tension where conductivity in the restored prairie was the greatest. Row crop was similar to VFS and VFS was similar to restored prairie.

In neither experimental year did conductivity at the two slope positions show any significant differences.

Overall lack of significant difference is likely a result of high within treatment and position variability which outweighs any possible treatment or position effects.

Table 2.5 Comparison of Hydraulic conductivity, K(ψ) (cm hr^{-1}) for Restored Prairie and Interim-1 at tensions of 0, -1, -2, -5, and -11 cm.*

Year			K(0)	K(-1)	K(-2)	K(-5)	K(-11)
2010	**Treatment**						
		Row Crop	**31.34a**	**10.83a**	**3.05a**	**0.30a**	**0.11a**
		Filter Strip	**26.25a**	**15.28a**	**7.15a**	**0.96a**	**0.17a**
		Restored Native Prairie	**6.86a**	**2.84a**	**2.11a**	**0.57a**	**0.14a**
	Position						
		Upslope	**19.62a**	**9.34a**	**3.69a**	**0.47a**	**0.13a**
		Foot slope	**16.15a**	**6.47a**	**3.48a**	**0.64a**	**0.15a**
2011	**Treatment**						
		Row Crop	**67.35a**	**33.42a**	**9.51a**	**1.50a**	**0.10a**
		Filter Strip	**49.84a**	**25.65a**	**9.97a**	**0.95a**	**0.14ab**
		Restored Native Prairie	**46.32a**	**20.68a**	**8.86a**	**1.07a**	**0.19b**
	Position						
		Upslope	**53.55a**	**25.96a**	**9.07a**	**1.19a**	**0.12a**
		Foot slope	**53.99a**	**26.19a**	**9.83a**	**1.11a**	**0.15a**

Significance only determined within effect and tension applied. Letters only hold for pressure and specific aspect being studied (i.e. position and pressure).
***Values with corresponding letters next to them indicate a lack of significant difference at the *p*<0.10 level.**

Number of Macropores

Basswood-4 and Orbweaver-2

In 2010 at the Basswood site the number of pores within all three size ranges was higher in the VFS at the foot slope position and upslope position than corresponding row crop positions (Table 2.6). The reverse scenario occurred in Weaver where at each landscape position row crop had a larger number of pores of all size ranges.

In 2011within the Basswood watershed there were more pores of the size ranges 0.01-0.025 cm and 0.025-0.05 cm in the row crop at the foot slope. While there were an equal number in row crop and VFS at the foot slope of the pore size > 0.05 cm. At the upslope position there were a greater number of pores of size 0.01-0.025 cm and >0.05 cm in the VFS than the row crop. However in the mid-size pore range of 0.025-0.05 cm a greater number of pores were in the row crop opposed to the VFS. In Weaver the row crop at foot slope and upslope positions had a larger number of pores in the two larger size ranges while the VFS had more pores at the smallest pore size range (Table 2.6).

Table 2.6 Porosity estimated from tension infiltrometer data at Basswood-4 and Weaver-2.*

Year	**Watershe**			**No. of pores per m^2**			
2010	Basswood	Tension	Pore radius, cm	FS_U	FS_F	RC_U	RC_F
		0-2	> 0.05	11	14	6	12
		2-5	0.025-0.05	217	855	60	349
		5-11	0.01-0.025	754	1504	495	795
	Weaver			FS_U	FS_F	RC_U	RC_F
		0-2	> 0.05	2	4	17	19
		2-5	0.025-0.05	50	98	462	268
		5-11	0.01-0.025	558	926	692	954
2011	Basswood			FS_U	FS_F	RC_U	RC_F
		0-2	> 0.05	23	5	12	5
		2-5	0.025-0.05	69	89	78	142
		5-11	0.01-0.025	4787	410	533	591
	Weaver			FS_U	FS_F	RC_U	RC_F
		0-2	> 0.05	45	11	64	17
		2-5	0.025-0.05	615	67	669	256
		5-11	0.01-0.025	8203	1583	505	1101

***Abbreviations: filter strip upslope (FS_U), filter strip foot slope (FS_F), row crop upslope (RC_U), row crop foot slope (RC_F).**

Interim-1 and restored native prairie

In 2010, the number of pores of all pore radius sizes was lowest in the restored native prairie (Table 2.7) except for in the pore size range of 0.025-0.05 cm at the upslope position in which the restored prairie had more pores than row crop and 0.01-0.025 cm where the number of pores in the prairie is greater than row crop at the foot slope and upslope positions. The VFS had the highest number of pores at each position (upslope and foot slope) for the two smaller pore size ranges when compared to row crop. Row crop had a slightly greater number of pores of size >0.05 cm at the upslope position. At pore sizes in the range of 0.01-0.025 and 0.025-0.05 cm, the number of pores was greatest at the foot slope position compared to the upslope for VFS whereas at the >0.05 cm pore size range the upslope had the greater number of pores compared to the foot slope position. For the row crop treatment the number of pores of size 0.01-0.025 cm was greatest at the foot slope position while pores of the larger sizes were greatest at the upslope position.

In 2011 of the three land uses, row crop had the largest number of pores at the upslope position for all pores sizes. Row crop had a greater number of pores at the foot slope for the >0.05 cm range. VFS had the greatest number of pores for the 0.025-0.05 cm ranges and restore prairie had the lowest at the foot slope. Row crop had the greatest number of pores at the foot slope position for the 0.01-0.025 cm range and restored prairie has the lowest.

The number of pores at the Interim site at all positions within all land uses increased from 2010 to 2011 except for the two smaller size ranges at the foot slope position in the VFS and the 0.025-0.05 cm range for the restored prairie at the upslope position.

The number of the largest pores of >0.05 cm appears to favor the row crop area in 2010 which may be in part due to surface cracks in the exposed soil. However, it appears that the total number of pores, including all pore size ranges, favors the VFS areas which may be potentially due to a greater amount of root growth. Results were essentially the opposite in 2011 total overall number of pores appeared to be greatest in the row crop areas however in all treatment* position sites the total number of pores did increase compared to 2010 expect for that of the VFS foot slope location.

Table 2.7 Porosity estimated from Tension Infiltrometer data at Interim-1 and restored native prairie.*

			No. of pores per m^2					
2010	Tension, cm	Pore radius, cm	FS_U	FS_F	RC_U	RC_F	PRAU	PRAF
	0-2	> 0.05	35	27	36	30	15	1
	2-5	0.025-0.05	701	1863	377	301	596	64
	5-11	0.01-0.025	873	4144	351	518	1501	602
2011								
	0-2	> 0.05	44	37	54	62	30	31
	2-5	0.025-0.05	1045	1714	1063	1275	652	587
	5-11	0.01-0.025	1246	2450	5632	4017	2392	2077

***Abbreviations: filter strip upslope (FS_U), filter strip foot slope (FS_F), row crop upslope (RC_U), row crop foot slope (RC_F), restored native prairie upslope, (PRAU), restored native prairie foot slope, (PRAF).**

2.5 CONCLUSION

The objective of this study was to compare soil hydraulic properties of a no till row crop site with native prairie vegetation filter strips at varied landscape positions to determine if soil hydraulic properties were impacted by land cover (row crop, VFS, and restored native prairie) and if topographic position impacted soil hydraulic properties. Variations in surface infiltration and number of pores were determined for the VFS, restored prairie, and row crop areas.

Results varied with year with hydraulic conductivity. Hydraulic conductivity in 2011 was significantly greater ($p<0.1$) than in 2010 at tensions 0, -1, -2, and -5. An explanation for this may be that experiments were conducted late in the growing season in 2010 and earlier in the growing season in 2011. Though the years were statistically different the results each year were the same in that there were no significant differences in soil hydraulic properties due to land cover or position near or at saturation (h= 0, -1 -2 cm) where the majority of water movement occurs. Landscape position in the drier year of 2011had a positive significant effect on soil hydraulic conductivity at saturation (h=0) in the Interim only analysis. An explanation for the reason why we saw no significant differences in the restored native prairie, VFS, and cropped areas could be due to the fact that at the time of experimentation the restored prairie had well-established dense vegetation and roots which could have been plugging pores thus restricting water movement effectively reducing infiltration thus causing the soil properties to seem similar (Gish and Jury, 1983).

In some individual experiments measurements on soil hydraulic properties varied greatly within watershed, land cover, and land scape position. This suggests that location of the field itself and variability in soil properties within the fields early in reestablishment may have a significant role in the overall effectiveness of perennial vegetation incorporation within row crop agricultural production. Though the combined value of the majority of the soil hydraulic properties affected by land covers and position in this experiment were not different enough to be significant results the runoff reduction in the overall project occurring at NSNWR suggests that some kind of change is occurring. However it may not be due to the subsurface properties. It may be that it is simply a result of the surface features such as greater and denser vegetation present over a longer period of time physically slowing the overland flow and allowing more time for infiltration into the soil.

Lack of consistent significant differences in the results of the influence of VFS on soil hydraulic properties likely due to high soil variability warrant further investigation into the overall influence VFS has on soil hydraulic properties. High variability at the field scale also shows that there is a need to study the impact land use has on soil hydraulic properties in Iowa on even more soil types and at an even larger scale to determine how effective VFS incorporation truly can be.

Laboratory experiments were conducted to measure saturated hydraulic conductivity and soil water retention on soil cores taken from the same locations as where the tension infiltration tests occurred. This information will be used to compare with field results and determine if the same relationships remain true.

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CHAPTER 3. LAB MEASURED SOIL HYDRAULIC PROPERTIES OF RESTORED PRAIRIE, ROW CROP AGRICULTURE, AND PRAIRIE FILTER STRIPS

3.1 ABSTRACT

Agricultural soil loss and runoff are of concern as they impact soil quality and downstream water quality. Soil loss and runoff are affected by surface infiltration which is influenced by soil physical properties such as soil hydraulic conductivity, bulk density, and porosity among others. Incorporation of buffers and vegetative filter strips on agricultural land are a practice implemented to provide downstream water quality benefits. Given that change in land cover may alter soil hydraulic properties there is a need to evaluate the impacts of vegetative filter strips compared to row crop on soil physical properties. The purpose of this study was to determine if there were differences between row crop and recently established vegetative filter strips (~ 4-5 years) former in CRP land located in central Iowa. We hypothesize that the vegetative filter strips in the form of prairie filter strips (PFS) located within the row crop will increase saturated hydraulic conductivity and decrease bulk density. Constant head saturated hydraulic conductivity and bulk density were determined in the laboratory on ~7.6 centimeter undistributed soil core samples extracted from three watersheds and one native restored prairie located within at the Neal Smith National Wildlife Refuge (NSNWR) south of Prairie city, Iowa. Results showed no significant difference in bulk density for any treatment or position in both years. The only significant difference found was in 2011 all watersheds analysis of saturated hydraulic conductivity is which PFS had greater saturated hydraulic conductivity than row crop.

Keywords. saturated hydraulic conductivity, constant head, bulk density, vegetative filter strips, restored native prairie

3.2 INTRODUCTION

Excess water from agricultural fields is of constant concern in the Midwest. When an excessive amount of rain falls onto fields and is not intercepted by vegetation or conditions are not adequate for infiltration into the soil profile it will eventually travel off site as overland flow. This is of concern because as water flows overland it begins to accumulate soil particles and other constituents which it carries off site. The accumulation and export of soil and nutrients deteriorates soil and water quality. The adverse effects on water quality often occur when runoff makes its way into surface waters, this is due to the addition of soil and nutrients such as nitrogen and phosphorous loss from the field (Carpenter et al., 1998; Donner, 2003).The addition of soil and nutrients to water bodies especially in excessive amounts contribute to reduce water storage capacity, increase turbidity, and increase in algae growth which can subsequently kill fish and other organisms due to the unfavorable conditions (Donner, 2003). Increased amounts of runoff can also have downstream impacts on quantity of water flow both in volume and peak flow (Schilling, 2005; Schilling and Spooner, 2006). Not only does runoff affect water quality and quantity but the accompanying soil loss in marginal areas can also result in reduced crop growth (Pierce et al. 1984).

In 1985 the Conservation Reserve Program (CRP), a government program in which crops on marginal farm land are retired from production and replaced with resource conserving vegetation, was established as a solution to the growing concerns related to erosion. It is estimated that if all CRP were to end than soil erosion would increase by 220 million tons/year 40% of which would be from water erosion (Claassen et al., 2001). While CRP provides benefit for the conservation of soil and water it requires land be taken out of production for a considerable amount of time, usually 10-15 years. Over the years increased demand for agricultural products and increased commodity prices have prompted producers to return marginal areas enrolled in CRP back to row crop production. In Iowa, if current trends continue it is estimate that approximately half a million hectares of CRP land will be returned to crop production (Secchi et al. 2010; Zhou et al., 2010). The reestablishment of crops on these marginal areas allows for the potential increase in soil loss and water quality impairment. It is important to continue to preserve our natural resources yet allow producers to meet the demands for their products. Thus, as this crop reestablishment continues simultaneous establishment of practices that preserve soil and water quality are essential to retaining the availability of future natural resources. To accommodate producer needs as well as maintain some level of environmental stewardship, alternatives to complete land return to production are being explored.

It has been shown that additional conservation practices such as the incorporation of vegetative filter strips and edge of field buffers along with traditional in-field best management practices such as reduced tillage and nutrient management produce greater overall environmental quality results than traditional management practices alone (Udawatta et al., 2011; Maringanti et al., 2011). A variety of plants are used in buffers, some choose to plant introduced species and others choose native species. Erosion control effectiveness varies with location and plant species used. Ryder and Fares (2008) tested cover crops of sudex (*Sorghum bicolor* [L.] Moench × *S. sudanense* [P.] Staph.), sunn hemp (*Crotalaria juncea* [L.]), and oats (*Avena sativa* [L.]) as a vegetative filter strip on small 7 x 9 m plots in Hawaii and found them effective at removing sediment though no increase in infiltration rate. Udawatta et al. (2011) used agroforestry buffers and grass buffers in Missouri in which both reduced soil loss compared to row crop although agroforestry had greater benefit.

Incorporation of filter strips composed of native perennial vegetation on Iowa soils has not been thoroughly studied. Many studies on riparian buffer and filter strips have been done in Iowa and the Midwest using switch grass and/or similar vegetation however none have be done utilizing native tall grass prairie vegetation for the filter strips. Because Iowa is such a leader in corn production and a lot of new corn production area will come at the expense of Iowa conservation land exploration of the effects of production on former conservation land as well as the use of native prairie mixtures in filter strips needs to be studied in Iowa on Iowa soil to determine the applicability of using such systems in Iowa as well as overall performance.

In response to this need a study on the environmental impacts of removing land from CRP to produce corn was established fall 2006 into spring 2007. Preliminary results of the study of twelve small watersheds with perennial vegetation in the form of vegetative buffers/filter strips within row crop showed that the watershed with perennial vegetation incorporated had less runoff and sediment loss than those that were 100% annual crop.

This study is the second of two smaller studies created to explain how the treatments with perennial reduced runoff and sediment.

For the purpose of this study the effects of filter strips on physical soil properties that affect surface and subsurface water movement are of the most importance.

The objective of this study was to determine the impact of different vegetation on lab measured soil hydraulic properties that are important to the transport of water from the surface into the soil profile and through the soil profile. Specifically, saturated hydraulic conductivity and bulk density were investigated. We hypothesize that the vegetative filter strips in the form of prairie filter strips (PFS) located within the row crop will increase saturated hydraulic conductivity and decrease bulk density.

3.3 MATERIALS AND METHODS

SITE DESCRIPTION

The study occurred at the Neal Smith National Wildlife Refuge (NSNWR) in central Iowa's Jasper County. NSNWR is an 8,654 acre mixed native and agroecosystem. Within the refuge there are reestablished areas containing native perennials predominantly tallgrass prairie along with farmland that is leased out while it awaits restoration. In the summer of 2006, a portion of land on the refuge which was in formerly under CRP bromegrass (*Bromus* L.) for at least 10 years was mulch tilled, with some areas also being mulch tilled in the spring 2007. The CRP was tilled in preparation for the experiment. A total of twelve small research watersheds in three different locations, called Basswood, Interim, and Orbweaver (from here on referred to as Weaver) are being used as part of the larger experiment. Six watersheds were established at Basswood, three at Interim, and three at Weaver (Figure 3.1). Each watershed contains 0%, 10%, or 20% perennial vegetation area incorporated within row crop in the form of prairie filter strips (PFS) and/or foot slope buffers. In spring 2007, soybeans [*Glycine mas.* (L.) Merr.] were planted in the row crop areas of each watershed beginning a 2 year no-till corn (*Zea mays* L.)-soybean [*Glycine mas.* (L.) Merr.] rotation. Since implementation in 2007, no disturbance has occurred on the no-till cropland beyond the yearly planting, fertilizer application, and harvesting. On July 7, 2007 the PFS were planted using a broadcast seeder. A mixture of over 20 native prairie forbs and grasses planted containing four primary species; indiangrass (*Sorghastrum* Nash), little bluestem

(*Schizachyrium* Nees), big bluestem (*Andropogon gerardii* Vitman), and aster (*Aster* L.) was used for establishment of the PFS.

Three of the twelve small watersheds (Basswood-4, Interim-1, and Weaver-2) as well as a site of long-term restored native prairie (+15 yrs. old) located adjacent to Interim-1 were chosen as the replicates in this study (Figure 3.2). Soil series at the study sites consist of primarily Ladoga (silt loam, Mollic Hapludalf) or Otley (silty clay loam, Oxyaquic Argiudolls) soils with average slopes of 8.2%, 7.7%, and 10.3% at Basswood, Interim, and Weaver, respectively. Soil particle size distribution for each specific watershed and slope position is listed in Table 3.1.

The cropland in 2010 was planted with Pioneer roundup ready corn in mid-April at all three watersheds and harvested October 13th and 14th. In 2011, Pioneer 93M11 soybeans were planted in Interim and Weaver on May 19th while Basswood was not planted until June 7th due to weather. Harvest in 2011 occurred on October 7th and 8th.

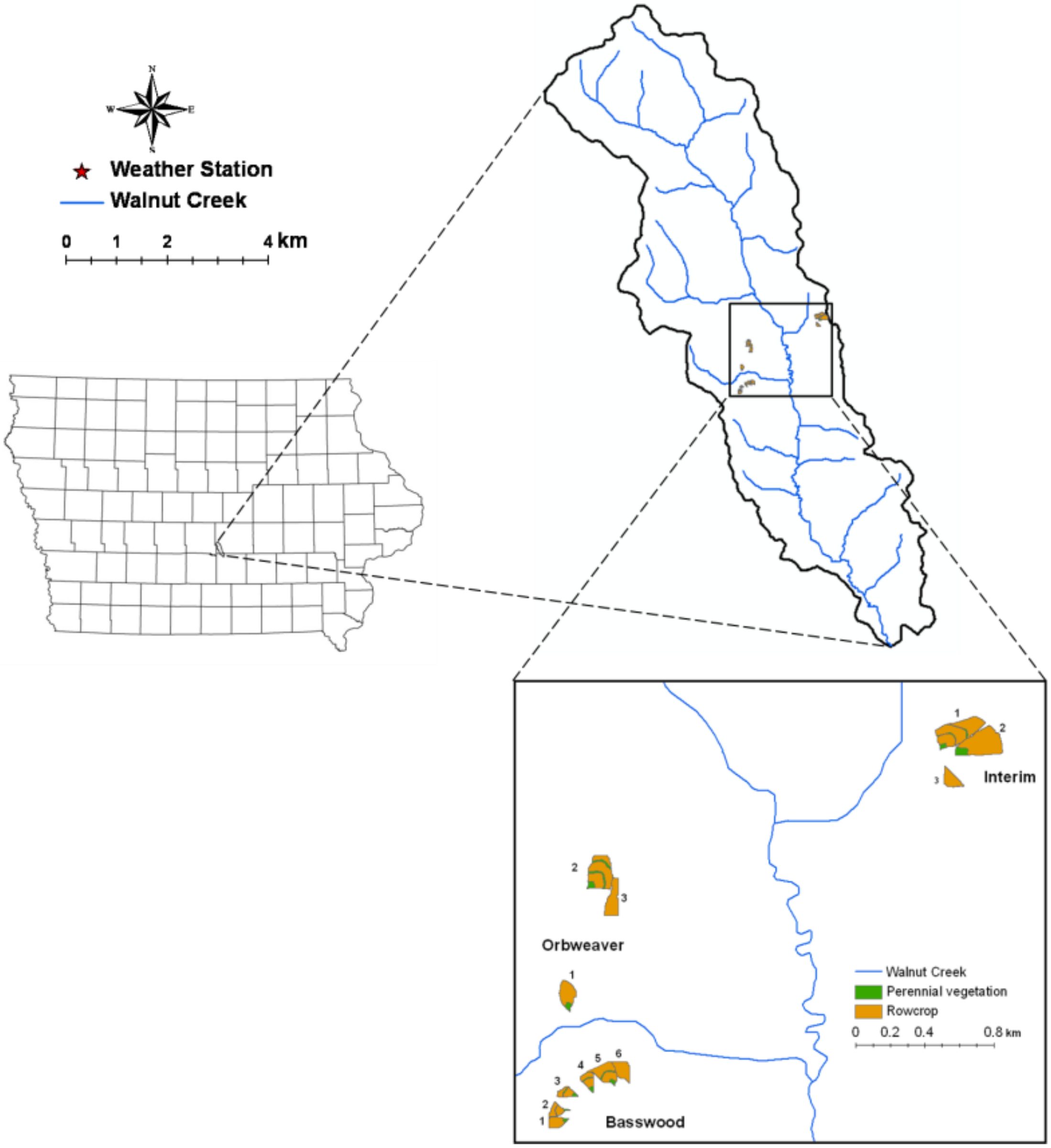

Figure 3.1 Research watersheds at the Neal Smith National Wildlife Refuge (NSNWR) Latitude 41.57654, Longitude -93.27264

Figure 3.2 Aerial view of the three experimental watersheds and restored prairie

Table 3.1 Watershed soil texture

Location	Slope Position	Depth (cm)	Soil Particle Size Distribution (%)		
			Sand	Silt	Clay
Basswood-4	**Upslope**	**0-15**	10.5	52.8	36.7
		15-30	9.7	53.8	36.5
		30-60	8.2	56.5	35.3
	Foot slope	**0-15**	11.7	58.2	30.2
		15-30	11.3	58.7	30.0
		30-60	11.0	54.8	34.2
Interim-1	**Upslope**	**0-15**	15.6	50.8	33.6
		15-30	15.0	50.6	34.4
		30-60	14.3	53.1	32.6
	Foot slope	**0-15**	27.1	42.8	30.1
		15-30	25.0	44.1	30.9
		30-60	21.1	45.8	33.1
Weaver-2	**Upslope**	**0-15**	10.3	55.3	34.3
		15-30	10.5	53.5	36.0
		30-60	10.5	53.3	36.2
	Foot slope	**0-15**	11.2	57.2	31.7
		15-30	12.5	57.8	29.7
		30-60	11.2	56.5	32.3
Prairie	**Upslope**	**0-15**	12.0	51.0	37.0
		15-30	12.8	53.8	33.5
		30-60	16.0	52.8	31.3
	Foot slope	**0-15**	31.5	39.3	29.3
		15-30	29.3	40.5	30.3
		30-60	25.8	42.0	32.2

Both the restored prairie and filter strips at the site are regularly maintained to control non-native plant species. The restored prairie is periodically burned to help manage plant species and the filter strips are spot sprayed as well as cut and baled to stay consistent with practices a private land owner might implement. During the research period of spring 2010 to fall 2011 the prairie vegetation was managed as follows; filter strips were cut and baled late October 2010 and mid November 2011. The restored prairie was left undisturbed in 2010 and burned in May 2011.

SOIL SAMPLING

Undisturbed soil samples to be used for laboratory measures of soil hydraulic properties were extracted from the restored prairie adjacent to Interim-1, Basswood-4, Interim-1, and Weaver-2. Sampling within each watershed occurred where the uppermost PFS was located which was at the shoulder slope position and at the very bottom at the foot slope position. With the PFS-row crop interface at each position as a guide, soil samples were taken approximately 3 m upslope of the interface into the row crop and approximately 3 m directly downslope of the interface into the PFS. Four samples were taken horizontally across the watershed at each slope position following along the edge of the PFS (Figure 3.3). Sixteen total locations were sampled within each watershed. Eight total locations were sampled from the native prairie, four upslope following along a similar topographic contour as the samples taken in Interim and four downslope again along a similar topographic contour as the foot slope samples in Interim (Figure 3.3). The same sampling strategy was used in Basswood and Weaver. For sampling in the native restored prairie the edge of the field was used as the guide. For the native prairie the samples were taken 5 m from the edge of the cropland and extending approximately 10 m out into the restored prairie.

Figure 3.3 Aerial of testing sites. Depicted site is Interim-1 and restored prairie

Soil Sampling 2010

In 2010, soil samples at NSNWR were taken in April prior to any field operations. Soil sampling was carried out following from American Society of Testing Material (ASTM) Standards. The exact standards used were ASTM 1587-00 Standard Practice for Thin-Walled Tube Sampling of Soils for Geotechnical Purposes, 4700-91 Standard Guide for Soil Sampling from the Vadose Zone, and 6282-98 Standard Guide for Direct Push Soil Sampling for Environmental Site Characterizations. A truck mounted #15-SC/ Model GSRPS Giddings Rig (Figure 3.4) was used to drive in and extract two 7.6 cm diameter by 45 cm long thin walled Shelby tubes (Figure 3.4). Each Shelby tube was pushed 30 centimeters down for a total sampling depth of 60 centimeters at each location. Three subsamples were later cut from the two tubes. The subsamples were approximately 7.6 cm long representing the 0-15, 15-30, and 30-60 cm depths. Afterwards the samples were placed in a cooler at 4°C until testing occurred.

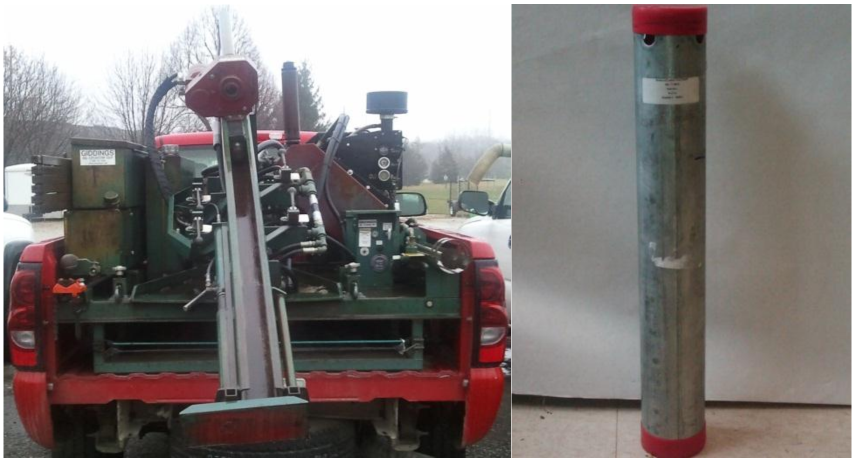

Figure 3.4 Soil sampling equipment Giddings Rig and Shelby tube used in the rig

Using a Garmin Etrex Legends GPS unit, GPS coordinates were taking during the time of sampling in 2010 to ensure that field experiments as well as soil sampling in 2011 would occur at approximately the same location.

Soil Sampling 2011

In May 2011, a Trimble GeoXT 3000 GPS unit was used to find the sample locations from the previous year. Once located soil samples were obtaining using a hammer soil core sampler (Fabricated by Howe's welding, Ames, IA). Two 7.6 cm diameter by 7.6 cm long rings were placed inside the sampler which was then manually driven into the ground to obtain two samples from the 0-15 cm soil depth range. The soil samples were transported back to the lab and placed in the cooler until testing. Of the two samples obtained the bottom 7.5-15 cm sample was used to represent the 0-15 cm depth range due to loose soil and incomplete samples from the top 0-7.5 cm.

The Hammer sampler was chosen for sampling in 2011 because soil sampling that year was confined to the surface 15 cm and not 60 cm as in 2010. Also the ground was too soft to drive on at the time sampling occurred.

SATURATED HYDRAULIC CONDUCTIVITY, K_{SAT}

The constant head test method (Klute and Dirksen, 1986) was utilized to determine saturated hydraulic conductivity (K_{sat}). In 2010, the approximately 7.6 centimeter long subsamples of the undisturbed soil samples were used for K_{sat} determination. In 2011, prefabricated 7.6 centimeter diameter by 7.6 centimeter long metal rings were used. A piece of cheese cloth was taped to the bottom of the samples. The purpose of the cheese cloth is to prevent the soil from falling out the bottom if the sample is loose. A small reservoir was made on top of each soil sample using duct tape in 2010 and an empty soil ring in 2011, to hold the constant head of solution then the subsamples were placed in a tub of test solution. A composition of 0.005M Calcium Chloride and 0.06% Formaldehyde was used for the test solution (Ochsner et al., 2005). Samples were left in the solution for at least twenty four hours to allow time for saturation from the bottom up. After apparent satiation (i.e., soil surface of sample appeared wet after at least twenty four hours had passed) the samples were mounted above a funnel and a small hydraulic head (approximately 2-5 cm) was applied to each sample using a Mariotte bottle (Figure 3.5). Drainage was measured using a 100 milliliter graduated cylinder and stopwatch. Each sample was run three times then allowed to drain, wrapped in cling wrap, and placed back into the cooler to preserve for later utilization in another experiment.

Conductivity using constant head method was determined in the lab by determining the time, t(s) for a predetermined volume, V(cm^3) of solution to pass through a sample of length, L(cm) for each sample. The determined time, known volume and sample length were used to determine saturated hydraulic conductivities using the formula below (Equation 1).

$$\mathbf{K_s = \frac{VL}{At\,(H_2 - H_1)}} \qquad (1)$$

where K_s (cm s^{-1}) is the saturated hydraulic conductivity, V (cm^3) is the drainage from the soil core of cross sectional area A (cm^2) and length L(cm), and (H_2-H_1) is the hydraulic head difference imposed across the sample, from the upper water level to the bottom of the core.

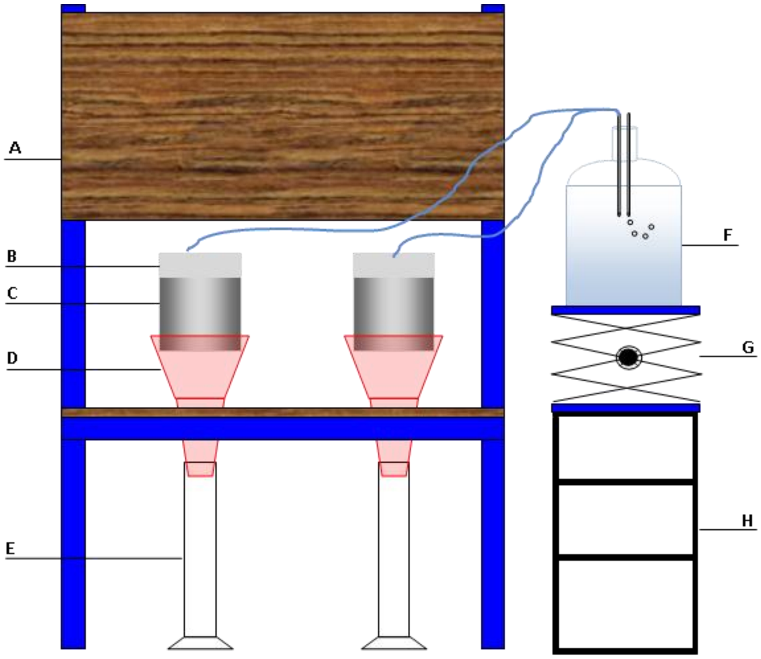

Figure 3.5 Constant head experimental set up schematic

a) sample stand, b) head reservoir (duct tape or empty core), c) soil sample, d) funnel, e) graduated cylinder, f) Mariotte bottle, g) jack stand, and h) shelf

BULK DENSITY AND POROSITY

Bulk density was determined on soil samples from 2010 and 2011. The soil cores were weighed prior to being placed in the oven so that final moisture content could be determined. The cores were placed in the drying oven at 105°C for 48 hours then weighed again to determine bulk density.

In the data analysis Equation 2 was used to determine bulk density.

$$\rho_b = \frac{M_s}{V_t} \qquad (2)$$

where ρ_b (g cm^{-3}) is the dry bulk density, M_s (g) is the mass of the soil, and V_t (cm^3) is the total sample volume.

From bulk density, porosity was determined using.

$$\phi = 1 - \frac{\rho_b}{\rho_s} \qquad (3)$$

where ρ_b (g cm^{-3}) is dry bulk density and ρ_s (g cm^{-3}) is the particle density, which was assumed to be 2.65 g cm^{-3}.

In this study there are only bulk density measurements for 15-30 and 30-60 cm and not 0-15 cm in 2010. The reason for this is that soil water retention experiments were being conducted on the 0-15 cm soil samples at the time and could not be dried for bulk density determination. Due to the fact that bulk density determination is usually completed after soil water retention, as completely drying the samples then rewetting would cause hysteresis and alter the soil water retention results.

STATISTICAL ANALYSIS

Statistical analysis conducted were the same for 2010 and 2011. Two separate analyses of the data were conducted each year. The first, a block design with paired data points, to analyze treatment and position of all the agroecosystem watersheds excluding the restored prairie. The second analysis, also with paired data, analyzed the differences in treatment and position between Interim-1 row crop and filter strips and restored prairie adjacent to interim-1. The analysis was done in this manner due to the Interim-1 site having restored native prairie vegetation located directly adjacent to this watershed while the other two watersheds did not.

Statistical analyses were conducted using Statistical Analysis Systems (SAS) software (SAS Institute Inc., Cary, NC). The Shapiro-Wilk test was conducted to test the data for normality. Based on non-normality of the original data the data was log transformed to obtain normality and facilitate statistical analysis. The Proc GLIMMIX procedure was utilized for determination of significance between treatment effects (block, treatment, and position) as well as their interactions. While the data was log transformed for the analysis it was back transformed for reporting of values.

3.4 RESULTS AND DISCUSSION

SATURATED HYDRAULIC CONDUCTIVITY

In 2010, there were no significant differences in the land use or position, nor the interactions between them at any depth tested in both statistical analyses done. There was only a significant difference of block in the all watersheds analysis at the 30-60 cm depth (Table 3.2), which is not to be unexpected since the blocks are located in different parts of the refuge and have varying soil types and slopes. The values obtained appear to be in the general range of those expected as expressed from the web soil survey to a little on the higher side for the soil types. However, important to note is that many of the samples areas lie on arbitrary lines between soil types thus soil properties can varying widely. Also soil type alone does not determine conductivity as other factors such as porosity and biological activity can and do have an influence.

In 2011, there was a significant difference in treatment in the analysis of all watersheds (Table 3.2 and 3.6). Conductivity of the filter strip was greater than that of the row crop. There were no differences however in conductivity at the foot slope and shoulder position. In the 2011 Interim only analysis there were no significant differences of any effect (Table 3.2 and 3.4).

Saturated hydraulic conductivity at the surface is important to soil water. However in 2010 the only analysis that showed any significant differences was the 2010 Interim only analysis. In which there were only significant differences at the lowest soil depth in which row crop was greater than the restored prairie. This is contrary to what would be expected. It was expect that the results from the conductivity tests in the lower depth would be similar to the upper two depth ranges and that PFS and restore prairie would be greater than row crop (Udawatta and Anderson, 2008).

Table 3.2 Analysis of variance of saturated hydraulic conductivity measured from constant head experiments at 0-15, 15-30, and 30-60 cm depth showing effect of block, land use, position, and position*land use

		Depth	0-15 cm		15-30 cm		30-60 cm	
Year	Analysis	Effect	F	*p*	F	*p*	F	*p*
2010	All watersheds							
		Block	0.18	0.84	0.09	0.91	3.59	0.09*
		Land use	0.74	0.42	2.36	0.18	0.08	0.78
		Position	0.09	0.77	0.54	0.49	0.05	0.84
		Position* Land use	0.36	0.57	0.96	0.37	0.59	0.47
	Interim Only							
		Land use	0.55	0.65	0.93	0.52	5.55	0.15
		Position	0.09	0.79	0.75	0.48	0.28	0.65
2011								
	All watersheds							
		Block	2.61	0.15	---	---	---	---
		Land use	3.82	0.10*	---	---	---	---
		Position	0.84	0.39	---	---	---	---
		Position* Land use	0.02	0.88	---	---	---	---
	Interim Only							
		Land use	2.08	0.32	---	---	---	---
		Position	0.15	0.73	---	---	---	---

***Asterisks imply different significant levels for *p* value. (**p*<0.1). The all watershed analysis excludes the prairie.**

Table 3.3 Saturated hydraulic conductivity, Ksat (cm hr^{-1}) land use and slope position in all watersheds (Basswood, Interim, Weaver) at depth ranges 0-15, 15-30, 30-60 cm

Year	Effect		0–15 cm	15-30 cm	30-60 cm
			---------------cm hr $^{-1}$-------------		
2010	Treatment				
		Row Crop	2.13a	0.36a	1.26a
		Filter Strip	4.95a	1.17a	1.47a
	Position				
		Upslope	2.80a	0.49a	1.29a
		Foot slope	3.78a	0.86a	1.44a
	Treatment*Position				
		Row Crop Upslope	2.47a	0.39a	1.46a
		Row Crop Foot slope	1.85a	0.33a	1.09a
		Filter Strip Upslope	3.17a	0.60a	1.13a
		Filter Strip Foot slope	7.73a	2.25a	1.91a
2011	Treatment				
		Row Crop	0.50a	---	---
		Filter Strip	1.75b	---	---
	Position				
		Upslope	1.26a	---	---
		Foot slope	0.70a	---	---
	Treatment*Position				
		Row Crop Upslope	0.64ab	---	---
		Row Crop Foot slope	0.39a	---	---
		Filter Strip Upslope	2.47b	---	---
		Filter Strip Foot slope	1.25ab	---	---

Values with corresponding letters next to them indicate a lack of significant difference at the *p*<0.10 level.

Table 3.4 Saturated hydraulic conductivity, Ksat (cm hr^{-1}) land use and slope position in Interim only at depth ranges 0-15, 15-30, 30-60 cm

Year			0–15 cm	15-30 cm	30-60 cm
			--------------------cm hr^{-1}	--------------	
2010	**Treatment**				
		Row Crop	**1.60a**	**0.29a**	**3.19a**
		Filter Strip	**14.99a**	**2.00a**	**2.72ab**
		Restored Native Prairie	**5.30a**	**0.91a**	**0.40b**
	Position				
		Upslope	**3.84a**	**0.48a**	**1.30a**
		Foot slope	**6.57a**	**1.34a**	**1.75a**
2011	**Treatment**				
		Row Crop	**0.58a**	---	---
		Filter Strip	**6.81a**	---	---
		Restored Native Prairie	**5.47a**	---	---
	Position				
		Upslope	**3.45a**	---	---
		Foot slope	**2.25a**	---	---

Values with corresponding letters next to them indicate a lack of significant difference at the *p*<0.10 level.

Bulk Density

In the all watersheds analysis for experimental year 2010, there were only significant differences in block and no other effects (Table 3.5). In the Interim only analysis there were no significant differences for any effect (Table 3.5).

In 2011 all watersheds analysis there were no significant differences in bulk density of any effect (Table 3.5 and 3.6). In the analysis of Interim only no significant differences were present by any effect either (Table 3.5 and 3.7).

Table 3.5 Analysis of variance of bulk density (g cm^{-3}) measured effect of block, land use, position, and position*land use at depth range 0-15, 15-30, and 30-60 centimeters

		Depth	**0-15 cm**		**15-30 cm**		**30-60 cm**	
Year	**Analysis**	**Effect**	**F**	***p***	**F**	***p***	**F**	***p***
2010	**All watersheds**							
		Block	**---**	**---**	**5.50**	**0.04****	**8.27**	**0.02***
		Land use	**---**	**---**	**0.82**	**0.40**	**0.02**	**0.90**
		Position	**---**	**---**	**1.38**	**0.29**	**2.98**	**0.13**
		Position* Land use	**---**	**---**	**1.48**	**0.27**	**0.01**	**0.92**
	Interim Only							
		Land use	**---**	**---**	**1.36**	**0.42**	**4.01**	**0.20**
		Position	**---**	**---**	**4.65**	**0.16**	**0.68**	**0.50**
2011	**All watersheds**							
		Block	**2.70**	**0.15**	**---**	**---**	**---**	**---**
		Land use	**1.75**	**0.23**	**---**	**---**	**---**	**---**
		Position	**1.75**	**0.23**	**---**	**---**	**---**	**---**
		Position* Land use	**0.06**	**0.81**	**---**	**---**	**---**	**---**
	Interim Only							
		Land use	**0.22**	**0.82**	**---**	**---**	**---**	**---**
		Position	**3.76**	**0.19**	**---**	**---**	**---**	**---**

***Asterisks imply different significant levels for *p* value. (**p<0.05, **p*<0.1). The all watershed analysis excludes the prairie.**

Table 3.6 Bulk density (g cm^{-3}) effects and interactions on all watersheds (Basswood, Interim, Weaver) at depth range 0-15, 15-30, and 30-60 centimeters

Year	Effect		0–15 cm	15–30 cm	30–60 cm
			---------------g cm^{-3}---------------		
2010	Treatment				
		Row Crop	---	1.28a	1.22a
		Filter Strip	---	1.25a	1.23a
	Position				
		Upslope	---	1.28a	1.25a
		Foot slope	---	1.25a	1.20a
	Treatment*Position				
		Row Crop Upslope	---	1.27a	1.24a
		Row Crop Foot slope	---	1.28a	1.20a
		Filter Strip Upslope	---	1.28a	1.25a
		Filter Strip Foot slope	---	1.22a	1.20a
2011	Treatment				
		Row Crop	1.44a	---	---
		Filter Strip	1.41a	---	---
	Position				
		Upslope	1.41a	---	---
		Foot slope	1.44a	---	---
	Treatment*Position				
		Row Crop Upslope	1.43a	---	---
		Row Crop Foot slope	1.45a	---	---
		Filter Strip Upslope	1.39a	---	---
		Filter Strip Foot slope	1.43a	---	---

Values with corresponding letters next to them indicate a lack of significant difference at the $p<0.10$ level.

Table 3.7 Bulk density (g cm^{-3}) effects and interactions on Interim only at depth range 0-15, 15-30, and 30-60 centimeters

Year			0–15 cm	15-30 cm	30-60 cm
			-----------------g cm $^{-3}$---------------		
2010	**Treatment**				
		Row Crop	**---**	**1.25a**	**1.18a**
		Filter Strip	**---**	**1.23a**	**1.20a**
		Restored Native Prairie	**---**	**1.30a**	**1.32a**
	Position				
		Upslope	**---**	**1.29a**	**1.25a**
		Foot slope	**---**	**1.22a**	**1.21a**
2011	**Treatment**				
		Row Crop	**1.39a**	**---**	**---**
		Filter Strip	**1.38a**	**---**	**---**
		Restored Native Prairie	**1.36a**	**---**	**---**
	Position				
		Upslope	**1.34a**	**---**	**---**
		Foot slope	**1.41a**	**---**	**---**

Values with corresponding letters next to them indicate a lack of significant difference at the $p<0.10$ level.

3.5 CONCLUSION

A two year comparison of the soil hydraulic properties of saturated hydraulic conductivity and bulk density was conducted in three watersheds and a restored prairie at the Neal Smith National Wildlife Refuge location in central Iowa. Over the two year study period there were very little significant differences in saturated hydraulic conductivity and bulk density due to land cover and landscape position. Saturated hydraulic conductivity values overall were greater in 2010 than 2011. In the All watersheds analysis 2010 buffer was significantly greater than 2011 buffer and the same was true for row crop. In the Interim only analysis overall 2010 values were also greater than 2011. However when broken down the only treatment which was not significantly lower in 2011 was the prairie. The decreases in 2011 were unexpected. It was expected that 2011 would have similar or improved soil hydraulic properties. It is believed that this could be due to differences in the time during the season in which the samples were taken (Zhou et al., 2008). Samples for 2010 were taken just prior to or at the beginning of spring when the soil was still hard enough to drive on yet soft enough to drive in a soil core. Thus vegetation in the PFS was dead or dormant and not occupying pore space and the row crop area had been exposed to freezing. On the other hand the samples for 2011 were taken well into spring after vegetation within the PFS had begun growing. In 2010, at the 30-60 cm depth range row crop had the highest $K_{sat.}$ Row crop was significantly greater than prairie but not significantly greater than PFS. At the 0-15 cm soil depth range in 2011 PFS had the highest saturated conductivity.

There were no significant differences in bulk density for treatment or location at any depth in both 2010 and 2011.

A limiting variable in this study was the temporal variability in sampling. The sampling occurred over different times in the season and thus different growth stages of the vegetation. A recommendation for future work to obtain a better understanding of the impact PFS have on soil hydraulic properties incorporated within row crop is, all sampling should be conducted at as close to the same time as possible and even possibly more than once throughout the season so that it can be determined how growth stage and thus rooting active affect the soil hydraulic properties of the system.

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CHAPTER 4. GENERAL CONCLUSION

4.1 CONCLUSION

This thesis reports on the effect of various land covers at various topographic positions on soil hydraulic properties of an agroecosystems formerly in Conservation Reserve Program (CRP), based on in-situ and laboratory testing. The investigated agroecosystems contained row crops in no-till corn-soybean rotation incorporated with a mixture of native perennial vegetation in the form of vegetative filter strips with prairie vegetation along the mid slope and/or up slope position and a buffer at the down slope position. Along with the agroecosystems two restored prairies approximately 15-20+ years old were investigated. Soil hydraulic properties tested were unsaturated hydraulic conductivity ($K(\psi)$), saturated hydraulic conductivity (K_{sat}), pore-size distribution, porosity, and bulk density.

Field experiments were conducted in 2010 and 2011 and consisted of Tension infiltrometer at five tensions (ψ = -11, -5, -2, -1, 0 cm H_2O) tested consecutively starting at ψ = -11 cm H_2O progressing towards saturation at ψ = 0 cm H_2O on all the land covers and position. From field experiments unsaturated hydraulic conductivity, $K(\psi)$ and saturated hydraulic conductivity, K_{sat} and pore size distribution were determined. Laboratory experiments consisted of constant head saturated hydraulic conductivity, K_{sat}, bulk density, and porosity.

It was originally hypothesized the investigation would show that the soil properties of the restored prairie would be significantly improved (e.g., greater hydraulic conductivity, porosity, and lower bulk density) over that of the vegetative filter strips and the row crop. It was also hypothesized that the vegetative filter strips would have improved soil properties over the row crop. In-situ and laboratory results varied from one another when comparing field saturated hydraulic conductivity, (K(0)) and saturated conductivity, K_{sat}. In-situ measured conductivity was much larger than laboratory determined conductivity. In most cases in-situ analysis had row crop having greater conductivity while laboratory analysis showed the exact opposite with VFS and restored prairie having the greatest conductivity. Based on results from both in-field and laboratory experiments we reject both hypotheses since there were few significant differences in soil hydraulic properties. Primarily conclusions are reported in the following sections.

4.1.1 FIELD STUDY

Field study results were very different from year to year. Hydraulic conductivities measured in 2011 were significantly greater ($p<0.1$) than in 2010 at tensions ψ = 0, -1, -2, and -5cm H_2O. This is likely due to the variation in time during the season that 2010 and 2011 experiments were conducted. During 2010 greater conductivity was in the row crop at the lowest tensions (ψ = 0 and -1) and greatest in the VFS at the higher tensions while not significant. The only significant difference was at ψ = -5 were VFS was significantly greater than row crop. There were no significant differences in slope position in 2010 for either analysis. In 2011 there was no significant difference in treatment the only significant difference was for position were the upslope position was greater than the foot slope. For the Interim only analysis in 2010 there were no significant differences of treatment or position. Overall the number of pores at all positions within all land uses increased with the exception of one or two from 2010 to 2011. It appears that the total number of pores, including all pore size ranges, favors a greater number of pores in the VFS areas.

4.1.2 LABORATORY STUDY

The laboratory study results showed that saturated hydraulic conductivity values were greater in 2010 than 2011. Likely this is due to differences in the time during the season the samples were taken. In both years, saturated hydraulic conductivity of VFS was greater than row crop; however, it was only significantly greater in 2011. In both years at the surface 0-15 cm soil depth range the VFS had the highest K_{sat} followed by the restored prairie while row crop had the lowest in the Interim only analysis. In 2010, VFS followed by restored prairie had greater K_{sat} at the 15-30 cm depth range. However, at the deepest soil depth range (30-60 cm) row crop had larger K_{sat} then VFS and restored prairie and the difference in K_{sat} between row crop and restored prairie was significant. There were no significant differences in bulk density for treatment or location at any depth in either year.

4.2 PROSPECTS FOR FUTURE RESEARCH

This experiment may have been conducted a little too early to obtain any significant results. The research site had only been established for 4-5 years which is too soon for significant changes according to some previous studies (Schwartz et al. 2003), though it will be able to provide a baseline for research to come. Other studies such as Udawatta et al. (2009) did find significant differences in soil properties within 5 years after establishment of buffers and grassed waterways in row crop watersheds. The factors of location and type of vegetative utilized in the experiments could be a possible explanation as to why significant differences were not found in this study. I believe location had the largest impact; Udawatta et al. (2009) conducted their study on the soils in Missouri which can and are quite different than those within Iowa. Also the average slopes on the watersheds in this study were greater than those of the other study. This thus shows the importance of site location and site characteristics when implementing various conservation practices. The vegetation influences are likely secondary to location and site characteristics. Both studies used a mix of cool and warm season vegetation with various rooting systems though not the exact same plant species. Therefore the establishment may have been very influential. When the prairie vegetation was planted it took some time of establishment to occur some even needed to be replanted. The time it took for some of the plant species to really establish themselves as well as fill in the buffers with dense instead of spotty vegetative cover may have influenced the initial effectiveness and thus the outcomes in the study. I believe as vegetation density and diversity increases that the native prairie vegetation will create changes in the soil hydraulic properties. Experimental year 2010 was quite different from experimental year 2011 in many aspects: 1) the precipitation over the research period was vastly different with 2010 being a very wet year and 2011 being much drier. Dosskey et al. (2007) stated that effectiveness of filter strips can vary substantially year to year due in part to differences in antecedent soil moisture. The second explanation for the differences in experimental year could be time during the season in which sampling and experiments were conducted. In 2010 soil sampling was done early in the year while in 2011 soil sampling was done later. While for field experiments 2010 were conducted later in the growing season than they were conducted in the 2011 growing season. A lot of the variability in sampling was unavoidable because of weather during the season; however, this may be an explanation for the varied results and the significant differences ($p<0.05$) between the two experimental years. Between weather and time of year the experiments were conduct it is predicted that time of year had the greatest influence on the variation in results. Another year of experimentation could have possibly determined which factor had the greatest influence. Further experimentation should be conducted a few years from now to include temporal changes of year and within year. The same laboratory and *in situ* experiments on K_{sat} should be conducted based on plant growth stage; early in the season prior to the beginning of the new growth cycle, mid-season when the growth cycle is in full swing, and late when senescing has or is occurring. This could help to explain the unexpected low conductivity results obtained in the restored prairie and possibly answer the question if root growth has a significant impact on effective porosity during the season.

This study is part of a larger research project which began in 2006 studying the effect of incorporating reconstructed perennial vegetation within row crop agriculture on land formally in CRP. For more details on the entire project, goals, preliminary results and continuously updated research results on hydrology and diversity please consult the project website at http://www.nrem.iastate.edu/research/STRIPs/index.php.

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APPENDIX A: MATERIALS AND METHODS - NEAL SMITH UNDISTURBED SOIL SAMPLING

Procedure for collection of relatively undisturbed soil samples

1. Equipment/Materials Needed:

- Electrical Tape
- Packing Tape
- Tape Measure
- Pens/Permanent Marks
- Labels
- Towel/Paper towels
- Shelby Tubes
- End Caps
- Transport Boxes
- Handheld GPS
- Giddings Rig
- WD40/Vegetable Oil Spray

2. Surface Preparation

At the predetermined sampling locations marked by flags remove any surface debris

3. Extraction/Retraction

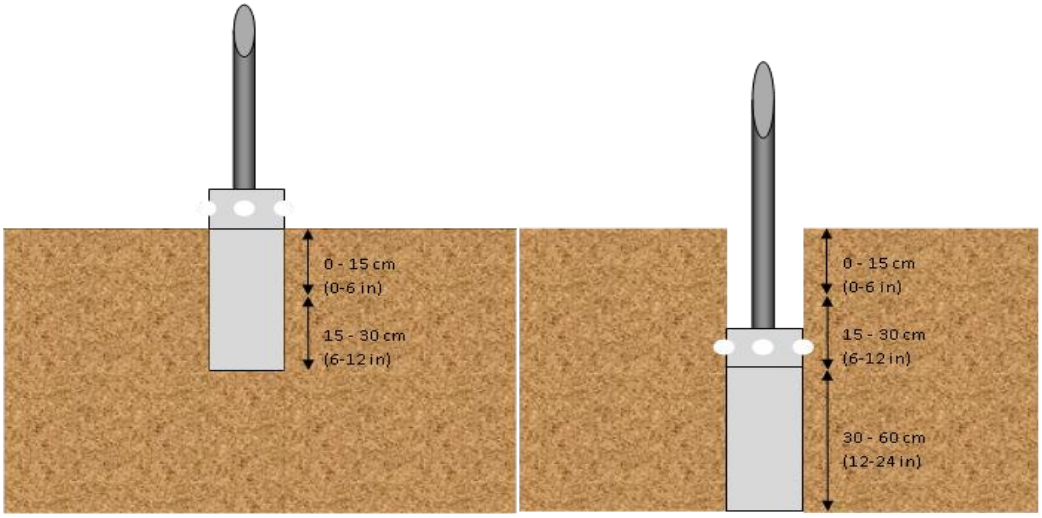
Obtain a clean unused 18” Shelby tube

If needed spray the outside and/or inside of the Shelby tube with WD40 or Vegetable oil to assist with insertion

Mount the Shelby tube to the Giddings rig

Push the Shelby tube mounted to the Giddings rig into the soil without rotation at the predetermined sampling location

Push the Shelby tube into the soil the entire length of the tube (This should be done twice at each location, for a total depth of 24 inches)



To withdraw, slowly rotate and pull the Shelby tube to shear the soil at the bottom and to reduce suction caused by insertion

Place an end cap on the bottom end of the Shelby tube

Carefully remove the Shelby tube from the Giddings rig

Place an end caps on the top of the Shelby tube

4. Labeling

Wipe down the exterior of the core with a towel/paper towel

Wrap both end caps with electrical tape to ensure cap security.

Place the correct label on the Shelby tube

- Project Name
- Sampler(s)
- Sample date
- Sample number and location

Place clear packing tape over the label to ensure the label affixes and won’t come off during transportation and storage

5. Transportation

Make sure there is foam on the bottom of the wooden transport box.

Place wooden box in the transport vehicle before placing cores to minimize core disturbance from excessive movement

Place the sealed and labeled cores in the wooden transport box in the direct they were extracted (bottom down, top up).

Insert extra foam between tubes to prevent movement (For protection against vibration and shock).

Make sure the wooden box with the cores is kept upright in the transportation vehicle and not laid horizontally.

(Due to weight, limited space and difficultly of movement stopped using wooden boxes instead placed tubes back in the cardboard box they came in.)

6. Completion

Before moving on to the next sampling site fill the extraction hole ¾ full with bentonite chips

7. Record Keeping

Use the handheld GPS unit to mark the exact location the sample was taken from

Measure the actual depth of the sampling hole

Measure length of soil actually extracted (length of soil in the tube)

Record Weather conditions

Sampling device used/type

Amount of force used to extract the sample

Soil Condition (Is soil core dripping water? Is ground water present in the hole?)

8. Storage

If all sampling is not complete remove the cores from the wooden boxes and place in the cooler immediate (same day) after returning to the lab.

If all sampling is complete core can remain in the wooden transport boxes and be placed in the cooler

Keep refrigerated at 39.2°F (4°C) until use.

References:

ASTM D 6282-98 Standard Guide for Direct Push Soil Sampling for Environmental Site Characterizations

ASTM D 1587-00 Standard Practice for Thin-Walled Tube Sampling of Soils for Geotechnical Purposes

ASTM 4700-91 Standard Guide for Soil Sampling from the Vadose Zone

ASTM D 4220-95 Standard Practices for Preserving and Transporting Soil Samples

APPENDIX B: MATERIALS AND METHODS - SOIL CORE CUTTING

Post sampling Experimental Preparation

Transport the 45 centimeter core samples from the cooler to the Gilman Machine Shop for cutting (0606 Gilman Hall)

Cut sample from the tubes between sections (0-15 cm, 15-30 cm, and 30-60 cm)

0-12 inch soil core

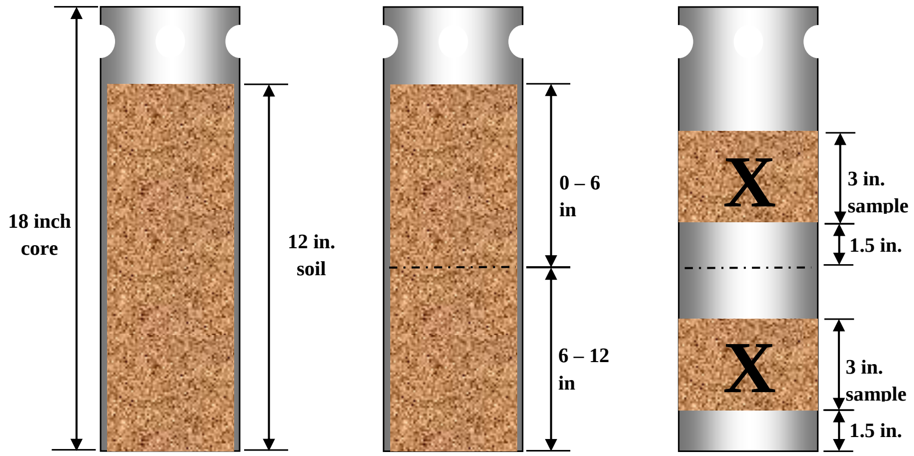
0-6 inch section

- Make a solid line 1.5in (3.8cm) from the bottom of the tube.
- Make another solid line 4.5in from the bottom of the tube.
- Mark an “X” between the two lines this section is the sample core.

6-12 inch section

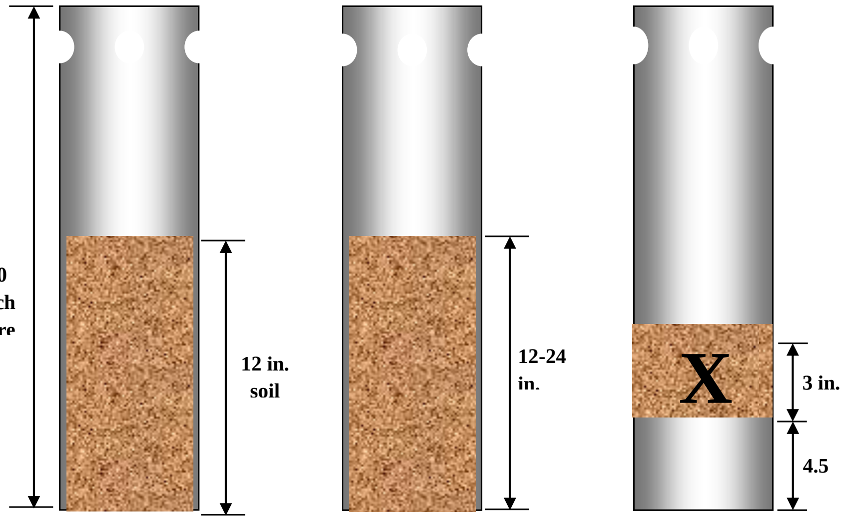
- Measure 7.5in from the bottom of the tube and make a solid line.
- Measure 10.5 in from the bottom of the tube and make another solid line.
- Mark an “X” between the two lines this section is the sample core.

(If the 6-12 inch section is too short due to soil compaction the cut section can be moved down closer to the midsection line as long as the sample core cut has 3 inches or soil.)

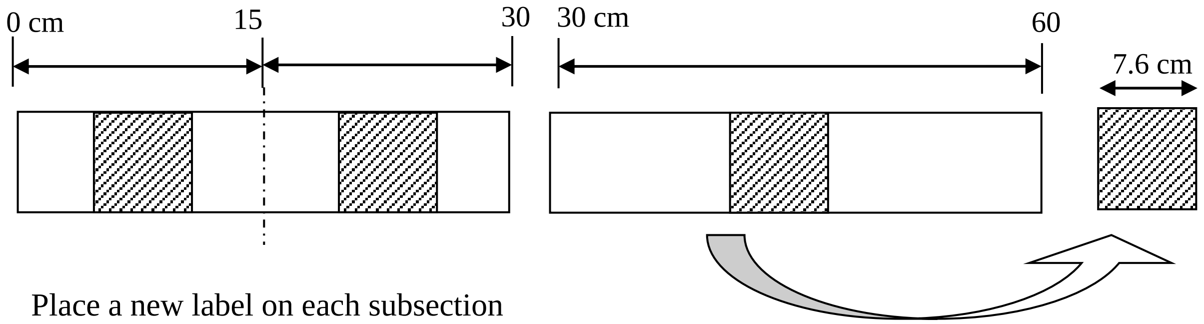


12-24 inch soil core

- Measure 4.5 inches up from the bottom of the core and draw a solid line around the entire circumference of the tube.
- Measure 7.5 inches up from the bottom of the core and draw another solid line around the entire circumference of the tube.
- Mark an “X” between the two lines this section is the sample core.



Cut out the middle 7.6 cm (~3.0 in) of each section



Place a new label on each subsection

- Date sampled
- Sampling Location
- Depth (0-15, 15-30, 30-60 cm)

Wrap the ends with saran wrap and electrical tape

Place cut sections into the cooler until needed

References:

Klute, A. and Dirksen, C. 1986. Hydraulic Conductivity and Diffusivity: Laboratory Methods. Samples and Test Fluid. Methods of Soil Analysis, Part 1. Physical and Mineralogical Methods. Soil Sci. Soc. Am. 28-3:691-694.

APPENDIX C: MATERIALS AND METHODS - EXPERIMENTAL SOLUTION

Solution Preparation

Final Solution: 0.005M Calcium Chloride ($CaCl_2$) 0.06% Formaldehyde (CH_2O)

Equipment:

35 L Nalgene Bottle with spout

Calcium Chloride ($CaCl_2$)

Formaldehyde (CH_2O)

$CaCl_2$ used is anhydrous (no water), 20 Mesh or smaller and CH_2O used is 37% W/W

Calculations:

Calcium Chloride Needed

_35_ L solution **x** 0.005 mol/L $CaCl_2$ = _0.175_ mol $CaCl_2$

_0.175_ mol $CaCl_2$ **x** 110.99 g/mol $CaCl_2$ = **_19.42_** g $CaCl_2$

Formaldehyde Needed

_35_ L solution **x** 0.0006 % by wt. = _0.027_ L CH_20

_0.027_ L CH_2O → _27_mL

_27_ mL CH_2O / 0.37 = **_72.97_** mL CH_2O **x** 0.37

References:

Ochsner, T.E., R. Horton, G.J. Kluitenberg, and Q. Wang. 2005. Evaluation of the Heat Pulse Ratio Method for Measuring Soil Water Flux. Soil Sci. Soc. Am. J. 69:757-765.

APPENDIX D: MATERIALS AND METHODS - SATURATED HYDRAULIC CONDUCTIVITY

Laboratory Hydraulic Conductivity Test Saturated Soils - Constant Head Method

Equipment:

- 100mL Graduated Cylinder
- Filter Paper/scrubber pad
- Digital Calipers
- Duct Tape
- Gauze/Mesh
- Stop Watch
- Funnel
- Empty Soil Ring
- Sample Soil Cores
- Pencil
- Data Sheets

Pre-Experimental preparation:

- Cut out pieces of gauze (or cloth) larger than the circumference of the sample core
- Cut two (2) pieces of tape long enough to wrap completely around the soil core
- Ruffin both sides of the soil using a wire brush
- Measure the soil core length with the digital caliper and record
- Measure the core diameter with the digital caliper and record
- Use the gauze and one piece of tape to secure the bottom of the sample and prevent soil loss.
- Wrap the second piece around the top of the core leaving extra tape above to hold the water head (or tape an empty soil ring top of the soil sample)
- Set the prepared core in a tub of test solution with the level just below the top of the sample for 24 hours to saturate or until sample appear saturated

Experimental Procedure:

Experimental set up

- Place a piece of scrubb pad on top of the soil sample
- Slowly pour water into the upper tape on the soil core until about 2/3 full
- Quickly transfer the core to the rack with the funnel
- Place tube over top of sample and start the Mariotte bottle to maintain constant head (put beaker under funnel to collect solution)

Experimental measurements

- Once the water level had become stable replace the beaker with a 100mL graduated cylinder
- Measure the time, *t* that passes for a water volume, *V* to pass through the sample
- Repeat the previous step three times as needed for accuracy

Post Experiment

- Let the solution drain from the sample
- Remove the core from the rack
- Remove the tape from the core
- Wrap the soil core with saran wrap and electrical tape and place back in the cooler
- Determine Saturated Hydraulic Conductivity

$$K_s = \frac{VL}{At\,(H_2 - H_1)}$$

K_s = Hydraulic conductivity

A = Sample cross sectional area (cm^2)

V = Volume of solution that flows through the cross sectional area of the sample (cm^3)

L = Sample length (cm)

t = time it took to go from H_1 to H_2

$(H_2 - H_1)$ = Imposed hydraulic head difference (cm)

References:

Klute, A. and Dirksen, C. 1986. Hydraulic Conductivity and Diffusivity: Laboratory Methods. Hydraulic Conductivity of Saturated Soils.P. 694-703 Methods of Soil Analysis.Part 1.2nd ed. Agron.Monor. 9. ASA and SSSA, Madison, WI.

APPENDIX E: MATERIALS AND METHODS - SOIL WATER RETENTION AND BULK DENSITY

Water Characteristic Curve - Main Drainage Curve (MDC) Procedure

Equipment:

- Tempe Cells
- Sample Soil Cores
- 250mL Erlenmeyer Flasks
- 1 Bar Ceramic Plates
- Air Compressor
- Electric Scale
- Bubbling Towers
- Drying Oven
- Data Sheets
- Pencil/Pen

Pre-Experimental preparation:

- Clean the inside of the Tempe cell, remove all excess soil particles/dirt etc. from the crevasses and the o-rings
- Remove the o-ring from the side groove of the bottom cap of the Tempe cell make sure it is clean of excess soil particles/dirt etc
- Place a small amount of stopcock grease on the clean, dry o-ring and put it back in the Tempe cell
- Remove the o-ring from the side groove of the top cap of the Tempe cell make sure it is clean of excess soil particles/dirt etc
- Place a small amount of stopcock grease on the clean, dry o-ring and put it back in the Tempe cell

Experimental Procedure:

- Soak the soil cores in the test solution until visibly saturated. (once water reaches the top of the core it is assumed saturated approx. 24 hours for soils with lower clay content, longer for soils with higher clay content)
- Soak porous plate in solution for 24 hours
- Place bottom cap onto the Tempe cell stand and attach to water reservoir (Tygon tubing from 3-way stopcock, spout pointing towards the back of the stand)
- Allow enough water from the reservoir to fill the bottom cap then turn off the water supply (removes air bubbles from the line)
- Place a 1 bar porous plate in the bottom of the bottom cap of the Tempe cell (Make sure there are no air bubbles beneath the plate)
- Carefully press the soil core into the bottom cap of the Tempe cell (Make sure the core is pressed all the way in the cell and has complete contact with the porous plate)
- Place the top cap onto the core (make sure it is pressed completely on the core so no gap exists)
- Hand fasten the top and bottom cap together by screwing butterfly (wing) nuts onto the threaded rods (do not over tighten the nuts)
- Slowly raise the reservoir water level to approximately 15 cm head above the sample core

To ensure saturation of cores or for cores with high clay content apply vacuum

- Connect the tubing from the top of the Tempe cell to a water trap (250 ml Erlenmeyer flask with rubber stopper containing two holes) and another tube from the water trap to the air supply system.

- Once all the Tempe cells are on the stand and connected complete saturation of the cores by turning on the water reservoir and applying 10-kPa vacuum to the top of the soil cores. (saturation can take hours or days depending on soil type)
- Check on the cores regularly to determine if saturation has occurred as the cores become saturated (water raises a few centimeters into tube atop Tempe cell) clamp the tube and turn off the water supply to the individual core.

Applying Tension

- Once all cores are saturated disconnect the Tempe cells from the water traps and water reservoir.
- Connect the Tempe cell directly to the pressure manifold. (Connect tubing atop Tempe cell to pressure valve)
- Clean out the water traps if needed and then fill the 250 ml Erlenmeyer with approximately 75mL water and record the weight.
- Connect the Tempe cell to the drainage system (Connect tubing at the bottom of the Tempe cell to the longer tube atop the Erlenmeyer flask with 75 ml water)
- Apply the desired tension to the Tempe cells

Experimental Measurements

- Connect a flask (with rubber stopper and tubes attached) containing 75mL of water to a empty Tempe cell (not under pressure, cover the inlet) and place it near the cells connected to the pressure system, weigh the flask every 24 hours (Used to measure evaporation)

- Every 24 hours disconnect all the flasks (rubber stopper and tubes attached) from the system, weigh them, record the weight, and reattach the flask to the Tempe cell it was removed from
- Once the core has reach equilibrium (24 hour outflow less than 10% of total outflow at that incremental tension) record total outflow and turn of pressure supply to that core
- Once all the cores have reached equilibrium increase pressure to next step

Post Experiment:

- Remove the core from the Tempe cell
- Measure the weight of the core with the moist soil
- Place the core in the oven and dry at 105°C for 48 hours
- Weigh the oven dried core
- Determine final moisture content

$$\theta = \frac{M_{ws} - M_{ods}}{\rho_w V_s}$$

θ =volumetric water content

M_{ws} = mass of the moist soil

M_{ods} = mass of the oven dried soil

ρ_w = density of water (1.0 g/cm^3)

V_s = volume of soil (volume of core sample, cm^3)

- Determine Total porosity

$$\emptyset = 1 - \frac{\rho_b}{\rho_s}$$

$\emptyset$ =total porosity

ρ_b = soil bulk density ($\rho_b = M_s/V_s$)

ρ_s = particle density ($\rho_s = M_s/V_t$)

(Soil water content at zero pressure is considered to be total porosity calculated)

References:

Dane, J.H. and Hopmans, J.W. Water Retention and Storage: Laboratory. *Methods of Soil Analysis: Physical Methods. Part* 4. 2002. Pg. 671-687

Powers, W.L., House, M.L., Tejral, R.D., Eisenhauer, D.E. 1999. A Simultaneous Data Collection System for Several Soil Water Release Curves. Am. Soc. Ag. Engr. Vol. 15(5): 477-481.

APPENDIX F: MATERIALS AND METHODS - UNSATURATED HYDRAULIC CONDUCTIVITY

In-Field Hydraulic Conductivity Test Unsaturated Soils – Tension Infiltrometer

Method

Equipment:

- Tension Infiltrometers Base
- Tension Infiltrometer Discs
- Computer
- Fine Silica Sand
- HHR Handheld
- Pressure Transducers
- Theta Probe
- Trash Bags
- Water Jugs
- Backpack
- Cheese Cloth
- Datasheets
- Funnel
- Garden Pruner/Clipper
- Infiltrometer Membranes
- Level (1 m & 6 in)
- Logbook & pen/pencil
- Metal Rings
- Carrying Case
    - Datalogger (CR10X)
    - 12 V Battery
    - Wiring
    - Computer Cable
    - Wire Strippers

Soil Surface Preparation

- Clip all vegetation from the surface (Do not pull) and create level surface
- Press the metal ring into the ground were vegetation was clipped
- Take picture of soil surface, note root density and visible pores

- Place piece of cheese cloth a few layer thick over the ring
- Use spray bottle of water to slightly moisten the cheese cloth
- Apply a thin layer of silica sand and use 6in level to make sure sand layer is level (min ~2-3mm)
- Use Theta probe to get three initial soil moisture outside the metal ring around each experimental location

Tension Infiltrometer set-up

- Close the valve on the tube, remove the stopper and fill the Infiltrometer, just below the pressure transducer inlet, using the funnel and jugs of water, place the rubber stopper back into the top
- Place the Infiltrometer close to the metal ring
- Fill a tub with enough water to cover the Infiltrometer disc
- Place the Infiltrometer disc upside down into the tub of water, wet disc membrane and attach it to the disc
- With the disc and membrane submerged in the tub connect the hose from the tension Infiltrometer to the disc
- Remove any air bubbles from the disc then carefully place the disc inside the metal ring with the silica sand
- Using the long level (1m or longer) make sure the disc and water outlet level on the Infiltrometer base are level, if not move the base around until they are level
- Once the disc and base are leveled secure the base in place so it does not tip over

Data collection (Computer and Data Logger):

- Connect push on connector to pressure transducers on Infiltrometers (color coded by cord and Infiltrometer)
- Connect USB interface from datalogger to computer COM port
- Turn on computer
- Open pc200w program (located on desktop)
- Connect battery to datalogger
- Pc200w interface
    a. **click connect** to connect the computer to the datalogger
    b. send program to datalogger
    c. set the clock
    d. click monitor data to make sure transducers are reading properly
- Set tension and turn on Infiltrometers and start experiment
- Document time that tension is changed
- Document when water is added to the Infiltrometer (cannot add water during test only between tensions)
- Save data after ever tension into the tension Infiltrometer folder on the computer desktop
- After all tensions are complete disconnect everything and return to cooler

<u>Data collection (Manual):</u>
(If logger not working it may be necessary to record manually)

- Using data sheets document the tension and starting water level of each Infiltrometer
- Start stopwatch/timer at the same time that the Infiltrometers are started

- When the timer goes off after the predetermined time has passed quickly restart the timer and record the water level of each Infiltrometer
- Repeat for every tension until completion of the experiment

References:

EijkelKamp Agrisearch Equipment. Tension Infiltrometer user manual

APPENDIX G: SOIL WATER RETENTION

G.1 MATERIALS AND METHODS

After completion of K_{sat} experiments soil water retention experiments using the multistep steady state outflow method utilizing Tempe cell (Dane and Hopmans, 2002; Powers. et al., 1999) were carried out. Due to time constraints only the surface 0-15 centimeter depth soil samples from 2010 were used to determine soil water retention. Soil samples were re-saturated using the same method as using in the K_{sat} experiment than each sample was transferred to a tin can and saturated weight was determined. Measurements were taken with an electric scale to accuracy 0.01 grams. The soil samples were mounted in Tempe cells then allowed to drain into 250 mL Erlenmeyer flask under normal atmospheric pressure as shown in Figure G.1. The flasks were removed and weighted at least every twenty four hours until drainage reached approximately zero. After drainage had reached approximately zero ($\leq$ 0.05 gram change) constant pressure was applied to the top of the samples and drainage was again measured every twenty four hours. Pressure remained at the same constant pressure until no more drainage occurred over the twenty four hour period. This process was repeated sequentially for the pressures of 3.8, 7.8, 13.8, 23.8, 43.80, and 103.8 cm water column. Upon completion of the last pressure the soil samples were removed from the Tempe cells and weighed to determine moisture content of final pressure step. Water content at the four pressure steps prior to the final pressure were determined by back calculation from the final step adding back the water that drained out at the previous step.

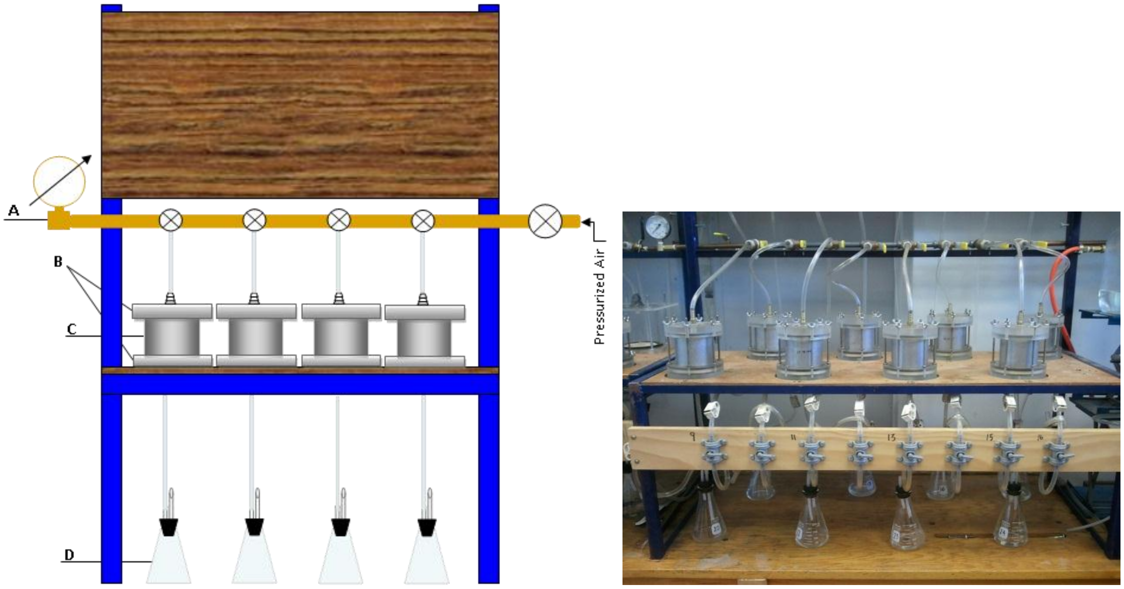


Figure G.1 Soil water retention experimental set up schematic and photo

a)air manifold, b)Tempe cell, c)soil sample, d)Erlenmeyer flask

Drainage total values at each applied pressure from the soil water retention test are used to calculate volumetric water content of the soil at the applied pressure (Equation 2).

$$\boldsymbol{\theta} = \frac{\mathbf{V_w}}{\mathbf{V_t}} \quad (2)$$

Where θ (cm^3 cm^{-3} or dimensionless) is the volumetric water content, V_w (cm^3) is the volume of water within the total sample volume V_t (cm^3).

G.2 RESULTS AND DISCUSSION

To be completed upon completion of experiment

Table G.1. Soil water content, θ (cm^3/cm^3)

	Pressure, h (cm H_2O)	3.8	7.8	13.8	23.8	43.8	103.8
Treatment/Position							
Row Crop Upslope							
	Basswood	0.418	0.409	---	0.407	0.404	0.373
	Interim	0.459	0.439	---	0.439	0.428	0.409
	Weaver	---	---	---	---	---	---
Filter Strip Upslope							
	Basswood	---	---	---	---	---	---
	Interim	0.453	0.421	---	0.418	0.4116	0.3941
	Weaver	---	---	---	---	---	---
Prairie Upslope							
		0.483	0.467	---	0.467	0.463	0.441
Row Crop Foot slope							
	Basswood	---	---	---	---	---	---
	Interim	0.470	0.461	---	0.455	0.441	0.420
	Weaver	---	---	---	---	---	---
Filter Strip Foot slope							
	Basswood	---	---	---	---	---	---
	Interim	0.415	0.406	0.411	0.404	0.401	0.381
	Weaver	---	---	---	---	---	---
Prairie Foot slope							
		0.460	0.439	---	0.439	0.432	0.415

APPENDIX H: RESEARCH NOTES

A total of 112 soil cores taken, 96 from the watersheds (3 watersheds x 16 sample sites x 2 depths) and 16 from prairie (8 sample sites x 2 depths).

Sixteen (16) cores total from each of the three watersheds (Basswood 4, Weaver 2, Interim 1).

Sampling reference location is buffer/row crop interface:

Only 3 of the 4 cores from each location (summit buffer, summit row crop, toe buffer, toe row crop) will be used the 4th will be reserved in case one of the other cores are damaged or unusable.

Eight (8) samples taken from a longer established prairie located next to the Interim sites.

Sampling Locations:

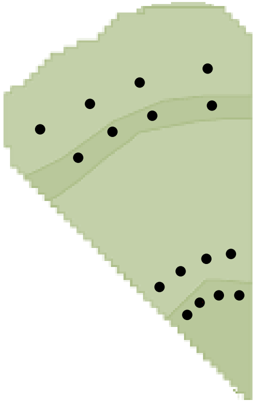
- Three (3) Agroecosystem watersheds
    - Basswood 4
    - Interim 1
    - Weaver 2
        - Upslope (Reference location is buffer/row crop interface)
            - Row Crop: 12 feet upslope of buffer in untrafficked isle
            - Buffer: 12 feet downslope into buffer
        - Downslope (Reference location is buffer/row crop interface)
            - Row Crop: 12 feet upslope of buffer in untrafficked isle
            - Buffer: 12 feet downslope into buffer
- One (1) Re-established Native Prairie
    - Upslope
        - Same contour as the samples to be taken at the upslope position in the Interim watershed.
    - Downslope
        - Same contour as the samples to be taken at the downslope position in the Interim watershed.

Number of Samples:

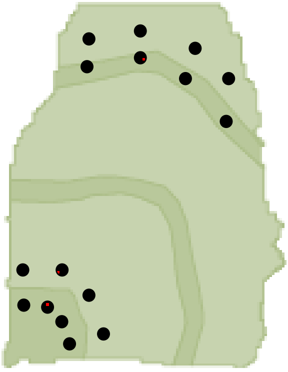
- Agroecosystem watersheds (Basswood 4, Weaver 2, Interim 1):
    - Total sixteen (16) cores per watershed

        - Four (4) samples per treatment-position combination within each watershed
            - (summit buffer, summit row crop, toe buffer, toe row crop)

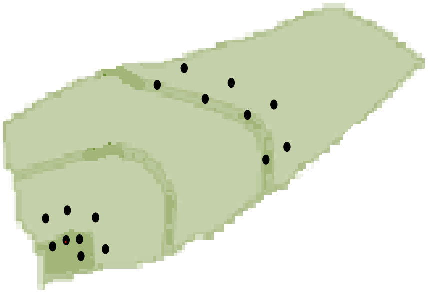
- Re-established Native Prairie
    - Total eight (8) samples taken from established prairie located next to the Interim sites.
        - Four (4) at upslope
        - Four (4) at downslope



Basswood 4



Weaver 2



Interim 1

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To my parents, thank you for teaching me and showing me how to confront adversity head on and to never give up even when things get tough, because the only one who can stop you from succeeding is you.

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