2012

root zone water quality and soil moisture dynamics of biomass cropping systems and landscape positions

Wade Welsh
Iowa State University

Recommended Citation

Welsh, Wade, "root zone water quality and soil moisture dynamics of biomass cropping systems and landscape positions" (2012). *Graduate Theses and Dissertations*. 12510.
http://lib.dr.iastate.edu/etd/12510

Root zone water quality and soil moisture dynamics of biomass cropping systems and landscape positions

By

Wade William Welsh

A thesis submitted to the graduate faculty

In partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Major: Biorenewable Resources and Technology

Program of Study Committee:
Matthew J. Helmers, Major Professor
Thomas M. Isenhart
Lisa A. Schulte-Moore

Iowa State University

Ames, Iowa

2012

TABLE OF CONTENTS

CHAPTER 1. GENERAL INTRODUCTION

CHAPTER 2. ROOT ZONE WATER QUALITY ASSOCIATED WITH VARIOUS BIOMASS CROPPING SYSTEMS AND LANDSCAPE POSITIONS

CHAPTER 3. SOIL MOISTURE DYNAMICS OF VARIOUS BIOMASS CROPPING SYSTEMS AND LANDSCAPE POSITIONS

CHAPTER 4. GENERAL CONCLUSIONS

APPENDIX

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Evaluating the water quality impacts and soil moisture dynamics of biomass production systems is essential to assessing their environmental impacts. The objective of this study is to determine potential water quality and soil moisture impacts of various production systems across different landscape positions. Five production systems are being evaluated: (1) continuous corn, (2) corn-soy/triticale-soy, (3) switchgrass, (4) triticale/sorghum, and (5) triticale/trees, at five landscape locations: (1) summit, (2) shoulder, (3) backslope, (4) toeslope, and (5) floodplain. Each production system is randomly assigned within three replicates at each landscape location. Soil water samples are taken monthly during the growing season from two suction lysimeters per plot at a depth of 60cm. Volumetric soil moisture measurements were taken monthly during the 2010 and 2011 growing seasons from two access tubes at 20 cm intervals to a depth of 120 cm. Significant differences among the cropping systems' NO_3-N concentrations in the root zone were observed with a likely association between nitrogen (N) fertilizer inputs to the systems containing corn. The triticale/sorghum system showed consistently lower NO_3-N concentrations in the root zone than the corn systems, although they received only slightly lower total N fertilizer. Higher NO_3-N concentration in the root zone was also not observed in the switchgrass plots following a significant N input from fertilization. The triticale/trees system had lower moisture and soil water storage in the upper 60 cm of the soil profile than the other systems in April, May, and October 2011, which may indicate increased evapotranspirative demand. The relatively larger amount of stubble and residue in the switchgrass plots may account for the higher moisture levels at the surface in April, May and September 2011. Quantifying environmental impacts of biomass production systems will aid in optimizing deployment as producers gear up to meet biomass production demand.

CHAPTER 1: GENERAL INTRODUCTION

1.1 Introduction

The Energy Independence and Security Act (EISA) of 2007 mandates that 136 billion liters of renewable fuels be produced in the United States annually by the year 2022 with 79 billion liters of this being cellulosic biofuel. The mandate also caps the production of grain based ethanol at 57 billion liters. As producers in the Midwest consider potentially shifting from conventional, first-generation grain-based biofuel feedstocks to advanced, second-generation feedstocks, it is necessary to consider the ecological impacts of these new cropping systems. It is anticipated, that overall, the production of dedicated energy crops will have lower demand for water (Pellegrino et al., 2007; Sokhansanj et al., 2009; Williams et al., 2009) and they show the potential to improve water quality because of fewer fertilizer inputs as well as more efficient use of nitrogen when compared to corn production systems (McLaughlin and Walsh, 1998; Graham, 2007). While there are likely water quality and quantity benefits to be garnered by the conversion of row crop agriculture to perennial biofuel feedstock systems, it is unlikely that these benefits will be the same everywhere on the landscape across all potential biomass cropping systems (Schulte et al., 2006). It is also possible, as Robertson et al. (2008) state, that the benefits of cellulosic crops could be negated by choosing poor locations to grow them. Crops grown on poor quality land may require relatively large inputs of fertilizer and water to make them economically viable, which would reduce the environmental benefit.

Corn stover in the form of residue from corn grain harvest represents a potentially large volume of biomass in the Midwest. Under current farming practices the stover is generally returned to the soil, which aids in protecting the soil from erosion and maintaining soil organic carbon. Large scale removal of corn stover for biofuel production will likely have negative environmental impacts such as increased erosion, reduction of soil quality, and more fertilizer input requirements (Wilhelm et al., 2004; Lal, 2006). Secchi et al., (2011) showed additional negative impacts by predicting that increased use of corn as a biofuel feedstock will have negative water quality impacts in the Upper Mississippi River Basin (UMRB). Their model used increasing value of corn grain from increased demand by biofuel production as the driver to increase the intensity of corn production in the region, which they estimated would increase the quantity of total N and total P at the outlet of the UMRB. This is of interest because increases in nitrate concentration in the Mississippi River from N fertilization of corn for grain production in the Midwest has been shown to be a major contributor to the enlargement of the hypoxic zone in the Gulf of Mexico (Goolsby et al., 1999; Turner and Rabalais, 2003).

A potential solution to this is incorporating a winter cover crop or double crop into the system to protect the soil from erosion, increase water infiltration, and increase evapotranspiration, which could contribute to reduced dissolved nutrient loss, runoff and erosion (Hartwig and Ammon 2002; Heggenstaller et al., 2008). Potential examples include incorporating a small grain (e.g., winter rye [*Secale cereals* L.], winter wheat [*Triticum aestivum* L.], or forage triticale [×*Triticosecale rimpaui* Wittm.]) into a continuous corn or corn-soybean rotation to form a corn/small grain or a corn-soybean-small grain/soybean production system. While these systems show benefits when compared to current systems, there is still concern about the further expansion of corn as a biofuel feedstock because of potential effects of increasing demand on the current food and feed system (Tilman et al., 2009).

Hallam et al. (2001) and Codgill (2008) demonstrated the potential of sorghum as a biomass crop with high yields and composition that allows for efficient conversion to biofuel. A negative aspect of growing sorghum is that it is not well suited to sloping areas due to the high rates of soil erosion on these types of sites (Buxton et al., 1999; Hallam et al., 2001). A winter cover crop incorporated with sorghum may reduce the erosion and make it more viable by reducing its negative environmental impacts (Reinbott et al., 2004).

Perennial plants have also been proposed and studied as energy crops. *Miscanthus* and Switchgrass (*Pancium virgatum)* are two of the herbaceous species that have received much attention as potential biofuel feedstocks (McKendry, 2002). Zhou et al. (2010) showed that nitrate-nitrogen (NO_3-N) concentrations in the vadose zone and shallow groundwater were lower under perennial filter strips than cropland. Woody species have also received attention as biofuel feedstocks in the form of waste from the timber industry as well as dedicated biomass crops (Mann and Tolbert, 2000).

The growth of switchgrass when compared to conventional row crops has been shown to have environmental benefits such as reduced erosion, reduced dissolved nutrient loss, and improved soil quality (Robertson et al., 2008; Diaz-Chavez et al., 2011; Love and Nejadhashemi, 2011). Much of this positive impact is attributed to its reduced fertilizer input requirements and perennial root system (McLaughlin and Kszos, 2005; Diaz-Chavez et al., 2011).

Woody biomass production systems have been shown to have substantial environmental benefits such as reduced erosion and nutrient loss as well as increased habitat to increase species diversity (Kort et al., 1998; Schultz et al., 2004). Kort et al. (1998) also noted that one potential negative impact is that when woody biomass crops mature, they shade out the ground below them. This may result in severe reduction of vegetative undergrowth, which could result in more erosion if the soil is left exposed after harvest of the trees. Another potential drawback of woody biomass crops is that they often lower the water table from their increased evapotranspirative demand. Kort et al. (1998) also noted a study from Australia where a pine plantation reduced the water table level enough to change a naturally perennial stream to an ephemeral stream. While, this will surely reduce water erosion, it is not necessarily beneficially to aquatic habitats and the species that rely on them. It was also noted that the reduction in soil moisture from the increased water demand from the trees can leave a soil more susceptible to wind erosion. The major detriment of growing woody species as a biomass crop lies in the fact that there is significant lag time (up to 10 years) between planting and harvest of a new crop. A potential way to mitigate this is to intercrop the trees with a faster growing species during the establishment of the slower growing trees. This has the potential to increase economic viability by producing biomass during the early, less productive years and may serve to control weed pressure on the woody crops and stabilize the soil (Schulte, 2010).

As Midwest producers gear up to meet the biomass production requirements of the EISA of 2007 there is an opportunity to design and implement biomass production systems that will produce significant economic, environmental, and social benefits (Dale, 2011). It is unlikely that any one of the systems outlined above will be best suited to produce superior biomass and yields and environmental benefits at all landscape locations at all times. After reviewing relevant literature it is clear that there is a need to evaluate the water quality and quantity aspects of biomass cropping systems while also considering their position on the landscape. This research will aid in the design of biomass production systems that perform at high levels when evaluated according to multifunctional criteria (Schulte, 2010).

1.2 Thesis overview

This thesis has been organized with a general introduction followed by two manuscripts, a general conclusion, appendices and acknowledgements. Each article consists of an abstract, introduction, materials and methods, results and conclusion. Chapter two contains a manuscript titled “Root zone water quality associated with various biomass cropping systems and landscape positions.” The objective of this study is to determine potential water quality impacts of various production systems across different landscape positions. Five production systems are being evaluated: (1) continuous corn, (2) corn-soy/triticale-soy, (3) switchgrass, (4) triticale/sorghum, and (5) triticale/trees, at five landscape locations: (1) summit, (2) shoulder, (3) backslope, (4) toeslope, and (5) floodplain. Each production system is randomly assigned within three replicates at each landscape location. Soil water samples are taken monthly during the growing seasons of 2010 and 2011 from two suction lysimeters per plot at a depth of 60 cm. Quantifying the environmental impacts of biomass production systems will aid in optimizing deployment as producers gear up to meet biomass production demand. Chapter three contains a manuscript titled “Soil moisture dynamics of various biomass cropping systems and landscape positions.” The objective of this study is to determine potential differences in soil moisture among the cropping systems and landscape positions during the growing season. The same cropping systems and landscape positions were used as in Chapter two. Soil moisture measurements were taken monthly at 20 cm intervals to a depth of 1.2 m at two access tubes per plot in 2010 and 2011. Quantifying the soil moisture dynamics will aid in optimizing the deployment of biomass cropping systems as producers gear up to meet biomass production demand. Chapter four contains general conclusions drawn from the research and suggests future work in this area. The appendix contains the results of erosion modeling of the research site using the Water Erosion Prediction Project (WEPP) and calibration of soil moisture sensors installed at the research site. The final section serves to acknowledge those who assisted in the work contained in this thesis.

1.3 References

Buxton, D.R., I.C. Anderson, and A. Hallam. 1999. Performance of sweet and forage sorghum grown continuously, double-cropped with winter rye, or in rotation with soybean and maize. *Agronomy Journal.* 91:93-101.

Cogdill, T.J. 2008. Investigation of management strategies for the production of sweet sorghum as a bioenergy crop and preservation of crop residue by the ensiling process. M.S. Thesis. Iowa State University, Ames, Iowa.

Dale, B.E. 2011. Biofuels and water: another opportunity to ‘do biofuels right’. *Biofuels, Bioprod.Bioref.* 5:347-349.

Diaz-Chavez, R., Berndes, G., Neary, D., Neto, A. E., Fall, M. 2011. Water quality assessment of bioenergy production. *Biofuels, Bioprod. Bioref.* 5:445-463.

Goolsby, D.A., and W. A. Battaglin. 2001. Long-term changes in concentrations and flux of nitrogen in the Mississippi River Basin, USA. *Hydrological Processes*. 15: 1209-1226.

Graham, R. L.2007. Forecasting the magnitude of sustainable biofeedstock supplies: the challenges and the rewards. *Biofuels, Bioprod. Biorefin.* 1:255–263.

Hallam, A., I.C. Anderson, and D.R. Buxton. 2001. Comparative economic analysis of perennial, annual, and intercrops for biomass production. *Biomass and Bioenergy.* 21:407- 424.

Hartwig, N.L., and H.U. Ammon. 2002. Cover crops and living mulches. *Weed Science.* 50:688-699.

Heggenstaller, A.H.,R.P. Anex, M. Liebman, D.N. Sundberg, and L.R. Gibson. 2008. Productivity and nutrient dynamics in bioenergy double-cropping systems. *Agronomy Journal.* 100:1740-1748.

Lal, R. 2006. Soil and environmental implications of using crop residues as biofuel feedstock. *International Sugar Journal.* 108:161-167.

Love, B. J., Nejadhashemi, P. 2011. Water quality impact assessment of large-scale biofuel crops expansion in agricultural regions of Michigan. *Biomass and Bioenergy.* 35: 2200-2216.

McLaughlin, S.B., and L.A. Kszos. 2005. Development of switchgrass (*Panicum virgatum*) as a bioenergy feedstock in the United States. *Biomass and Bioenergy.* 28:515-535.

Mc Laughlin, S. B., and M.E. Walsh. 1998. Evaluating environmental consequences of producing herbaceous crops for bioenergy. *Biomass Bioenergy.* 14:317-324.

Pellegrino, J., M Antes, B. Zotter, H. Andres, C. Scher. 2007. Water Impacts from Increased Biofuels Production: An Analysis of Water Issues Based on Future Feedstock Production Scenarios; NREL: Golden, CO.

Reinbott, T.M., S.P. Conley, and D.G. Blevins. 2004. No-tillage corn and grain sorghum responses to cover crop and nitrogen fertilization. *Agronomy Journal.* 96:1158-1163.

Robertson, G.P., V.H. Dale VH, O.C. Doering, et al. 2008. Sustainable biofuels redux. *Science.* 322:49-50.

Schulte, L.A. 2010. Developing A Portfolio Of Sustainable Regional Feedstock Production Systems For The U.S. Midwest. AFRI Project Summary.

Schulte, L.A., M. Liebman, H. Asbjornsen and T.R. Crow. 2006. Agroecosystem restoration through strategic integration of perennials. *Journal of Soil and Water Conservation.* 61:164A-169A.

Sokhansanj, S., S. Mani, A. Turhollow, A. Kumar, D. Bransby, L. Lynd, M. Laser. 2009. Large-scale production, harvest and logistics of switchgrass (*Panicum virgatum* L.) – current technology and envisioning a mature technology. *Biofuels, Bioprod. Biorefin.* 3:124–141.

Tilman, D., R. Socolow, J. Foley, J. Hill, E. Larson, L. Lynd, S. Pacala, J. Reilly, T. Searchinger, C. Somerville, and R. Williams. 2009. Beneficial biofuels – the food, energy, and environment trilemma. *Science.* 325:270–271.

Turner, R. E., and Rabalais. 2003. Linking landscape and water quality in the Mississippi River Basin for 200 years. *BioScience.* 53:563-572.

Wilhelm, W.W., J. M. F. Johnson, J. L. Hatfield, W. B. Voorhees, and D. R. Linden. 2004. Crop and soil productivity response to corn residue removal: a literature review. *Agronomy Journal.* 96:1–17.

Williams, P. R. D., D, Inman, A.Aden, and G.A. Heath. 2009. Environmental and sustainability factors associated with next-generation biofuels in the U.S.: What do we really know? *Environmental Science and Technology*. 43:4763-4775.

Zhou, X., M. J. Helmers, H. Asbjornsen, R. Kolka, and M. D. Tomer. 2010. Perennial filter strips reduce nitrate levels in soil and shallow groundwater after grassland-to-cropland conversion. *Journal of Environmental Quality.* 39:2006-2015.

CHAPTER 2: ROOT ZONE WATER QUALITY ASSOCIATED WITH VARIOUS BIOMASS CROPPING SYSTEMS AND LANDSCAPE POSITIONS

2.1 Abstract

Evaluating the water quality impacts of biomass production systems is essential to assessing their environmental impacts. The objective of this study is to determine potential water quality impacts of various production systems across different landscape positions. Five production systems are being evaluated: (1) continuous corn, (2) corn-soy/triticale-soy, (3) switchgrass, (4) triticale/sorghum, and (5) triticale/trees, at five landscape locations: (1) summit, (2) shoulder, (3) backslope, (4) toeslope, and (5) floodplain. Each production system is randomly assigned within three replicates at each landscape location. Soil water samples are taken monthly during the growing season from two suction lysimeters per plot at a depth of 60 cm. NO_3-N concentrations were significantly different between the production systems with a likely association with fertilizer input. Corn systems had the highest concentrations and the triticale/tree treatment had the lowest. Relative to other systems in this study, high concentrations in the corn plots following fertilization were observed. A similar increase was not observed in the switchgrass or triticale/sorghum systems following fertilizer application. This may indicate that these systems are more efficient at N uptake. Quantifying the environmental impacts of biomass production systems will aid in optimizing deployment as producers gear up to meet biomass production demand.

2.2 Introduction

The Energy Independence and Security Act (EISA) of 2007 mandates that 136 billion liters of renewable fuels be produced in the United States annually by the year 2022 with 79 billion liters of this being advanced biofuel, mostly cellulosic. The mandate also caps the production of grain-based ethanol at 57 billion liters. As producers in the Midwest prepare to shift from conventional, first-generation grain based biofuel feedstocks to advanced, second-generation feedstocks, it is necessary to consider the ecological impacts of these new cropping systems. It is anticipated that overall, the production of dedicated energy crops will improve water quality because of fewer fertilizer inputs as well as more efficient use of nitrogen when compared to corn production systems (McLaughlin and Walsh, 1998; Graham, 2007). While there are likely water quality benefits to be achieved by the conversion of row crop agriculture to perennial biofuel feedstock systems, it is unlikely that these benefits will be the same everywhere on the landscape across all potential biomass cropping systems (Schulte et al., 2006). It is also possible, as Robertson et al. (2008) state, that the benefits of cellulosic crops could be negated by choosing poor locations to grow them. Crops grown on poor quality land may require relatively large inputs of fertilizer and water to make them economically viable, which would reduce the environmental benefit.

Corn stover in the form of residue from corn grain harvest represents a potentially large volume of biomass from the current agriculture system in the Midwest. Under current farming practices the stover is generally returned to the soil which aids in protecting the soil from erosion and maintaining soil organic carbon. Large scale removal of corn stover for biofuel production will likely have negative environmental impacts such as increased erosion, reduction of soil quality, and more fertilizer input requirements (Wilhelm et al., 2004; Lal, 2006). Secchi et al.,

(2011) showed additional negative impacts by predicting that increased use of corn as a biofuel feedstock will have negative water quality impacts in the Upper Mississippi River Basin (UMRB). Their model used increasing value of corn grain from increased demand by biofuel production as the driver to increase the intensity of corn production in the region, which they estimated would increase the quantity of total N and total P at the outlet of the UMRB. This is of interest because increases in nitrate in the Mississippi River from nitrogen fertilization of corn for grain production in the Midwest has been shown to be a major contributor to the enlargement of the hypoxic zone in the Gulf of Mexico (Goolsby et al., 1999 and Turner and Rabalais, 2003).

A potential solution to mitigate some of the negative aspects of intensive row crop farming is incorporating a winter cover crop or double crop into the system to protect the soil from erosion, increase water infiltration, and evapotranspiration which could contribute to reduced dissolved nutrient loss, runoff and erosion (Hartwig and Ammon 2002; Heggenstaller et al., 2008). Potential examples include incorporating a small grain (e.g., winter rye [*Secale cereals* L.], winter wheat [*Triticum aestivum* L.], or forage triticale [×*Triticosecale rimpaui* Wittm.]) into a continuous corn or corn-soybean rotation to form a corn/small grain or a corn-soybean-small grain/soybean production system. While these systems show benefits when compared to current systems, there is still concern about the further expansion of corn as a biofuel feedstock because of potential effects of increasing demand on the current food and feed system (Tilman et al., 2009) and the likely negative environmental impacts (Secchi et al., 2011).

Hallam et al. (2001) and Codgill (2008) demonstrated the potential of sorghum (*Sorghum bicolor* (L.) Moench) as a biomass crop with high yields and composition that allows for efficient conversion to biofuel. A negative aspect of growing sorghum is that it is not well suited to sloping areas due to its high rates of soil erosion on these types of sites (Buxton et al., 1999;

Hallam et al., 2001). A winter cover crop incorporated with sorghum may reduce the erosion and make it more viable by reducing its negative environmental impacts (Reinbott et al., 2004).

Perennial plants, both herbaceous and woody, have also been proposed and studied as energy crops. *Miscanthus* and switchgrass (*Pancium virgatum)* are two of the herbaceous species that have received much attention as a potential biofuel feedstock (McKendry, 2002). Woody species have also received attention as a biofuel feedstock in the form of waste from the timber industry as well as dedicated biomass crops (Mann and Tolbert, 2000).

The growth of switchgrass when compared to conventional row crops has been shown to have environmental benefits such as reduced erosion, reduced dissolved nutrient loss, and improved soil quality (Diaz-Chavez et al., 2011, Robertson et al., 2008, Love and Nejadhashemi, 2011). Much of this positive impact is attributed to its reduced fertilizer input requirements and perennial root system (McLaughlin and Kszos, 2005 and Diaz-Chavez et al., 2011).

Woody biomass production systems have been shown to have substantial environmental benefits such as reduced erosion and nutrient loss as well as increased habitat to increase species diversity (Kort et al., 1998; Schultz et al., 2004). Kort et al. (1998) also noted that one potential negative impact is when woody biomass crops mature, they shade out the ground below them which results in severe reduction of vegetative undergrowth that could result in more erosion if the soil left is exposed after harvest of the trees. Another potential drawback of woody biomass crops is that they often lower the water table from their increased evapotranspirative demand. Kort et al. (1998) also noted a study from Australia where a pine plantation reduced the water table level enough to change a naturally perennial stream to an ephemeral stream. While, this will surely reduce water erosion, it is not necessarily beneficially to aquatic habitats and the species that rely on them. It was also noted that the reduction in soil moisture from the increased water demand from the trees can leave a soil more susceptible to wind erosion. The major detriment of growing woody species as a biomass crop lies in the fact that there is significant lag time (up to 10 years) between planting and harvest of a new crop. A potential way to mitigate this is to intercrop the trees with a faster growing species during the establishment of the slower growing trees. This has the potential to increase economic viability by producing biomass during the early, less productive years and may serve to control weed pressure on the woody crops and stabilize the soil (Schulte, 2010).

As Midwest producers gear up to meet the biomass production requirements of the EISA of 2007 there is an opportunity to design and implement biomass production systems that will produce significant economic, environmental, and social benefits (Dale, 2011). It is unlikely that any one of the systems outlined above will be best suited to produce superior biomass and yields and environmental benefits at all landscape locations at all times. After reviewing relevant literature it is clear that there is a need to evaluate the water quality aspects of biomass cropping systems while also considering their position on the landscape. The objective of this study is to evaluate NO_3-N concentrations in the root zone of various biomass cropping systems across landscape positions. This research will aid in the design of biomass production systems that perform at high levels when evaluated according to multifunctional criteria (Schulte, 2010).

2.3 Materials and methods

2.3.1 Research site

The research site is located in Story County, Iowa, approximately 15 km Southwest of the city of Ames (Figure 2.1). A randomized, replicated block experiment has been established to compare five biomass systems across five landscape positions (summit, shoulder, backslope, toeslope and floodplain). There is a 20 m elevation difference from the summit to the floodplain position, ranging from 325 m to 305 m above sea level. Each biomass production system is randomly assigned within each of three blocks at each landscape position for a total of 75 plots. All plots in the upper four landscape positions have slope lengths of 24.4m (80 ft) and widths of 18.3m (60 ft) and those in the floodplain have slope lengths of 18.3m (60 ft) and widths of 24.4m (80 ft). Each plot has an area of 0.5 ha (0.11 ac) and there is a 6m (19.7 ft) buffer between plots to accommodate equipment and isolate plots. The buffer around the tree plots is at least 18.3 m (60 ft) to accommodate the larger above and below ground influence of the trees. Areas between the plots have been planted in tall fescue which establishes quickly, stabilizes the soil and is tolerant of equipment traffic. Treatments were established at the site from the fall of 2008 to the spring of 2009. Prior to this, the upland portions of the research site were managed under a corn – soybean rotation and the downslope portions of the floodplain position consisted of mixed grasses.

2.3.2 Biomass cropping systems

The five biomass cropping systems being evaluated are (1) continuous corn (*Zea mays*), (2) corn-soybean-triticale/soybean (*Zea mays-Glycine max-Glycine max*/×*Triticosecale)* (3) corn-switchgrass (*Zea mays-Pancium virgatum),* (4) triticale/sorghum (×*Triticosecale*/*Sorghum bicolor*), and (5) triticale/trees (×*Triticosecale* / *Populus alba X P. grandidentata*). Specific biomass systems were selected based on their compatibility with existing agricultural systems and their potential to provide either superior biomass yields (triticale/sorghum), some biomass yield while mitigating some negative environmental impacts (corn-soybean-triticale/soybean, corn-switchgrass), or some short-term biomass yield and superior long-term yield while strongly mitigating negative environmental impacts (triticale/trees) compared to conventional corn production systems. All cropping systems are managed using no till practices. The continuous corn system serves as a baseline from which to compare the alternative biomass cropping systems. Corn-switchgrass is an intercropping system in which corn provided weed control and a harvestable crop of grain and stover in the first year (2009) as the switchgrass was established. Corn-soybean-triticale/soybean supplements the conventional corn-soybean rotation with a winter triticale biomass crop. Triticale is planted the September following the first soybean harvest, serves as a winter cover crop reducing exposure of soil to water and wind erosion, and is then harvested as a biomass crop in the early summer; it is followed immediately by soybean which is then harvested for grain in the fall. Triticale/sorghum is a double-cropping system in which winter triticale is planted in the fall and then harvested the following June. After triticale harvest, sorghum is planted into its stubble and harvested in September. Triticale/trees is an intercropping system in which winter triticale was planted in October before the trees are planted in May. Triticale is then harvested from between the tree rows as a biomass crop in early July, providing biomass productivity and a harvestable crop while the high-yield aspen trees (Crandon clone) are establishing. Triticale is then replanted between rows in the fall (Schulte, 2010).

2.3.3 Landscape positions

Five landscape positions, including (1) summit, (2) shoulder, (3) backslope, (4) toeslope, and (5) floodplain, are being evaluated for this study (Figure 2.2a). The summit position consists of four soil types. Block one has three plots on Zenor sandy loam and two plots on Clarion loam. All plots in block two are in Nicollet loam and all plots in block three are in Clarion loam. The shoulder position is dominated by Clarion loam however; half of the first replicate is in Zenor sandy loam. All of the backslope landscape position is planted in Clarion loam. The toeslope position has replicate one in Spillville loam and replicates two and three in Clarion loam. All of the floodplain position is in Coland clay loam (Figure 2.2b).

As described by the National Cooperative Soil Survey of the United States, Clarion series consists of very deep, moderately well drained soils on uplands. These soils were formed in glacial till and have slopes that range from 1 to 9 percent. The Coland series consists of very deep, poorly drained soils formed in alluvium. These soils are on floodplains and alluvial fans in river valleys and upland drainage ways in dissected till plains. Slope ranges from 0 to 5 percent. The Nicollet series consists of very deep, somewhat poorly drained soils that formed in calcareous loamy glacial till on till plains and moraines. Slopes range from 0 to 5 percent. The Spillville series consists of very deep, moderately well drained or somewhat poorly drained soils formed in dark colored, medium-textured alluvium. Spillville soils are on nearly level flood plains and gently sloping footslopes on uplands. Slope ranges from 0 to 5 percent. The Zenor series consists of very deep, somewhat excessively drained, moderately rapidly permeable soils formed in glacial outwash on uplands and, less commonly, on stream benches. Slope ranges from 2 to 30 percent.

2.3.4 Data collection

To measure NO_3-N concentrations in the root zone, two porous cup suction lysimeters (Model 1920F1L24, Soilmoisture Equipment Corp., Santa Barbara, CA) were installed per plot. Holes were vertically cored using a 5 cm auger and were at least 8 m from the edges of the plot and the other lysimeter in the plot. Soil from the cored hole was sieved through a 2mm sieve and mixed with water to create a slurry which was poured back into the hole prior to inserting the lysimeter to ensure good soil contact with the porous cup. Bentonite clay was placed 10 cm below the surface to seal around the lysimeter tube to prevent preferential flow to the porous cup. A threaded PVC cap was placed at ground level over the lysimeter to allow access and protect it from farming operations. Native soil removed from the sample site was then used to backfill around the lysimeter and cap as necessary to fill voids. Negative tension (-55 kPa) was applied using a hand vacuum pump and water samples are extracted approximately 1 week later. Composite samples from each pair of lysimeters were acidified using 1 mL (per 145 mL sample) 10% H_2SO_4 and refrigerated at 4^oC before analysis. Nitrate-nitrogen concentrations in the samples were determined by the automated flow injection Cadmium Reduction method using a Lachat Quickchem 8000 Automated Ion Analyzer system with a 0.1 mg L^{-1} detection limit (Lachat Instruments, Milwaukee, WI). Nitrate was reduced to nitrite by a cadmium/copper column. Nitrite was diazotized with sulfanilamide and then reacted with N-(1-naphthyl-)-ethylenediamine dihydrochloride at a pH of 8.5 to form a colored (pink to red) azo compound, whose intensity is proportional to the amount of nitrate plus nitrite in the sample. Nitrite was assumed to be negligible. Measurements were made with a colorimeter at a wavelength of 520 nm. Concentrations in samples were determined by comparing sample absorbance with those obtained from a calibration curve comprised of standards containing NO_3-N concentrations from 0.25 to 30.0 mg NO_3-N L^{-1}. Samples with concentrations above 30 mg NO_3-N L^{-1} were determined by diluting the samples and calculating actual concentration in the original sample.

Precipitation was monitored at the Iowa State University South Reynoldson Farm (1.5 km SE of research site). Precipitation data was collected from April 1st to October 31st of each year. Water samples were taken once per month, on average, throughout the growing season. Samples were taken on June 7th, July 9th, August 3rd, September 4th, and October 14th in 2010, and April 21st, May19th, June15th, July14th, August 9th and September 9th in 2011. There were no samples available for collection in October 2011 due to dry conditions.

2.3.5 Statistical analysis

Data was analyzed with the SAS statistical Software Package (SAS Institute, 2001) using the MIXED procedure to perform the analysis of variance. We tested differences among NO_3-N concentrations between experimental treatments (continuous corn, corn-soy-triticale/soy, switchgrass, and triticale/trees), landscape position (summit, shoulder, backslope, toeslope, and floodplain) and month. Interactions among the variables were also tested. Statistical significance was evaluated at $P \leq 0.05$. Means were separated using a least significant difference when effects were significant. Data was analyzed for each year as well as each month separately to determine seasonal effects.

2.4 Results and discussion

Precipitation between the two years was similar and consistent with the 20 year average from mid-April until early June. After this time, 2010 saw much more precipitation than 2011 (Figure 2.3). Overall, 2011 remained very close to the 20 year average during the study period while 2010 had double the 20 year average amount of precipitation from early June to the end of October.

Overall, during both 2010 and 2011, there was a treatment and month effect as well as an interaction between the treatment and the month on NO_3-N concentration in the root zone (Table 2.1). In 2010, the months of June and July had higher NO_3-N concentrations than October and September (Table 2.2). August had higher concentrations than June and lower than October and September. There was a general decline in NO_3-N concentration from June to October in 2010 (Figure 2.4a and 2.5a). The decrease in NO_3-N concentrations as the season progressed are likely attributable to dilution, leaching, and plant uptake (Zhou et al, 2010). NO_3-N concentrations were higher in July, than all other months in 2011 (Figure 2.4b and 2.5b). There was a decrease in NO_3-N concentration at the end of the growing season in 2011. There were no overall, annual landscape position effects on the NO_3-N concentrations. There was also no observed interaction between the treatment or landscape position or the landscape position and the month. The upper four landscape positions (summit, shoulder, backslope, and toeslope) had lower NO_3-N concentrations than the floodplain positions in October 2010 (Table 2.3b). It is possible that there were higher rates of mineralization at the floodplain position from higher levels of organic matter potentially due to previous land use (mixed grasses in floodplain vs. row crop in other landscape positions). No other differences among the landscape positions were observed in any month in 2010. Similar results were observed in April 2011 as in October 2010, where the upper four landscape positions had lower NO_3-N concentrations than the floodplain positions (Table 2.3b). The shoulder positions also had lower concentrations than the toeslope positions in April 2011. These were the only differences in NO_3-N concentrations among the landscape positions in any month in 2011.

Generally, the systems with corn in the crop rotation and their associated higher nitrogen fertilizer inputs showed higher NO_3-N concentrations in the root zone (Table 2.3a). The continuous corn cropping systems had higher NO_3-N concentrations than the other treatments in July 2010 (Figure 2.5). Similar results were observed in June 2010, but there were not enough samples collected for statistical analysis. There was 150 kg N/ha applied to all continuous corn plots on May 7th, 2010, which is likely a major factor for the higher NO_3-N concentrations in the root zone in June and July, 2010. In August 2010, the triticale/sorghum systems had higher NO_3-N concentrations than all other treatments, which are likely associated with the addition of 100kg N/ha to these plots on July 1st, 2010. The continuous corn systems had higher concentrations than the switchgrass and triticale/trees systems in August, 2010, which is likely still a result of the May 7th fertilization. The corn-soy-triticale/soy systems had higher NO_3-N concentrations than the triticale/trees systems in August 2010. In September 2010, the sorghum/triticale and corn/soy-triticale-soy systems had higher concentrations than the switchgrass and triticale/trees systems. The corn-soy-triticale/soy system had higher NO_3-N concentrations than all other treatments in October 2010. While there were differences among the treatments during September and October, the concentrations were significantly lower during these months than in June, July and August. During April, 2011, the corn-soy-triticale/soy and continuous corn systems had higher concentrations of NO_3-N than the switchgrass and triticale/trees systems, which may be associated with the prior year fertilizations. The triticale/sorghum system also had higher NO_3-N concentrations than the switchgrass and triticale systems. The switchgrass plots did not receive any nitrogen fertilizer in 2010, which could explain this difference and low NO_3-N concentration for this system. May 2011 results were similar with the continuous corn and corn-soy-triticale/soy systems having higher concentrations than the triticale/trees system. The switchgrass and triticale/sorghum systems had concentrations that were less than continuous corn, not different than corn-soy-triticale/soy and greater than triticale/trees. The months of June, July and August 2011 all had the continuous corn and corn-soy-triticale/soy systems with higher NO_3-N concentrations than the other three systems, although there were not enough samples collected in August to determine statistical differences. The peak concentrations of NO_3-N in the corn plots were higher in 2011 (47.3 mg L^{-1}) than in 2010 (23.7 mg L^{-1}). This may be attributed to higher levels of fertilizer application in 2011 (168 kg/ha in 2011, 150kg/ha in 2010), more dilution and leaching from high levels of precipitation in 2010, more mineralization in 2011, and accumulation of nitrogen from fertilization in the systems (Zhou et al., 2010). There were not enough samples collected in September 2011 to determine differences among the treatments and there were no samples to be collected in October 2011 due to dry conditions.

On May 11, 2011 there was 124 kg N/ha applied to the switchgrass plots, though no large rise in root zone NO_3-N concentrations was observed as in the corn plots following addition of nitrogen fertilizer. This is likely attributed to greater uptake and/or immobilization of switchgrass in nitrogen uptake. Randall et al., (1997) reported 37 X higher NO_3-N loss through subsurface drainage under corn than perennial crops used in the conservation reserve program. It is also consistent with Zhou et al. (2010) who showed that NO_3-N concentrations in the vadose zone and shallow groundwater were lower under perennial filter strips than cropland. The double cropping system of triticale/sorghum had only slightly lower total annual N fertilization than the corn plots (130kg/ha vs 150 kg/ha in 2010 and 160kg/ha versus 168kg/ha in 2011, respectively); however, they consistently showed significantly lower NO_3-N concentrations in the root zone, with the exception of August 2010, when the two were not significantly different. This could be partially attributed to the total application of N fertilizer was split between a spring fertilization of the triticale (30kg/ha in 2010 and 33.6kg/ha in 2011) and a larger summer application following the planting of sorghum (100kg/ha in 2010 and 112kg/ha in 2011). Other likely contributing factors to the lower NO_3-N concentrations in the triticale/sorghum system are the longer period of the growing season when N is being taken up by the plants as well as the high N uptake efficiency of the sorghum (Lovelli et al., 2008). Another possible explanation for this is the relatively lower precipitation following application of fertilizer in 2011 versus 2010, which may not have transported the NO_3-N to the 60 cm collection depth. There was also likely some loss to volatilization since the fertilizer was surface applied in granular urea form and there was little precipitation following application. No-till practices may have also hindered the movement of the surface applied fertilizer to the root zone because of higher compaction when compared to conventional till systems.

To put these values in context, the standard for NO_3-N concentration in surface waters used as a source for drinking water is 10 mg L^{-1} (USEPA, 1986) and it is recommended that total nitrogen concentrations in streams and rivers remain below 3.26 mg L^{-1} to prevent potential damage to aquatic ecosystems in this area (ecoregion VI, sub-ecoregion 47) (USEPA, 2000). There was never an observed value over either of these in the triticale/trees system and the corn treatments remained consistently above both. Switchgrass generally remained below both USEPA values; with the exception of three months (of 11) it had NO_3-N concentrations above the recommendations for preventing damage to aquatic ecosystems, but below the drinking water source standard. The triticale/soy treatment generally had NO_3-N concentrations near or below the aquatic ecosystem recommendation and the triticale/sorghum system generally had NO_3-N concentrations between the aquatic ecosystem recommendation and the standard for drinking water sources.

2.5 Conclusion

As agricultural producers in the Midwest potentially consider shifting from grain based biofuel feedstocks to second-generation, cellulosic feedstocks it is essential that we assess the environmental impacts of these new cropping systems. We have studied the effect of various biomass production systems across landscape positions on NO_3-N concentration in the root zone. While others have shown impacts from the landscape location of biomass crops, we did not observe a definitive landscape effect to this point in this study on NO_3-N concentration. We did observe significant differences among the cropping systems, with a likely association between nitrogen fertilizer inputs to the systems containing corn and NO_3-N concentrations in the root zone. The triticale/sorghum system showed consistently lower NO_3-N concentrations in the root zone than the corn systems although they received only slightly lower total N fertilizer. A rise in NO_3-N concentration in the root zone was also not observed in the switchgrass plots following a significant N input from fertilization. This may indicate that the triticale/sorghum double cropping system and the perennial switchgrass systems are more efficient at N uptake or that the NO_3-N did not get transported to the root zone. Quantifying the environmental impacts of biomass production will aid in optimizing the future deployment of biofuel feedstocks by providing part of the information needed to assess their multifunctional performance. It would be beneficial to expand this study into the future to refine and expand on observed differences among the biomass production systems. This would facilitate a more full understanding of the perennial cropping systems which should aid in them demonstrating their full potential.

2.6 References

Buxton, D.R., I.C. Anderson, and A. Hallam. 1999. Performance of sweet and forage sorghum grown continuously, double-cropped with winter rye, or in rotation with soybean and maize. *Agronomy Journal.* 91:93-101.

Cogdill, T.J. 2008. Investigation of management strategies for the production of sweet sorghum as a bioenergy crop and preservation of crop residue by the ensiling process. M.S. Thesis. Iowa State University, Ames, Iowa.

Dale, B.E. 2011. Biofuels and water: another opportunity to 'do biofuels right'. *Biofuels, Bioprod.Bioref.* 5:347-349.

Diaz-Chavez, R., Berndes, G., Neary, D., Neto, A. E., Fall, M. 2011. Water quality assessment of bioenergy production. *Biofuels, Bioprod. Bioref.* 5:445-463.

Goolsby, D.A., and W. A. Battaglin. 2001. Long-term changes in concentrations and flux of nitrogen in the Mississippi River Basin, USA. *Hydrological Processes*. 15: 1209-1226.

Graham, R. L.2007. Forecasting the magnitude of sustainable biofeedstock supplies: the challenges and the rewards. *Biofuels, Bioprod. Biorefin.* 1, 255–263.

Hallam, A., I.C. Anderson, and D.R. Buxton. 2001. Comparative economic analysis of perennial, annual, and intercrops for biomass production. *Biomass and Bioenergy.* 21:407- 424.

Hartwig, N.L., and H.U. Ammon. 2002. Cover crops and living mulches. *Weed Science.* 50:688-699.

Heggenstaller, A.H.,R.P. Anex, M. Liebman, D.N. Sundberg, and L.R. Gibson. 2008. Productivity and nutrient dynamics in bioenergy double-cropping systems. *Agronomy Journal.* 100:1740-1748.

Kort, J., M. Collins, and D. Ditsch. 1998. A review of soil erosion potential associated with biomass crops. *Biomass and Bioenergy.* 14:351-359.

Lal, R. 2006. Soil and environmental implications of using crop residues as biofuel feedstock. *International Sugar Journal.* 108:161-167.

Love, B. J., Nejadhashemi, P. 2011. Water quality impact assessment of large-scale biofuel crops expansion in agricultural regions of Michigan. *Biomass and Bioenergy.* 35: 2200-2216.

Lovelli, S., M. Monteleone, G. Posca, M. Perniola. 2008. Nitrogen balance during Sweet Sorghum cropping cycle as affected by irrigation and fertilization rate. *Italian Journal of Agronomy.* 4:253-260.

McKendry, Peter. 2002. Energy production from biomass (part 1): overview of biomass. *Bioresource Technology*. 83: 37-46.

McLaughlin, S.B., and L.A. Kszos. 2005. Development of switchgrass (*Panicum virgatum*) as a bioenergy feedstock in the United States. *Biomass and Bioenergy.* 28:515-535.

McLaughlin, S. B., and M.E. Walsh. 1998. Evaluating environmental consequences of producing herbaceous crops for bioenergy. *Biomass Bioenergy.* 14, 317-324.

Pellegrino, J., M Antes, B. Zotter, H. Andres, C. Scher. 2007. Water Impacts from Increased Biofuels Production: An Analysis of Water Issues Based on Future Feedstock Production Scenarios. NREL: Golden, CO.

Randall, G.W., D.R. Huggins, M.P. Russelle, D.J. Fuchs, W.W. Nelson, and J.L. Anderson. 1997. Nitrate losses through subsurface tile drainage in conservation reserve program, alfalfa, and row crop systems. *J. of Environmnetal Quality*.26:1240-1247.

Reinbott, T.M., S.P. Conley, and D.G. Blevins. 2004. No-tillage corn and grain sorghum responses to cover crop and nitrogen fertilization. *Agronomy Journal.* 96:1158-1163.

Robertson, G.P., V.H. Dale VH, O.C. Doering, et al. 2008. Sustainable biofuels redux. *Science.* 322: 49-50.

SAS. 2003. SAS User's Guide. Version 9.2. SAS Institute, Inc., Cary, NC.

Schulte, L.A. 2010. Developing A Portfolio Of Sustainable Regional Feedstock Production Systems For The U.S. Midwest. AFRI Project Summary.

Schulte, L.A., M. Liebman, H. Asbjornsen and T.R. Crow. 2006. Agroecosystem restoration through strategic integration of perennials. *Journal of Soil and Water Conservation.* 61:164A-169A.

Secchi, S., P. W. Gassman, M. Jha, L. Kurkalova, C. L. Kling. 2011. Potential water quality changes due to corn expansion in the Upper Mississippi River Basin. *Ecological Applications*, 21(4), pp.1086-1084.

Sokhansanj, S., S. Mani, A. Turhollow, A. Kumar, D. Bransby, L. Lynd, M. Laser. 2009. Large-scale production, harvest and logistics of switchgrass (*Panicum virgatum* L.) – current technology and envisioning a mature technology. *Biofuels, Bioprod. Biorefin. 3*: 124–141.

Tilman, D., R. Socolow, J. Foley, J. Hill, E. Larson, L. Lynd, S. Pacala, J. Reilly, T. Searchinger, C. Somerville, and R. Williams. 2009. Beneficial biofuels – the food, energy, and environment trilemma. *Science.* 325:270–271.

Turner, R. E., and Rabalais. 2003. Linking landscape and water quality in the Mississippi River Basin for 200 years. *BioScience.* 53:563-572.

United States Environmental Protection Agency. 1986. Quality criterion for water. EPA 440/5-86-001 p. 189.

United States Environmental Protection Agency. 2000. Ambient water quality criteria recommendations. EPA 822-B-00-017 p. vi.

Wilhelm, W.W., J. M. F. Johnson, J. L. Hatfield, W. B. Voorhees, and D. R. Linden. 2004. Crop and soil productivity response to corn residue removal: a literature review. *Agronomy Journal*. 96:1–17.

Williams, P. R. D., D, Inman, A.Aden, and G.A. Heath. 2009. Environmental and sustainability factors associated with next-generation biofuels in the U.S.: What do we really know? *Environmental Science and Technology*. 43:4763-4775.

Zhou, X., M. J. Helmers, H. Asbjornsen, R. Kolka, and M. D. Tomer. 2010. Perennial filter strips reduce nitrate levels in soil and shallow groundwater after grassland-to-cropland conversion. *Journal of Environmental Quality*. 39:2006-2015.

Table 2.1. Effect of treatment, landscape position, and month on NO_3-N concentration.

2010

Treatment	Landscape position	Month	Treatment X Landscape position	Treatment X month	Landscape position X month
$p<0.0001$	$p=0.0982$	$p<0.0001$	$p=0.3465$	$p<0.0001$	$p=0.8778$
5<2=4<1, 3<1		JUN=JUL<OCT=SEPT, JUN<AUG<OCT=SEPT			
2011					
$p<0.0001$	$p=0.0528$	$p<0.0001$	$p=0.2227$	$p<0.0001$	$p=0.5096$
5=3<2=1, 5<4<2=1		JUN=APR=MAY=AUG<JUL			

Treatment: 1-cont. corn, 2-corn-soy-triticale/soy, 3-switchgrass, 4-triticale/sorghum, 5-triticale/trees

Table 2.2. Monthly effects of treatment and landscape position on NO_3-N concentration.

Month	Treatment	Landscape position	Treatment X Landscape position
		2010	
June	not enough data to compare		
July	p<0.0001 5=4=2=3<1	p=0.6050	p=0.6491
August	p<0.0001 5<1<4, 3=2<4, 3<1	p=0.1568	p=0.6661
September	p=0.0094 3=5<2=4	p=0.3788	p=0.2966
October	p<0.0001 4=3=5=1<2	p<0.0001 1=3=2=4<5	p<0.0001
		2011	
April	p<0.0001 5=3<4<2, 5=3<1	p<0.0001 2<1=3=4<5	p=0.1110
May	p=0.0232 5=3<1,5<2, 4<1	p=0.2873	p=0.8556
June	p=0.0176 5=4=3<1=2	p=0.9636	p=0.9721
July	p<0.0001 5=3=4<2=1	p=0.3871	p=0.3196
August	not enough data to compare		
September	not enough data to compare		

Treatment: 1-cont. corn, 2-corn-soy-triticale/soy, 3-switchgrass, 4-triticale/sorghum, 5-triticale/trees

Landscape positon: 1-summit, 2-shoulder, 3-backslope, 4-toeslope, 5-floodplain

Table 2.3. Comparison of NO_3-N by (a) treatment and (b) landscape position.

Comparison of NO_3-N concentrations by treatment

(a)	April	May	June	July	August	September	October
			2010				
continuous corn			21.9	23.7 b	6.2 c	2.3 ab	1.0 a
corn-soy-**trit/soy**			##	1.5 a	3.7 bc	3.2 b	4.1 b
switchgrass	#	#	7.6 ##	2.6 a	0.5 ab	0.1 a	0.4 a
sorghum/trit			##	1.1 a	10.8 d	3.3 b	0.3 a
trees			1.9	0.0 a	0.0 a	0.2 a	0.4 a
			2011				
continuous corn	9.6 cd	17.7 c	8.6 b	47.3 b	##	##	
corn-soy-trit/soy	11.6 d	12.4 bc	13.5 b	34.2 b	##	##	
switchgrass	3.2 a	6.1 ab	3.1 a	6.4 a	1.4 ##	0.7 ##	#
sorghum/trit	7.6 bc	7.4 ab	2.5 a	6.5 a	6.3	4.0	
trees	2.1 a	1.4 a	0.1 a	0.3 a	0.4	0.5	

Comparison of NO_3-N concentrations by landscape position

(b)	April	May	June	July	August	September	October
			2010				
Summit			##	4.4 a	2.6 a	0.6 a	0.6 a
Shoulder			6.8	5.2 a	3.0 a	1.7 a	0.7 a
Backslope	#	#	5.6 ##	6.4 a	2.7 a	2.5 a	0.6 a
Toeslope			9.3	6.9 a	6.4 a	1.6 a	0.9 a
Floodplain			##	5.9 a	6.7 a	2.8 a	3.5 b
			2011				
Summit	4.7 ab	6.1 a	3.7 a	21.6 a	##	##	
Shoulder	4.5 a	11.0 a	6.5 a	24.2 a	##	##	
Backslope	4.9 ab	4.5 a	6.0 a	10.9 a	3.9 ##	## ##	#
Toeslope	7.7 b	15.6 a	6.3 a	20.7 a	##	0.5	
Floodplain	12.3 c	8.0 a	5.2 a	17.4 a	##	2.6	

LS Means estimate of NO_3-N concentration (mg/L), Different letters in same month and year indicate difference at $p<0.05$, # no samples collected, ## not enough data for statistical analysis

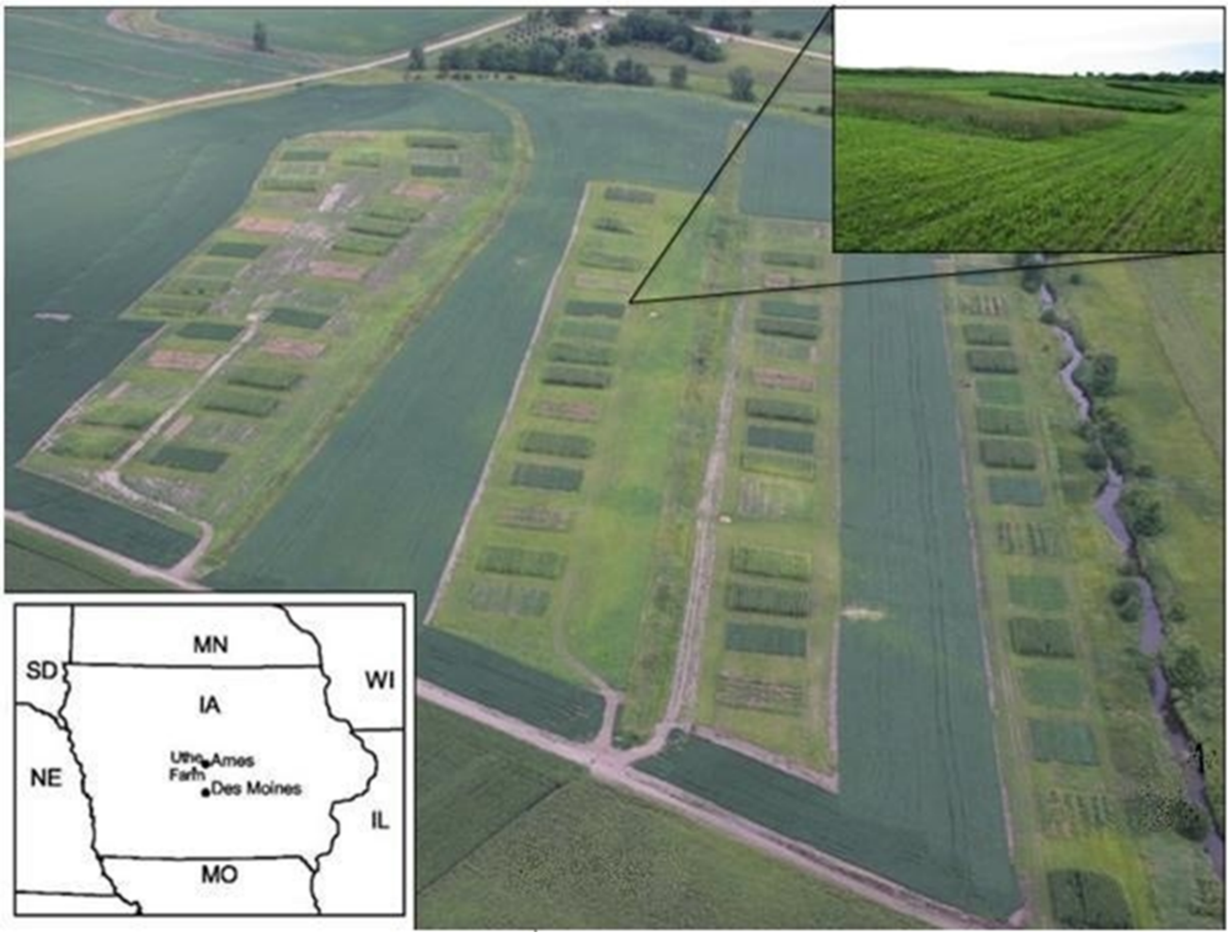


Figure 2.1. Iowa State University Uthe research farm (Schulte, 2010)

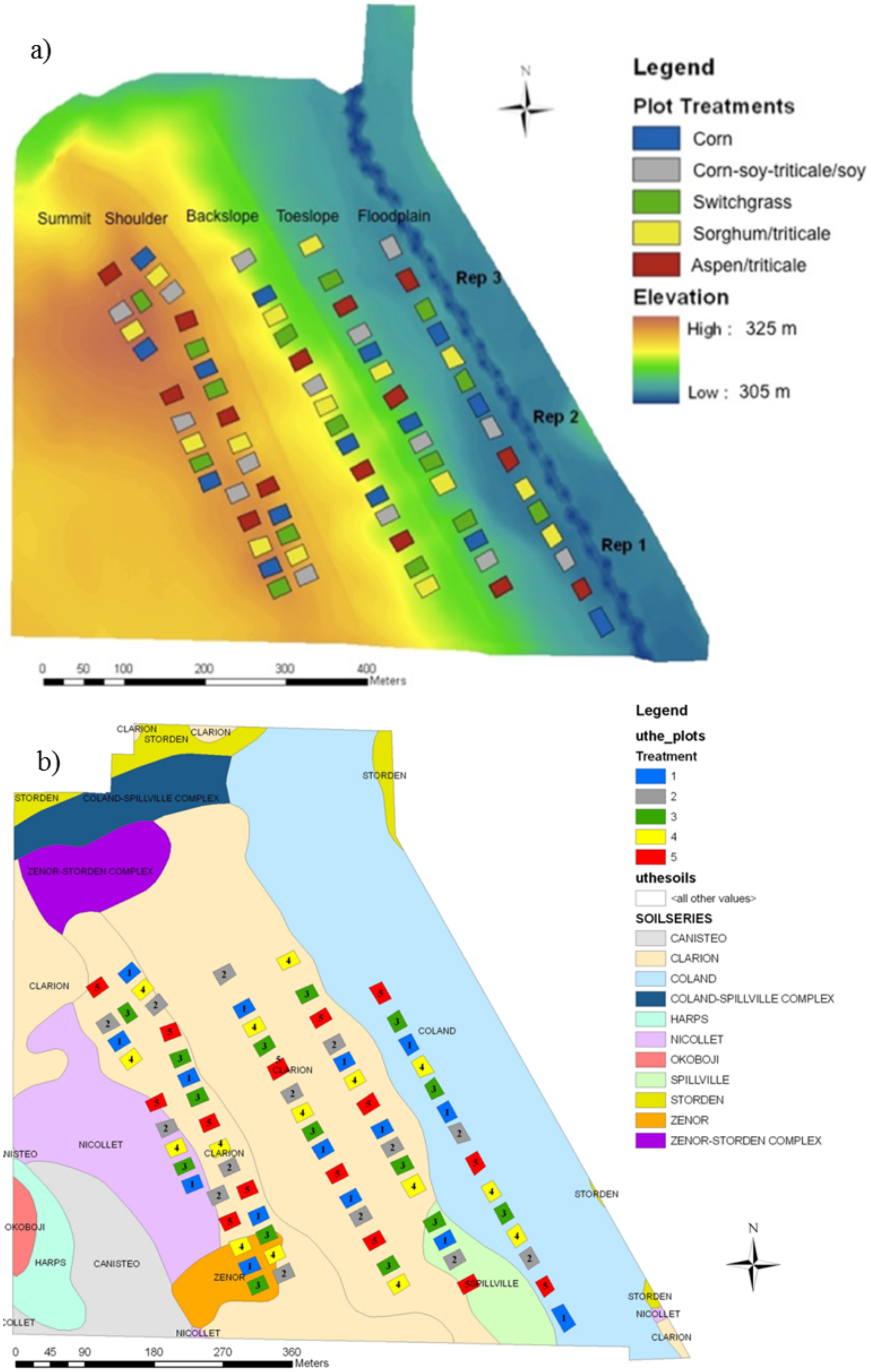


Figure 2.2. Landscape positions (a) and Soils (b) at the ISU Uthe research farm (Schulte, 2010)

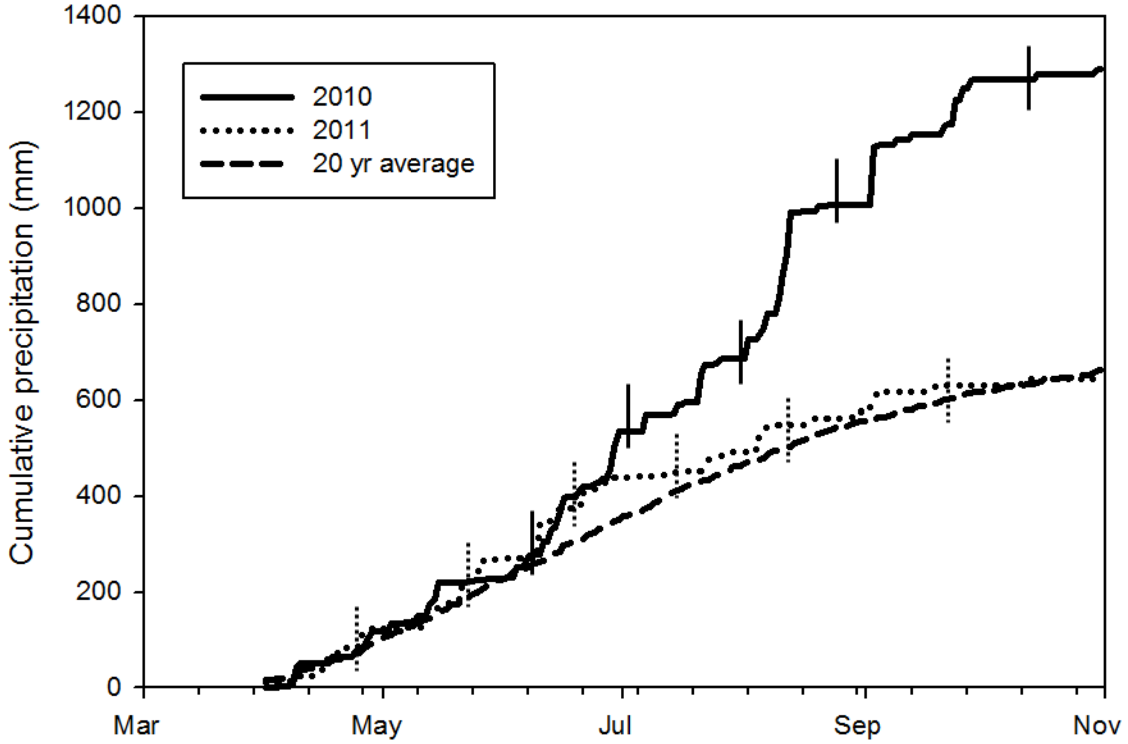


Figure 2.3. Comparison of precipitation from April 1st to October 31st in 2010, 2011 and the 20 year average. Vertical lines indicate sampling dates.

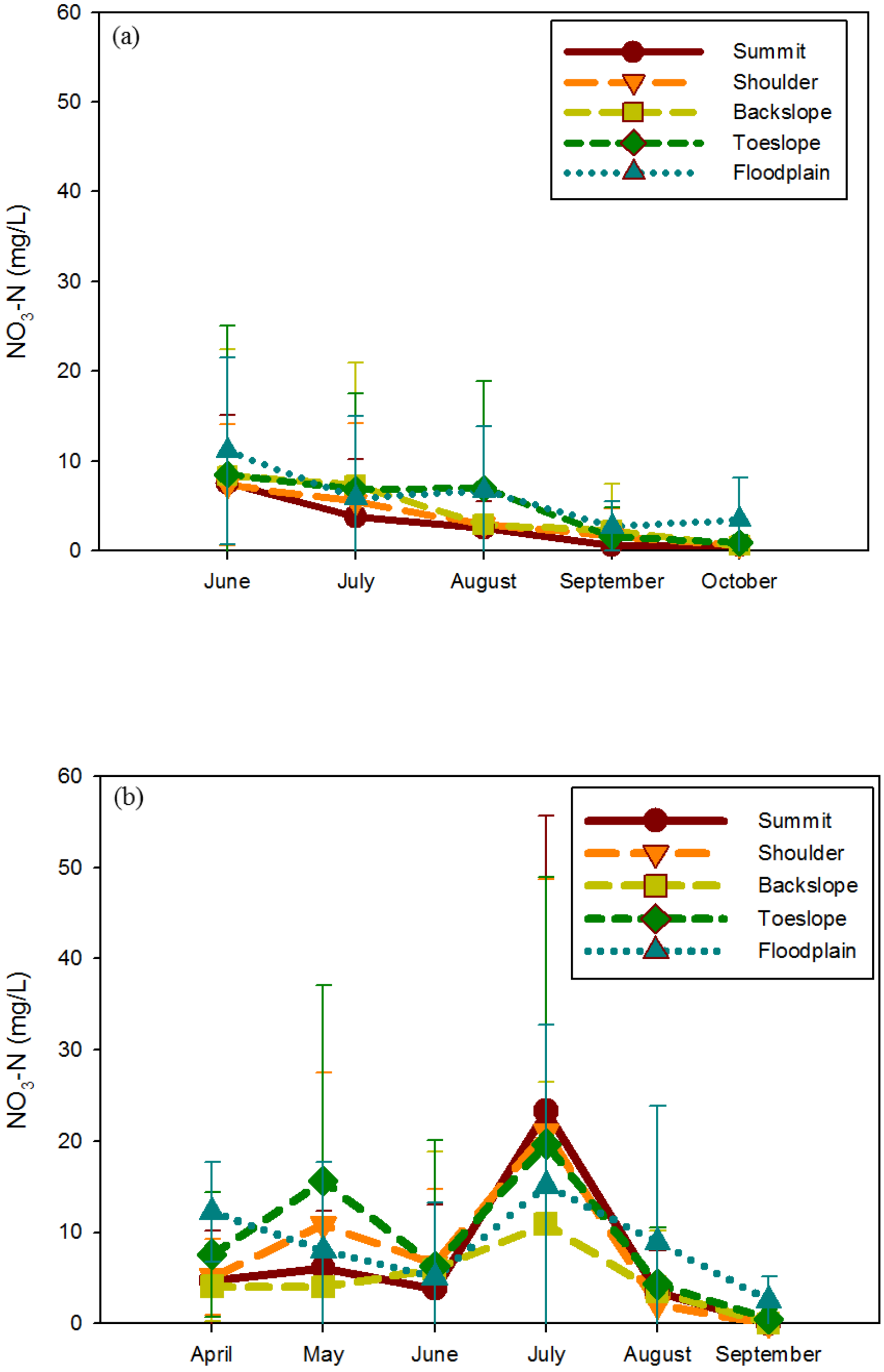
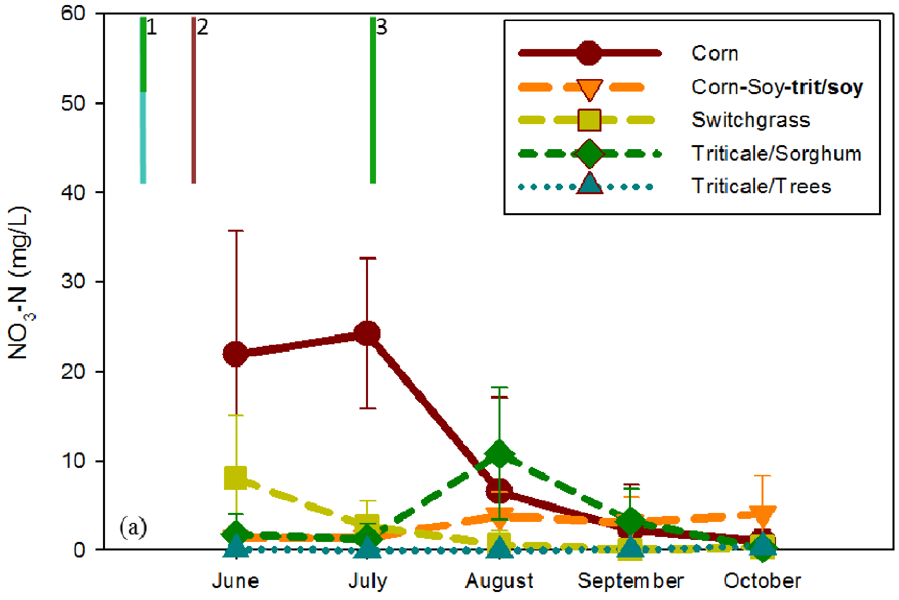
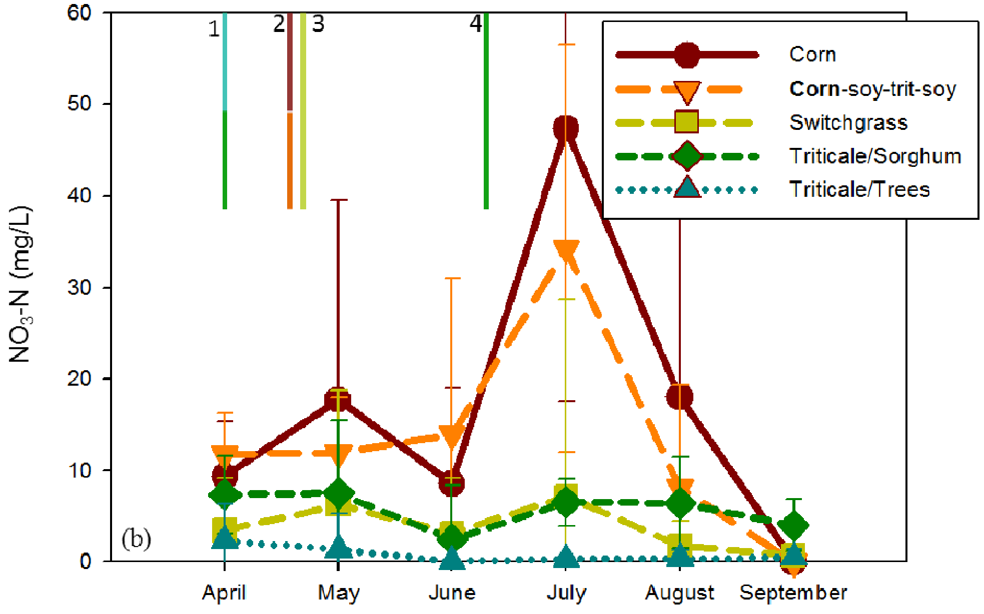


Figure 2.4. NO_3-N concentrations by landscape position in (a) 2010 and (b) 2011. Error bars indicate standard deviation of the sample NO_3-N concentrations.



1) April 14th- 30kg N/ha to Triticale/Sorghum, 12.5 kg N/ha to Triticale between tree rows (samples from w/in rows), 2) May 7th -150 kg N/ha to corn, 3) July 1st – 100 kg N/ha to Triticale Sorghum



1) April 29th 33.6 kg N/ha to Triticale/sorghum and to the triticale between the tree rows in triticale/trees (samples taken from within rows), 2) May 10th 168 kg N/ha to corn and 124 kg N/ha to corn-soy-trit-soy, 3) May 11th 124 kg N/ha to switchgrass, 4) June 30th 112 kg N/ha to Triticale/sorghum.

Figure 2.5. NO_3-N concentration by treatment in (a) 2010 and (b) 2011. Error bars indicate standard deviation of the sample NO_3-N concentrations.

CHAPTER 3: SOIL MOISTURE DYNAMICS OF VARIOUS BIOMASS CROPPING SYSTEMS AND LANDSCAPE POSITIONS

3.1 Abstract

Evaluating the soil moisture dynamics of biomass production systems is essential to assessing their water use and associated environmental impacts. The objective of this study is to determine potential soil moisture impacts of various production systems across different landscape positions. Five production systems are being evaluated: (1) continuous corn, (2) corn-soy-triticale/soy, (3) switchgrass, (4) triticale/sorghum, and (5) triticale/trees, at five landscape locations: (1) summit, (2) shoulder, (3) backslope, (4) toeslope, and (5) floodplain. Each production system is randomly assigned within three replicates (blocks) at each landscape location. Volumetric soil moisture measurements were taken monthly at 20 cm intervals during the 2010 and 2011 growing seasons from two access tubes to a depth of 120 cm. The triticale/trees system had lower moisture and soil water storage in the upper 60 cm of the soil profile than the other systems in April, May, and October 2011, which may indicate increased evapotranspirative demand. The relatively larger amount of stubble and residue in the switchgrass plots may account for the higher moisture levels at the surface in April, May and September 2011. Quantifying the soil moisture dynamics of biomass production systems will aid in optimizing deployment as producers gear up to meet biomass production demand.

3.2 Introduction

The Energy Independence and Security Act (EISA) of 2007 mandates that 136 billion liters of renewable fuels be produced in the United States annually by the year 2022 with 79 billion liters of this being advanced biofuel, mostly cellulosic. The mandate also caps the production of grain based ethanol at 57 billion liters. As producers in the Midwest prepare to shift from conventional, first-generation, grain-based biofuel feedstocks to advanced, second-generation, cellulosic feedstocks, it is necessary to consider the ecological impacts of these new cropping systems. It is estimated that in the US, 80% of total water consumed is for agricultural irrigation (Solley et al., 1998). It is anticipated that overall, the production of dedicated energy crops will have lower demand for water (Pellegrino et al., 2007; Sokhansanj et al., 2009; Williams et al., 2009). Globally, the conversion from current agricultural use to bioenergy production will reduce agricultural water demand by 54-82% (Berndes, 2002). While there are likely water use benefits to be achieved by the conversion of row crop agriculture to perennial biofuel feedstock systems, it is unlikely that these benefits will be the same everywhere on the landscape across all potential biomass cropping systems (Schulte et al., 2006). It is also possible, as Robertson et al. (2008) state, that the benefits of cellulosic crops could be negated by choosing poor locations to grow them. Crops grown on poor quality land may require relatively large inputs of water to make them economically viable, which would reduce the environmental benefit.

Corn stover in the form of residue from corn grain harvest represents a potentially large volume of biomass in the current agriculture environment in the Midwest. Under current farming practices the stover is generally returned to the soil which aids in protecting the soil from erosion and maintaining soil organic carbon. Large scale removal of corn stover for biofuel production will likely have negative environmental impacts such as increased erosion, reduction of soil quality, and more fertilizer input requirements (Wilhelm et al., 2004; Lal, 2006).

A potential solution to this is incorporating a winter cover crop or double crop into the system to protect the soil from erosion, increase water infiltration, and evapotranspiration which could contribute to reduced dissolved nutrient loss, runoff and erosion (Hartwig and Ammon 2002; Heggenstaller et al., 2008). Potential examples include incorporating a small grain (e.g., winter rye [*Secale cereals* L.], winter wheat [*Triticum aestivum* L.], or forage triticale [×*Triticosecale rimpaui* Wittm.]) into a continuous corn or corn-soybean rotation to form a corn/small grain or a corn-soybean-small grain/soybean production system. While these systems show benefits when compared to current systems, there is still concern about the further expansion of corn as a biofuel feedstock because of potential effects of increasing demand on the current food and feed system (Tilman et al., 2009).

Hallam et al. (2001) and Codgill (2008) demonstrated the potential of Sorghum as a biomass crop with high yields and composition that allows for efficient conversion to biofuel. It also has greater water use efficiency (Stone et al., 2010). A negative aspect of growing Sorghum is that it is not well suited to sloping areas due to its high rates of soil erosion on these types of sites (Buxton et al., 1999; Hallam et al., 2001). A winter cover crop incorporated with Sorghum may reduce the erosion and make it more viable by reducing its negative environmental impacts (Reinbott et al., 2004).

Perennial plants have also been proposed and studied as energy crops. *Miscanthus* and Switchgrass (*Pancium virgatum)* are two of the herbaceous species that have received much attention as a potential biofuel feedstock (McKendry, 2002). Conversion of row crop to perennial species has been predicted to reduce peak storm run-off (Gerla, 2007). Woody species have also received attention as a biofuel feedstock in the form of waste from the timber industry as well as dedicated biomass crops (Mann and Tolbert, 2000).

The growth of Switchgrass when compared to conventional row crops has been shown to have environmental benefits such as reduced erosion, reduced dissolved nutrient loss, and improved soil quality (Diaz-Chavez et al., 2011, Robertson et al., 2008, Love and Nejadhashemi, 2011). Much of this positive impact is attributed to its reduced fertilizer input requirements and perennial root system (McLaughlin and Kszos, 2005 and Diaz-Chavez et al., 2011).

Woody biomass production systems have been shown to have substantial environmental benefits such as reduced erosion and nutrient loss as well as increased habitat to increase species diversity (Kort et al., 1998; Schultz et al., 2004). Kort et al. (1998) also noted that one potential negative impact is when woody biomass crops mature they shade out the ground below them. This results in severe reduction of vegetative undergrowth which could result in more erosion if the soil left is exposed after harvest of the trees. Another potential drawback of woody biomass crops is that they often lower the water table from their increased evapotranspirative demand. Kort et al. (1998) noted a study from Australia where a pine plantation reduced the water table level enough to change a naturally perennial stream to an ephemeral stream. While, this will surely reduce water erosion, it is not necessarily beneficial to aquatic habitats and the species that rely on them. It was also noted that the reduction in soil moisture from the increased water demand from the trees can leave a soil more susceptible to wind erosion. The major detriment of growing woody species as a biomass crop lies in the fact that there is significant lag time (up to 10 years) between planting and harvest of a new crop. A potential way to mitigate this is to intercrop the trees with a faster growing species during the establishment of the slower growing trees. This has the potential to increase economic viability by producing biomass during the early, less productive years and may serve to control weed pressure on the woody crops and stabilize the soil (Schulte, 2010).

As Midwest producers gear up to meet the biomass production requirements of the EISA of 2007 there is an opportunity to design and implement biomass production systems that will produce significant economic, environmental, and social benefits (Dale, 2011). It is unlikely that any one of the systems outlined above will be best suited to produce superior biomass and yields and environmental benefits at all landscape locations at all times. After reviewing relevant literature it is clear that there is a need to evaluate the soil moisture dynamics of biomass cropping systems while also considering their position on the landscape. This research will aid in the design of biomass production systems that perform at high levels when evaluated according to multifunctional criteria (Schulte, 2010).

3.3 Materials and Methods

3.3.1 Research Site

A randomized, replicated experiment has been established to compare the five biomass systems across five landscape positions; (1) summit, (2) shoulder, (3) backslope, (4) toeslope and (5) floodplain (Figure 3.1). There is a 20 m elevation difference from the summit to the floodplain position and ranges from 325 m to 305 m above sea level. Each biomass production system is randomly assigned within each of three replicates at each landscape position for a total of 75 plots. All plots in the upper four landscape positions have slope lengths of 24.4 m (80 ft) and widths of18.3 m (60 ft) and those in the floodplain have slope lengths of 18.3m (60 ft) and widths of 24.4 m (80 ft). Each plot has an area of 0.5 ha (0.11 ac) and there is a 6m buffer between plots to accommodate equipment and isolate plots. The buffer around the tree plots is at least 18.3 m (60 ft) to accommodate the larger above and below ground influence of the trees. Areas between the plots have been planted in tall fescue which establishes quickly, stabilizes the soil and is tolerant of equipment traffic. Treatments were established at the site from the fall of 2008 to the spring of 2009. Prior to this the upland portions of the research site were managed under a corn – soybean rotation and the riparian areas consisted of mixed grasses. Each plot has been instrumented with two access tubes to a depth of 1.2 m.

It is also known that there is some amount of artificial, subsurface drainage, but it has not been determined to what extent this drainage influences the research site. There were six tile outlets identified draining into the creek below the floodplain position indicating artificial subsurface drainage in the poorly drained soils of the floodplain position. However, the type or extent of this subsurface drainage across the research site is not known.

3.3.2 Biomass cropping systems

The five biomass cropping systems being evaluated are (1) continuous corn (*Zea mays*), (2) corn-soybean-triticale/soybean (*Zea mays-Glycine max-Glycine max*/×*Triticosecale)* (3) corn-switchgrass (*Zea mays-Pancium virgatum)*, (4) triticale/sorghum (×*Triticosecale*/*Sorghum bicolor*), and (5) triticale/trees (×*Triticosecale* / *Populus alba X P. grandidentata*). Specific biomass systems were selected based on their compatibility with existing agricultural systems and their potential to provide either superior biomass yields (triticale/sorghum), some biomass yield while mitigating some negative environmental impacts (corn-soybean-triticale/soybean, corn-switchgrass), or some short-term biomass yield and superior long-term yield while strongly mitigating negative environmental impacts (triticale/trees), compared to conventional corn production systems. All cropping systems are managed using no till practices. The continuous corn system serves as a baseline with which to compare the alternative biomass cropping systems. Corn-switchgrass is an intercropping system in which corn provided weed control and a harvestable crop of grain and stover in the first year (2009) as the switchgrass biomass crop was established. Corn-soybean-triticale/soybean supplements the conventional corn-soybean rotation with a winter triticale biomass crop. Triticale is planted the September following the first soybean harvest, serves as a winter cover crop reducing exposure of soil to water and wind erosion, and is then harvested as a biomass crop in the early summer; it is followed immediately by soybean which is then harvested for grain in the fall. Triticale/sorghum is a double-cropping system in which winter triticale is planted in the fall and then harvested the following June. After triticale harvest, sorghum is planted into its stubble and harvested in September. Triticale/trees is an intercropping system in which winter triticale was planted in October before the trees are planted in May. Triticale is then harvested from between the tree rows as a biomass crop in early July, providing biomass productivity and a harvestable crop while the high-yield aspen trees (Crandon clone) are establishing. Triticale is then replanted between rows in the fall (Schulte, 2010).

3.3.3 Landscape positions

Five landscape positions (summit, shoulder, backslope, toeslope, and floodplain) are being evaluated for this study (Figure 3.2a). The summit position consists of four soil types. Replicate one has three plots on Zenor sandy loam and two plots on Clarion loam. All plots in replicate two are in Nicollet loan and all plots in replicate three are in Clarion loam. The shoulder position is dominated by Clarion loam however; half of the first replicate is in Zenor sandy loam. All of the backslope landscape position is planted in Clarion loam. The toeslope position has replicate one in Spillville loam and replicates two and three in Clarion loam. All of the floodplain position is in Coland clay loam (Figure 3.2b). The field capacity of each landscape position (Table 3.1) and soil series (Table 3.2) was determined using the United States Department of Agriculture Web Soil Survey (www.websoilsurvey.nrcs.usda.gov). When there were different soils in a landscape position, the weighted mean was determined and used for the entire landscape position.

As described by the National Cooperative Soil Survey of the United States, the Clarion series consists of very deep, moderately well drained soils on uplands. These soils were formed in glacial till and have slopes that range from 1 to 9 percent. The Coland series consists of very deep poorly drained soils formed in alluvium. These soils are on floodplains and alluvial fans in river valleys and upland drainage ways in dissected till plains. Slope ranges from 0 to 5 percent. The Nicollet series consists of very deep, somewhat poorly drained soils that formed in calcareous loamy glacial till on till plains and moraines. Slopes range from 0 to 5 percent. The Spillville series consists of very deep, moderately well drained or somewhat poorly drained soils formed in dark colored, medium-textured alluvium. Spillville soils are on nearly level flood plains and gently sloping footslopes on uplands. Slope ranges from 0 to 5 percent. The Zenor series consists of very deep, somewhat excessively drained, moderately rapidly permeable soils formed in glacial outwash on uplands and, less commonly, on stream benches. Slope ranges from 2 to 30 percent.

3.3.4 Data Collection

Two soil moisture access tubes were installed per research plot for a total of 150 access tubes. The access tubes are 52 mm inside diameter schedule 40 PVC and 120 cm in length with a 3.7 mm wall thickness. The access tubes were installed by taking a soil core down to 120 cm soil depth with a 5.7 cm (2-1/4 inch) soil tube (Giddings Machine Company, part # ST-144) fitted with a quick relief bit (part # ST-230). The access tube hole was then sized to fit the PVC pipe with the end plugged with a # 11 EPDM rubber stopper using a 5.7 cm (2-1/2 inch) by 122 cm (48 inch) soil tube (Giddings Machine Company, part # ST-146) fitted with a reverse taper bit (part # ST-211). Soil coring and access tube installation was accomplished with a tractor mounted hydraulic soil corer (Giddings Machine Company, Fort Collins, CO; model number HDGSRTS) mounted to a John Deere tractor (Deere and Company, Moline IL, Model 4110 compact utility tractor). Access tubes were capped with a 5 cm (2 inch) PVC end cap, and covered with a 10 cm (4 inch) PVC sewer clean out fitting to prevent damage from equipment used to plant and harvest crops within plots (Ontl, unpublished).

Precipitation was monitored at the Iowa State University South Reynoldson Farm (1.5 km SE of research site). Precipitation data was collected from April 1st to October 31st of each year. Soil moisture was monitored monthly at 20 cm intervals (0-20 cm, 20-40 cm, 40-60 cm, 60-80 cm, 80-100 cm, 100-120 cm) to a depth of 1.2 m using an impedance probe and time domain reflectometry (TDR). Potential evapotranspiration (PET) information was from the Iowa Environmental Mesonet (www.mesonet.agron.iastate.edu) Ames, IA monitoring site. Soil moisture was monitored using a ML2 ThetaProbe Soil Moisture Sensor with the HH2 Handheld Moisture Meter (Delta-T Devices, Cambridge UK, marketed in the United States by Dynamax, Inc., Houston, TX) for measuring volumetric water content in the upper 6 cm and an Imko TRIME-FM instrument with a TRIME-T3 tube access probe (MESA Syst. Co., Medfield, MA) to measure volumetric water content from 20-120 cm. Three readings were taken at the 0-6 cm depth and two readings at all other depths at each soil moisture access tube for a total of 1950 readings per month. Individual volumetric water content measurements were converted to a maximum value of 46%, which is the mean measured porosity for the research site (Ontl, unpublished data). This would represent a completely saturated situation and values over 46% were generally only observed during wet conditions. Since there were no readings in the 6-20 cm profile, the values from the 0-6 cm profile were used to represent the 0-20 cm portion of the soil profile. The mean of the observed values at each depth in each plot were analyzed to determine differences among the treatments and landscape positions during each year as well as each month. Evaluating the soil moisture at each individual depth gives an integrated measure of the soil water storage. The mean volumetric water content of each depth was used to calculate (volumetric water content X length of soil profile) a soil water storage value for that 20 cm portion of the soil profile. These values were then summed to calculate the soil water storage in the 0-60 cm and 0-120 cm portions of the soil profile. Soil water storage represents the quantity (cm) of water in a given depth of the soil profile. This is useful because when subtracted from the field capacity, it will give us the available storage. More available storage allows for a larger quantity of water to infiltrate prior to water running off the surface. During precipitation events, increased available storage has the potential to reduce runoff and associated negative impacts e.g., erosion, nutrient and pesticide transport, and flooding. However, the available storage does not affect runoff caused by precipitation rates that exceed the infiltration rate. Soil moisture measurements were taken on the 3rd, 4th, 7th and 9th of June, the 13th and 14th of July, the 28th and 29th of August and the 25th and 26th of September in 2010 and on the 5th and 7th of April, 10-11th of May, 7-8th of June, 7-8th of July, 8-9th of August, 8-9th of September, and the 13th and 14th of October in 2011. With the exception of June 2010, which took four days, it took two days to collect the data from all access tubes each month.

3.3.5 Statistical analysis

Data was analyzed with the SAS statistical Software Package (SAS Institute, 2001) using the MIXED procedure to perform the analysis of variance. Differences in soil water storage among experimental treatments (continuous corn, corn-soy-triticale/soy, switchgrass, and triticale/trees), landscape position (summit, shoulder, backslope, toeslope, and floodplain) and month were tested. Interactions among the variables were also tested. Statistical significance was evaluated at $P \leq 0.05$. Means were separated using a least significant difference when effects were significant. Data for the 0-60 cm and 0-120 cm soil profiles were analyzed separately. Each depth of the volumetric soil moisture was also analyzed separately. Data analysis was conducted on each year as well as each month to determine seasonal effects.

3.4 Results and discussion

Precipitation between the two years was similar and consistent with the 20 year average from mid-April until early June. After early June, 2010 had much more precipitation than 2011 (Figure 3.3). Overall in 2011, precipitation remained very close to the 20 year average during the study period while 2010 had about double the 20 year average precipitation from early June to the end of October.

Soil moisture

There were more differences in soil moisture at individual depths among both the cropping systems and the landscape positions in the shallower depths than the deeper depths (Tables 3.3-3.8). This is likely contributed to more rapid soil moisture changes from greater evapotranspitation (ET) influence at shallower depths. Generally the shallow depths were drier than the deeper depths. In 2010, the only treatment effect observed was in June at the 20-40 cm depth (Table 3.4). This should be interpreted with caution because the June 2010 data was collected on 4 separate days over a 7 day period that saw 4 rain events totaling 53 mm (Table 3.9). Soil moisture data was collected starting at the summit and working down the landscape finishing at the floodplain. Generally, the upper three landscape positions (summit, shoulder, and backslope) were collected on the first day and the lower two landscape positions (toeslope and floodplain) were collected on the second day. This temporal difference should be considered when interpreting the landscape position results because it allows for the possibility of drying from evaporation or wetting from precipitation during or between sampling days. There were significant differences in the landscape positions at the 0-20 cm (Table 3.3), 20-40 cm (Table 2.4), 40-60 cm (Table 3.5), and 60-80 cm (Table 3.6) depths in June 2010 but, the same caution should be exercised here as discussed above for the treatment effect in June 2010. The floodplain position had higher soil moisture (Table 3.3) at the 0-20 cm depth in July 2010 which could be a result of the 18 mm of rain between the two days of collection, although this does not explain why the toeslope was the driest position. Precipitation during data collection (18 mm on day 1 and 0.3 mm on day 2) may account for the 0-20 cm depth (Table 3.3) being wetter in the floodplain in September 2010.

In 2011, there were more differences in soil moisture among the cropping systems than in 2010. This is likely associated with many variables such as differences in precipitation (Figure 3.3); cropping system two was planted in corn in 2011 versus triticale/soy in 2010, and the perennial systems were more mature. The 0-20 cm depth was wetter in the switchgrass plots in April, May and September 2011 which may be attributed to the relatively larger amount of stubble and residue (Table 3.3). The triticale/trees system was drier at the 0-20 cm depth (Table 3.3) in May, September, and October 2011 and the 0-40 cm depth (Table 3.4) in April and October 2011. This may suggest that the trees have matured enough to have higher ET than the other systems. In 2011 the 0-20 cm and 20-40 cm depths were generally wetter as you moved from higher to lower on the landscape. October 2011 was the exception to this and may be partially but, not completely explained from precipitation just prior to data collection. Data was collected on two days (October 13th -14th) this month with these two positions being collected on the 14th and the upper three positions collected on the 13th. October 11th, 12th, and 13th received 1.27 mm, 0.25 mm, and 11.17 mm of precipitation respectively (Table 3.11). It stopped raining in the early morning prior to the first day of data collection and the site was muddy. The two days of collection had high temperatures of 17.2°C and 19.4°C respectively and average wind speeds of 26.4 kph (gusts to 64.4 kph) and 13.8 kph (gusts to 38.6 kph) respectively. It is possible that evaporation between the two sampling days contributed to the lower values in the toeslope and floodplain positions but, this does not explain all of the water loss. The potential evapotranspiration (PET) between the rain event prior to collecting soil moisture data and the last day of sampling was 1.1 cm and the differences in soil water storage ranged from 3.2 to 5.3 cm between the upper three positions and the lower two (Table 3.11). It is also important to note that PET represents the maximum possible ET, and actual ET was almost certainly less than PET. Further research is warranted to investigate this.

Soil water storage

Soil water storage in 2010 in the 0-60 cm profile for the landscape positions (Figure 3.4) and the cropping systems (Figure 3.5), as well as the 0-120 cm profile for the landscape positions (Figure 3.6) and cropping systems (Figure 3.7) had a general increase as the season progressed, which is consistent with the unusually large amount of precipitation. There was a significant difference in soil water storage among the months during 2010 (Table 3.9). In the 0-60 cm profile, June was the driest followed by July then August and September (which were not different from each other). The 0-120 cm profile had the same patterns with the exception that September was significantly wetter than August. In 2010, there was an overall landscape position effect on soil water storage observed in the 0-60 cm profile with the summit being the driest and the floodplain being the wettest. The shoulder, backslope and toeslope were all significantly wetter than the summit and drier than the floodplain (Table 3.9). The majority of this annual difference is during the month of June (Table 3.10). As discussed in the soil moisture section, this should be interpreted with caution because the June 2010 data was collected on 4 separate days over a 7 day period that saw 4 rain events totaling 53 mm (Table 3.11). It is very likely that these precipitation events influenced the observed soil moisture (and therefore soil water storage). The same effect was not statistically significant in the 0-120 cm profile. While, the floodplain position appears to have less water stored in the 0-60 and the 0-120 cm profile during August 2010, this is almost certainly from missing all soil water storage values for the 0-20 cm profile for the floodplain (and about ½ from the shoulder and toeslope). Since there are three soil water storage values summed (0-20 cm, 20-40 cm, 40-60cm) to calculate the 0-60 cm soil water storage, missing one of the three for an entire landscape position is very likely causing this apparent effect. Using the mean of the data that was on hand was considered, but this would not work in the floodplain in August 2010 because there are no observations. It would also not be appropriate for other positions because there were significant differences among the replicates (blocks) observed within landscape positions. The soil water storage value from 0-120 cm in August 2010 was lower in the floodplain (Table 3.12) than the other positions but, as discussed previously, this is almost certainly due to the lack of the 0-20 cm data in this landscape position. The summit in September was also missing some of the data which may account for the lower soil water storage. There was no overall treatment effect observed in the 0-60 cm or the 0-120 cm profile during 2010 (Table 3.9). These lack of differences may be partially due to the young age of the perennial systems (switchgrass and trees were planted in 2009) in the study site. The root systems of the perennial plants may not be well enough developed to show a difference in water uptake compared to the annual systems. This is consistent with Thornton et al. (1998) for the tree plots, where they found no difference in erosion, which is likely in part due to water use, in the establishment phase. It is also consistent with what Mann and Tolbert (2000) found for the switchgrass plots, where they did not detect a difference in runoff between switchgrass and no-till corn until the 2nd year after establishment. There was no interaction observed between the treatment and the landscape position in 2010 (Table 3.13).

Soil water storage in 2011 in the 0-60 cm profile for the landscape positions (Figure 3.8) and the cropping systems (Figure 3.9), as well as the 0-120 cm profile for the landscape positions (Figure 3.10) and cropping systems (Figure 3.11) showed a general decrease at the end of the season which is consistent with relatively dry conditions in the late part of 2011. There was an overall landscape effect on soil water storage in the 0-60 cm profile in 2011 with the backslope being significantly wetter than the toeslope and floodplain (which were not different from each other). The summit and shoulder positions had soil water storage values between these but, not significantly different than any (Table 3.9). There are differences in how well drained the soils are among the landscape positions, but this does not explain why the backslope position is wetter. By the drainage classes from USDA Web Soil Survey (www.websoilsurvey.nrcs.usda.gov) it appears that the shoulder and backslope positions would, on average, be the most well drained positions (Table 3.2). It is likely that the small spatial differences among the landscape positions are not well represented in the web soil survey. The soils data was mapped at a scale of 1:15,840 which would not likely allow for sub-plot, or even plot to plot differentiation between soil properties. It should also be noted that the differences between soils are most likely not defined by abrupt lines, but a gradual change that may occur over several plots, replicates, or even landscape positions. A detailed soils analysis is being conducted and will be useful for plot to plot evaluation. April and May 2011 had lower soil water storage in the 0-120 cm profile in the summit and shoulder positions than in the toeslope and floodplain positions (Table 3.14). These are the only landscape effects that are not explained by lack of data (July) or precipitation (October) in the 0-120 cm profile in 2011 (Table 3.12b). The toeslope and floodplain positions were drier than the other positions at all depths down to 100 cm and had lower soil water storage values in both the 0-60 cm and 0-120 cm profiles in October 2011.

The triticale/trees cropping system had lower soil water storage in the 0-60 cm profile in April, May and October of 2011 which may indicate increased ET demand. The trees may have matured enough to be showing higher ET compared to the other systems during these months. Another contributing factor could be increased interception of rainfall from the trees and leaf litter on the ground. Similar results were observed by Mitchell (1997) and Mann and Tolbert (2000) who saw decreased erosion after the first year of growing biomass crops, although they attributed much of the reduced erosion to increased raindrop interception from branches and leaf litter, increased infiltration likely contributed as well. The triticale may also be contributing to the increased water use during these months but, if so it would be expected to see similar results in the other systems with triticale if it was the major factor in increased water use. The soil moisture measurements were taken from within the tree rows, so the trees would likely have more influence than the triticale. The switchgrass plots had higher moisture levels in the 0-20 cm profile in April, May and September, 2011. While the biomass is removed from all plots, it is likely that there was more residue and stubble in these plots than others, which could have lessened the effects of evaporation and contributed to the higher moisture levels at the surface.

3.5 Conclusion

As producers in the Midwest prepare to potentially shift from first-generation, grain based biofuel feedstocks to second-generation, cellulosic feedstocks, it is essential to assessing biomass production systems' water use and associated environmental impacts. This study analyzed soil moisture impacts of various production systems across different landscape positions. Five production systems were evaluated: (1) continuous corn, (2) corn-soy/triticale-soy, (3) switchgrass, (4) triticale/sorghum, and (5) triticale/trees, at five landscape locations: (1) summit, (2) shoulder, (3) backslope, (4) toeslope, and (5) floodplain. The triticale/trees system had lower soil moisture and soil water storage in the upper 60 cm of the soil profile than the other systems in April, May, and October 2011, which may indicate increased evapotranspirative demand. The relatively larger amount of stubble and residue in the switchgrass plots may account for the higher moisture levels at the surface in April, May and September 2011. There is a clear requirement to continue monitoring the soil water dynamics because this study potentially shows differences emerging among the biomass cropping systems that will likely become more apparent as the perennial systems continue to mature. Quantifying the soil moisture dynamics of biomass production systems will aid in optimizing deployment as producers gear up to meet biomass production demand by providing part of the information needed to assess their multifunctional performance. It will also aid in the development of hydrologic regulation and potential incentives for biomass production systems as we gain a clearer understanding of the benefits and drawbacks of each system.

3.6 References

Bernds, G. 2002. Bioenergy and water- the implications of large-scale bioenergy production for water use and supply. *Global Environmental Change-Human and Policy Dimensions.* 12:253-271.

Buxton, D.R., I.C. Anderson, and A. Hallam. 1999. Performance of sweet and forage sorghum grown continuously, double-cropped with winter rye, or in rotation with soybean and maize. *Agronomy Journal* 91:93-101.

Cogdill, T.J. 2008. Investigation of management strategies for the production of sweet sorghum as a bioenergy crop and preservation of crop residue by the ensiling process. M.S. Thesis. Iowa State University, Ames, Iowa.

Dale, B.E. 2011. Biofuels and water: another opportunity to 'do biofuels right'. *Biofuels, Bioprod.Bioref.* 5:347-349.

Diaz-Chavez, R., Berndes, G., Neary, D., Neto, A. E., Fall, M. 2011. Water quality assessment of bioenergy production. *Biofuels, Bioprod. Bioref.* 5:445-463.

Hallam, A., I.C. Anderson, and D.R. Buxton. 2001. Comparative economic analysis of perennial, annual, and intercrops for biomass production. *Biomass and Bioenergy* 21:407- 424.

Hartwig, N.L., and H.U. Ammon. 2002. Cover crops and living mulches. *Weed Science* 50:688-699.

Heggenstaller, A.H.,R.P. Anex, M. Liebman, D.N. Sundberg, and L.R. Gibson. 2008. Productivity and nutrient dynamics in bioenergy double-cropping systems. *Agronomy Journal* 100:1740-1748.

Gerla, P. 2007. Estimating the effect of cropland to prairie conversion on peak storm run-off. *Restoration Ecology* 4:720-730.

Lal, R. 2006. Soil and environmental implications of using crop residues as biofuel feedstock. *International Sugar Journal* 108:161-167.

Love, B. J., Nejadhashemi, P. 2011. Water quality impact assessment of large-scale biofuel crops expansion in agricultural regions of Michigan. *Biomass and Bioenergy* 35:2200-2216.

Mann, L., and V. Tolbert. 2000. Soil Sustainability in Renewable Biomass Plantings. *AMBIO: A Journal of the Human Environmne.* 29:492-498.

McLaughlin, S.B., and L.A. Kszos. 2005. Development of switchgrass (*Panicum virgatum*) as a bioenergy feedstock in the United States. *Biomass and Bioenergy* 28:515-535.

McKendry, Peter. 2002. Energy production from biomass (part 1): overview of biomass. *Bioresource Technology*. 83: 37-46.

Mitchell, B.M. 1997. Hydrologic impacts of converting cotton to short-rotation cottonwood in the Mississippi Delta. MSc Thesis. Mississippi State University, Starkville, MS, USA.
Kort, J., M. Collins, and D. Ditsch. 1998. A review of soil erosion potential associated with biomass crops. *Biomass and Bioenergy* 14:351-359.

Pellegrino, J., M Antes, B. Zotter, H. Andres, C. Scher. 2007. Water Impacts from Increased Biofuels Production: An Analysis of Water Issues Based on Future Feedstock Production Scenarios; NREL: Golden, CO.

Reinbott, T.M., S.P. Conley, and D.G. Blevins. 2004. No-tillage corn and grain sorghum responses to cover crop and nitrogen fertilization. *Agronomy Journal* 96:1158-1163.

Robertson, G.P., V.H. Dale VH, O.C. Doering, et al. 2008. Sustainable biofuels redux. *Science* 322:49-50.

SAS. 2003. SAS User's Guide. Version 9.2. SAS Institute, Inc., Cary, NC.

Schulte, L.A. 2010. Developing A Portfolio Of Sustainable Regional Feedstock Production Systems For The U.S. Midwest. AFRI Project Summary.

Schulte, L.A., M. Liebman, H. Asbjornsen and T.R. Crow. 2006. Agroecosystem restoration through strategic integration of perennials. *Journal of Soil and Water Conservation* 61:164A-169A.

Schultz, R.C., T.M. Isenhart, W.W. Simpkins, and J.P. Colletti. 2004. Riparian forest buffers in agroecosystems- lessons learned from the Bear Creek watershed, central Iowa, USA. *Agroforestry Systems* 61:35-50.

Sokhansanj, S., S. Mani, A. Turhollow, A. Kumar, D. Bransby, L. Lynd, M. Laser. 2009. Large-scale production, harvest and logistics of switchgrass (*Panicum virgatum* L.) – current technology and envisioning a mature technology. *Biofuels, Bioprod. Biorefin. 3*:124–141.

Solly, W.B., R.R. Pierce, H.A. Pearlman. 1998. Estimating the use of water in the united States in 1995. Reston, VA. USGS Circular 1200, 79p.

Stone, K.C., P.G. Hunt, K.B. Cantrell, and K.S. Ro. 2010. The potential impacts of biomass feedstock production on water resource availability. *Bioresource Technology.* 101:2014-2025.

Thornton, F.C., J.D. Joslin, B.R. Bock, A.E. Houston, T. Green, S. Schoenholtz, D. Pettry, and D.D. Tyler. 1998. Environmental effects of growing woody crops on agricultural land: first year effects on erosion and water quality. *Biomass and Bioenergy* 15:57-67.

Tilman, D., R. Socolow, J. Foley, J. Hill, E. Larson, L. Lynd, S. Pacala, J. Reilly, T. Searchinger, C. Somerville, and R. Williams. 2009. Beneficial biofuels – the food, energy, and environment trilemma. *Science* 325:270–271.

Wilhelm, W.W., J. M. F. Johnson, J. L. Hatfield, W. B. Voorhees, and D. R. Linden. 2004. Crop and soil productivity response to corn residue removal: a literature review. *Agronomy Journal* 96:1–17.

Williams, P. R. D., D, Inman, A.Aden, and G.A. Heath. 2009. Environmental and sustainability factors associated with next-generation biofuels in the U.S.: What do we really know? *Environmental Science and Technology*. 43:4763-4775.

Table 3.1. Soil water storage and drainage information for landscape locations

	Water content at field capacity (1/3 bar)(%)	Soil water storage @ field capacity (0-120cm)	Soil water storage @ field capacity (0-60cm)	Drainage class	Notes
Summit	27.8	33.4	16.7	Zenor- somewhat excessively drained, Nicollet- somehhat poorly drained, Clarion- well drained	Rep 1 , 3/5 Zenor sandy loam, 2/5 Clarion loam; Rep 2 Nicollet loam; Rep 3 Clarion loam
Shoulder	27.8	33.4	16.7	Zenor- somewhat excessively drained, Clarion- well drained	Rep 1, 1/2 Zenor sandy loam, 1/2 Clarion loam, Reps 2&# Clarion loam
Backslope	27.5	33.0	16.5	Well drained	Clarion Loam
Toeslope	28.9	34.7	17.3	Spillville- moderately well drained, Clarion- well drained	Rep 1 Spillville loam, Reps 2&3 in Clarion loam
Floodplain	35.1	42.1	21.1	poorly drained	Coland clay loam

Soil data is from Web soil survey (USDA), When a landscape position had multiple soils, a weighted average was used for that landscape position

Table 3.2. Soil water content and drainage information

Soil series	Water content at field capacity (1/3 bar) (%)	Drainage class
Clarion (1&2)*	28.2	well drained
Clarion (3&4)*	26.5	well drained
Coland	35.1	poorly drained
Nicollet	29.6	somewhat poorly drained
Spillville	31.7	moderately well drained
Zenor	18.7	somewhat excessively drained

1-summit, 2-shoulder, 3-backslope, 4-toeslope

Table 3.3. Results of comparison of soil moisture (%) 0-20 cm

		2010	2011	2010	2011	2010	2011
Depth (cm)	Month	Cropping system	Cropping system	Landscape position	Landscape position	Landscape position* cropping system	Landscape position* cropping system
0-20	April		***p=0.0005***		***p<0.0001***		p=0.0824
	1	#	19.6 a	#	18.0 a	#	
	2		19.1 a		19.3 ab		
	3		22.3 b		20.0 b		
	4		20.4 a		19.8 b		
	5		19.1 a		23.5 c		
	May		***p<0.0001***		***p<0.0001***		***p=0.0122***
	1	#	16.3 c	#	14.6 a	#	
	2		14.3 b		15.0 ab		
	3		18.9 d		18.3 c		
	4		16.2 c		14.7 ab		
	5		12.8 a		15.9 b		
	June	p=0.4108		***p<0.0001***		p=0.8811	
	1		#	23.0 a	#		#
	2			28.2 b			
	3			22.3 a			
	4			26.6 b			
	5			30.7 c			
	July	p=0.8832		***p<0.0001***		p=0.7069	
	1		##	27.0 b	##		##
	2			27.7 b			
	3			27.6 b			
	4			24.5 a			
	5			34.9 c			
	August	p=0.4048	p=0.6090	p=0.8417	***p<0.0001***	p=0.6219	p=0.3912
	1				31.7 b		
	2				32.0 b		
	3				31.2 b		
	4				25.7 a		
	5				31.7 b		
	September	p=0.6228	***p=0.0019***	***p<0.0001***	***p=0.0026***	p=0.9911	p=0.5441
	1		18.4 ab	20.0 a	18.3 ab		
	2		20.1 abc	20.3 a	20.2 bc		
	3		21.4 c	22.4 a	21.4 c		
	4		20.7 bc	20.1 a	16.6 a		
	5		16.5 a	26.0 b	20.6 bc		
	October		***p=0.0104***		***p<0.0001***		p=0.4521
	1	#	25.7 b	#	27.7 c	#	
	2		26.4 b		28.0 c		
	3		26.7 b		27.7 c		
	4		26.4 b		21.0 a		
	5		23.7 a		24.6 b		

LS means of volumetric soil moisture (%)
Cropping systems: 1=continuous corn, 2=corn-soy-triticale/soy, 3=switchgrass, 4=triticale/sorghum, 5=triticale/trees
Landscape positions: 1=summit, 2=shoulder, 3=backslope, 4=toeslope, 5=floodplain
no data collected
not enough data for statistical analysis

Table 3.4. Results of comparison of soil moisture (%) 20-40 cm

Depth (cm)	Month	2010 Cropping system	2011 Cropping system	2010 Landscape position	2011 Landscape position	2010 Landscape position* cropping system	2011 Landscape position* cropping system
20-40	April		***p=0.0290***		***p=0.0129***		p=0.9982
	1	#	43.3 ab	#	41.4 a	#	
	2		44.9 ab		43.4 ab		
	3		45.0 b		44.5 b		
	4		45.0 b		45.4 b		
	5		41.8 a		45.1 b		
	May		p=0.1586		p=0.1825		p=0.7281
	1	#		#		#	
	2						
	3						
	4						
	5						
	June	***p=0.0145***	***p=0.0013***	***p<0.0001***	p=0.0698	p=0.3642	p=0.1315
	1	33.1 b	39.8 bc	27.0 a			
	2	32.4 b	42.7 c	32.9 b			
	3	33.1 b	38.2 ab	33.9 b			
	4	29.0 a	35.7 a	33.3 b			
	5	31.1 ab	37.0 ab	31.6 b			
	July	p=0.6748	p=0.2968	p=0.3150	p=0.3011	p=0.6029	p=0.1965
	1						
	2						
	3						
	4						
	5						
	August	p=0.4936	p=0.1678	p=0.2083	p=0.2396	p=0.7068	p=0.6242
	1						
	2						
	3						
	4						
	5						
	September	p=0.2893	p=0.1054	p=0.2243	***p=0.0215***	p=0.7397	p=0.5815
	1				36.6 ab		
	2				39.4 bc		
	3				39.9 c		
	4				37.2 abc		
	5				35.6 a		
	October		***p=0.0010***		***p<0.0001***		p=0.2292
	1	#	32.5 b	#	33.8 c	#	
	2		34.5 b		37.3 d		
	3		35.2 b		38.3 d		
	4		35.0 b		30.0 b		
	5		28.6 a		26.3 a		

LS means of volumetric soil moisture (%)
Cropping systems: 1=continuous corn, 2=corn-soy-triticale/soy, 3=switchgrass, 4=triticale/sorghum, 5=triticale/trees
Landscape positions: 1=summit, 2=shoulder, 3=backslope, 4=toeslope, 5=floodplain
no data collected
not enough data for statistical analysis

Table 3.5. Results of comparison of soil moisture (%) 40-60 cm

Depth (cm)	Month	2010	2011	2010	2011	2010	2011
		Cropping system	Cropping system	Landscape position	Landscape position	Landscape position* cropping system	Landscape position* cropping system
40-60	April	#	p=0.1918	#	***p=0.0026***	#	p=0.7698
	1				40.8 a		
	2				41.0 a		
	3				44.4 b		
	4				45.4 b		
	5				45.0 b		
	May	#	p=0.3646	#	p=0.2670	#	p=0.8879
	1						
	2						
	3						
	4						
	5						
	June	p=0.1749	p=0.5583	***p=0.0289***	p=0.1612	p=0.8657	p=0.7269
	1			28.9 a			
	2			31.5 ab			
	3			34.3 b			
	4			31.7 ab			
	5			31.0 a			
	July	p=0.8249	p=0.1939	p=0.4009	p=0.2036	p=0.7672	p=0.6327
	1						
	2						
	3						
	4						
	5						
	August	p=0.3767	p=0.0520	p=0.2300	p=0.4047	p=0.8458	p=0.4716
	1						
	2						
	3						
	4						
	5						
	September	p=0.7995	***p=0.0470***	p=0.4961	p=0.4841	p=0.8916	p=0.6784
	1		32.9 a				
	2		34.6 ab				
	3		37.5 b				
	4		38.7 b				
	5		36.5 ab				
	October	#	p=0.0582	#	***p<0.0001***	#	p=0.5755
	1				34.4 b		
	2				35.2 b		
	3				37.4 b		
	4				26.2 a		
	5				29.5 a		

LS means of volumetric soil moisture (%)
Cropping systems: 1=continuous corn, 2=corn-soy-triticale/soy, 3=switchgrass, 4=triticale/sorghum, 5=triticale/trees
Landscape positions: 1=summit, 2=shoulder, 3=backslope, 4=toeslope, 5=floodplain
no data collected
not enough data for statistical analysis

Table 3.6. Results of comparison of soil moisture (%) 60-80 cm

		2010	2011	2010	2011	2010	2011
Depth (cm)	Month	Cropping system	Cropping system	Landscape position	Landscape position	Landscape position* cropping system	Landscape position* cropping system
60-80	April	#	p=0.2807	#	***p=0.0006***	#	p=0.6602
	1				38.8 a		
	2				41.5 b		
	3				43.9 bc		
	4				46.0 c		
	5				44.3 bc		
	May	#	p=0.6689	#	p=0.1163	#	p=0.3257
	1						
	2						
	3						
	4						
	5						
	June	p=0.4770	p=0.6047	***p=0.0426***	p=0.1674	p=0.7998	p=0.5569
	1			28.8 a			
	2			32.3 ab			
	3			34.4 b			
	4			32.4 b			
	5			32.7 b			
	July	p=0.6491	p=0.2297	p=0.2852	p=0.2483	p=0.6282	p=0.6138
	1						
	2						
	3						
	4						
	5						
	August	p=0.7589	p=0.2777	p=0.1850	p=0.6168	p=0.3794	p=0.7671
	1						
	2						
	3						
	4						
	5						
	September	p=0.8303	***p=0.0093***	p=0.0612	p=0.0983	p=0.5506	p=0.5562
	1		33.6 a				
	2		33.4 a				
	3		36.0 b				
	4		39.7 b				
	5		38.7 b				
	October	#	p=0.1175	#	***p<0.0001***	#	p=0.5541
	1				35.0 b		
	2				36.4 b		
	3				37.1 b		
	4				30.1 a		
	5				28.1 a		

LS means of volumetric soil moisture (%)
Cropping systems: 1=continuous corn, 2=corn-soy-triticale/soy, 3=switchgrass, 4=triticale/sorghum, 5=triticale/trees
Landscape positions: 1=summit, 2=shoulder, 3=backslope, 4=toeslope, 5=floodplain
no data collected
not enough data for statistical analysis

Table 3.7. Results of comparison of soil moisture (%) 80-100 cm

Depth (cm)	Month	2010 Cropping system	2011 Cropping system	2010 Landscape position	2011 Landscape position	2010 Landscape position* cropping system	2011 Landscape position* cropping system
80-100	April		p=0.4693		***p<0.0001***		p=0.7567
	1	#		#	38.3 a	#	
	2				39.6 a		
	3				44.1 b		
	4				45.9 b		
	5				45.5 b		
	May		p=0.8136		***p=0.0010***		p=0.4170
	1	#		#	39.1 a	#	
	2				38.3 a		
	3				42.6 b		
	4				44.2 b		
	5				42.8 b		
	June	p=0.6740	p=0.7866	p=0.1586	***p=0.0204***	p=0.3953	p=0.3633
	1				37.8 a		
	2				39.6 ab		
	3				42.9 b		
	4				42.4 b		
	5				42.2 b		
	July	p=0.5218	p=0.5659	p=0.1649	p=0.1269	p=0.8825	p=0.6491
	1						
	2						
	3						
	4						
	5						
	August	p=0.8979	p=0.4613	p=0.0874	p=0.6282	p=0.6059	p=0.8843
	1						
	2						
	3						
	4						
	5						
	September	p=0.6262	***p=0.0402***	***p=0.0037***	***p=0.0138***	p=0.7917	p=0.7650
	1		35.3 ab	38.3 a	33.2 a		
	2		34.1 a	41.2 ab	35.7 b		
	3		37.8 ab	44.1 bc	39.0 b		
	4		39.6 b	44.6 c	39.7 b		
	5		38.9 b	42.8 bc	38.1 b		
	October		p=0.2750		***p=0.0002***		p=0.4033
	1	#		#	36.6 b	#	
	2				36.1 b		
	3				38.0 b		
	4				32.1 a		
	5				30.3 a		

LS means of volumetric soil moisture (%)
Cropping systems: 1=continuous corn, 2=corn-soy-triticale/soy, 3=switchgrass, 4=triticale/sorghum, 5=triticale/trees
Landscape positions: 1=summit, 2=shoulder, 3=backslope, 4=toeslope, 5=floodplain
no data collected
not enough data for statistical analysis

Table 3.8. Results of comparison of soil moisture (%) 100-120 cm

		2010	2011	2010	2011	2010	2011
Depth (cm)	Month	Cropping system	Cropping system	Landscape position	Landscape position	Landscape position* cropping system	Landscape position* cropping system
100-120	April	#	p=0.6999	#	***p<0.0001***	#	p=0.7497
	1				41.2 b		
	2				36.9 a		
	3				43.8 bc		
	4				45.7 c		
	5				45.7 c		
	May	#	p=0.9258	#	***p=0.0001***	#	p=0.3874
	1				42.1 b		
	2				36.9 a		
	3				42.2 b		
	4				44.6 b		
	5				43.5 b		
	June	p=0.8592	p=0.8786	p=0.0541	p=0.1512	p=0.4400	p=0.4194
	1						
	2						
	3						
	4						
	5						
	July	p=0.6815	p=0.9748	p=0.1652	p=0.3835	p=0.7844	p=0.6237
	1						
	2						
	3						
	4						
	5						
	August	p=0.8706	p=0.8853	***p=0.0270***	p=0.2644	p=0.8444	p=0.8709
	1			39.9 a			
	2			39.7 a			
	3			44.1 b			
	4			43.9 b			
	5			42.4 ab			
	September	p=0.3463	p=0.6623	***p=0.0018***	p=0.3590	p=0.4151	p=0.9759
	1			39.0 a			
	2			40.8 ab			
	3			44.5 c			
	4			44.5 c			
	5			43.6 bc			
	October	#	p=0.6931	#	p=0.0561	#	p=0.8532
	1						
	2						
	3						
	4						
	5						

LS means of volumetric soil moisture (%)
Cropping systems: 1=continuous corn, 2=corn-soy-triticale/soy, 3=switchgrass, 4=triticale/sorghum, 5=triticale/trees
Landscape positions: 1=summit, 2=shoulder, 3=backslope, 4=toeslope, 5=floodplain
no data collected
not enough data for statistical analysis

Table 3.9. Precipitation (mm) and potential evapotranspiration (PET) prior to collecting soil moisture measurements

	Total precipitation/PET prior	Collection	Collection	Days prior to data collection				
2010	to last day of data collection	day 2	day 1	-1	-2	-3	-4	-5
June	53.3/34.0	*25.4/9.1	0/2.4	*0/1.7	6.1/7.8	20.1/4.0	*1.8/6.9	*0.0/6.3
July	24.9/39.5	5.6/6.1	0.3/7.0	18/6.8	1/2.2	0.0/4.0	0.0/6.8	0.0/6.5
August	0.3/41.6	0.0/5.8	0.0/6.1	0.0/7.0	0.0/6.7	0.0/5.4	0.3/5.4	0.0/5.2
September	91.7/15.7	0.3/4.0	18/3.3	0.0/0.1	23.6/4.5	0.8/1.6	49/1.4	0.0/0.8
2011								
April	14.0/31.5	13.7/1.7	0.0/3.2	0.0/5.7	0.0/5.6	0.0/4.5	0.0/7.2	0.3/3.6
May	24.1/42.6	22.3/4.6	0.0/3.5	0.0/11.0	0.0/7.0	0.0/8.6	0.0/5.9	1.8/5.9
June	0.0/53.5	0.0/2.5	0.0/9.9	0.0/12.0	0.0/9.1	0.0/6.8	0.0/4.8	0.0/8.5
July	1.0/32.6	0.0/5.7	0.0/4.3	0.0/5.3	0.3/3.3	0.3/5.9	0.3/2.4	0.3/6.1
August	54.9/26.5	0.0/5.2	4.6/6.2	0.0/3.7	0.0/5.3	15.7/3.0	34.5/1.4	0.0/1.7
September	19.0/30.0	0.0/4.4	0.3/4.9	0.3/4.2	0.0/3.9	0.0/3.8	0.0/4.2	18.5/4.7
October	12.7/23.3	0.0/3.7	0/3.9	11.2/3.7	0.3/1.0	1.3/3.1	0.0/2.5	0.0/5.3

Data displayed as Precipitation (mm)/Potential evapotranspiration (PET)(mm). *Data collection days in June 2010. Days prior to first day of collection in June 2010 had 19.6/3.9, 1.5/6.2, 3.6/7.7,0/7.1,0/8.6 mm of precipitation/PET, respectively.

Table 3.10. Results of comparison of soil water storage 0-60 cm and 0-102 cm.

Depth	Treatment	Landscape position	Month	Treatment X Landscape position	Treatment X month	Landscape position X month
			2010			
0-60cm	p=0.9595	p<0.0001 1<2=4=3<5	p<0.0001 June<July<Aug=Sept	p=0.8871	p=0.3537	p=0.0002
0-120cm	p=0.9331	p=0.0598	p<0.0001 June<July<Aug<Sept	p=0.9306	p=0.0161	p=0.0001
			2011			
0-60cm	p=0.0876	p=0.0056 4=5<3	p<0.0001 Jun<Jul=Oct<Sept<May<Apr<Aug	p=0.5543	p<0.0001	p<0.0001
0-120cm	p=0.4654	p=0.1028	p<0.0001 Jun<Sept<Oct<Jul<May<Aug<Apr	p=0.5075	p<0.0001	p<0.0001

Treatment: 1-cont. corn, 2-corn-soy-triticale/soy, 3-switchgrass, 4-triticale/sorghum, 5-triticale/trees
Landscape position: 1-summit, 2-shoulder, 3-backslope, 4-toeslope, 5-floodplain.

Table 3.11. Soil water storage 0-60 cm by (a) treatment and (b) landscape position

Treatment							
(a)	April	May	June	July	August	September	October
2010							
continuous corn	#	#	18.3 a	18.2 a	17.2 a	21.2 a	#
corn-soy-**trit/soy**			18.2 a	19.3 a	18.2 a	21.6 a	
switchgrass			18.2 a	19.0 a	17.9 a	20.3 a	
sorghum/trit			17.1 a	18.8 a	18.0 a	21.7 a	
trees			17.4 a	19.6 a	18.0 a	21.0 a	
2011							
continuous corn	21.0 ab	19.3 ab	15.7 a§	17.7 a§	21.3 a	17.6 a	17.5 ab
corn-soy-trit/soy	21.6 ab	20.0 bc	16.9 a§	18.4 a§	22.5 a	18.8 a	18.5 bc
switchgrass	22.1 b	20.7 c	16.7 a§	17.8 a§	22.6 a	19.8 a	19.2 c
sorghum/trit	22.1 b	20.1 bc	15.6 a§	19.2 a§	23.1 a	19.3 a	19.2 c
trees	20.6 a	18.6 a	15.3 a§	17.8 a§	22.0 a	17.7 a	16.8 a

Landscape position							
(b)	April	May	June	July	August	September	October
2010							
Summit	#	#	15.8 a	18.4 ab	18.5 b	19.5 a	#
Shoulder			18.5 b	18.5 ab	17.9 ab	20.9 a	
Backslope			18.1 b	19.4 bc	19.1 b	22.3 a	
Toeslope			18.3 b	18.1 a	17.8 ab	21.3 a	
Floodplain			18.7 b	20.6 c	16.0 a§	22.0 a	
2011							
Summit	20.1 a	18.9 a	15.3 a§	19.1 b	22.1 ab	18.0 a	19.2 b
Shoulder	20.8 ab	19.2 a	15.9 a§	19.5 b	23.0 b	19.0 a	20.0 b
Backslope	21.8 bc	20.8 b	16.7 a§	20.1 b	23.1 b	20.1 a	20.7 b
Toeslope	22.1 c	20.0 ab	15.6 a§	16.3 a§	21.0 a	17.9 a	16.0 a
Floodplain	22.7 c	19.8 ab	15.3 a§	15.7 a§	21.1 ab	18.1 a	15.4 a

LS Means estimate of soil water storage (cm), Different letters in same month and year indicate difference at $p<0.05$, # no samples collected, §No data from 0-20 cm

Table 3.12. Soil water storage 0-120 cm by (a) treatment and (b) landscape position

			Treatment				
(a)	April	May	June	July	August	September	October
			2010				
continuous corn	#	#	37.1 a	36.6 a	40.7 a	47.7 a	#
corn-soy-**trit/soy**			37.8 a	39.5 a	42.5 a	46.4 a	
switchgrass			36.9 a	37.8 a	42.8 a	43.7 a	
sorghum/trit			35.4 a	38.8 a	43.2 a	47.0 a	
trees			35.7 a	40.5 a	41.9 a	44.9 a	
			2011				
continuous corn	46.2 a	43.7 a	39.2 a§	42.2 a§	43.9 a	38.9 a	37.5 a
corn-soy-trit/soy	48.0 a	45.3 a	41.9 a§	43.7 a§	46.0 a	40.2 ab	38.2 a
switchgrass	47.8 a	45.7 a	39.7 a§	42.0 a§	46.2 a	43.3 bc	40.5 a
sorghum/trit	48.0 a	45.0 a	39.5 a§	44.3 a§	47.6 a	41.2 c	40.6 a
trees	45.7 a	43.4 a	40.1 a§	43.2 a§	46.2 a	40.8 abc	37.6 a

			Landscape position				
(b)	April	May	June	July	August	September	October
			2010				
Summit	#	#	33.9 a	37.8 a	42.0 ab	40.1 a	#
Shoulder			36.9 a	37.5 a	41.4 ab	45.8 ab	
Backslope			36.9 a	40.0 a	45.1 b	48.8 b	
Toeslope			38.4 a	38.5 a	43.7 b	47.9 b	
Floodplain			36.9 a	39.5 a	38.9 a	47.1 b	
			2011				
Summit	43.7 a	43.0 ab	38.2 a§	42.7 abc	44.8 a	38.8 a	41.2 b
Shoulder	44.3 a	42.1 a	39.7 a§	44.4 bc	46.2 a	40.2 a	41.3 b
Backslope	48.1 ab	46.3 c	42.3 a§	45.7 c	47.6 a	43.3 a	43.2 b
Toeslope	49.7 b	46.5 c	41.0 a§	42.2 ab§	45.4 a	41.2 a	35.2 a
Floodplain	49.8 b	45.3 bc	40.0 a§	40.3 a§	45.8 a	40.8 a	33.6 a

LS Means estimate of soil water storage (cm), Different letters in same month and year indicate difference at p<0.05, # no samples collected, §No data from 0-20 cm

Table 3.13. Results of comparison of soil water storage 0-60 cm

	Treatment	Landscape position	Treatment X Landscape position
		2010	
June	p=0.2907	p=0.0011 1<2=3=4=5	p=0.8354
July	p=0.2263	p=0.0017 4=1=2<5, 4<3	p=0.9568
August	p=0.8528	p=0.0371 5<1=3	p=0.9293
September	p=0.7680	p=0.1572	p=0.8589
		2011	
April	p=0.0238 5<3=4	p<0.0001 1=2<5, 1<3=4	p=0.9121
May	p=0.0224 5=1<3, 5<2=4	p=.0383 1=2<3	p=0.7584
June	p=0.0724	p=0.1297	p=0.4459
July	p=0.1920	p<0.0001 5=4<1=2=3	p=0.4103
August	p=0.1407	p=0.0349 4<2=3	p=0.5731
September	p=0.0543	p=0.0724	p=0.7362
October	p=0.0073 5=1<3=4, 5<2	p<0.0001 5=4<1=2=3	p=0.3732

Treatment: 1-summit, 2-shoulder, 3-backslope, 4-toeslope, 5-floodplain
Landscape position: 1-cont. corn, 2-corn-soy-triticale/soy, 3-switchgrass, 4-triticale/sorghum, 5-triticale/trees

Table 3.14. Results of comparison of soil water storage 0-120 cm

	Treatment	Landscape position	Treatment X Landscape position
2010			
June	p=0.6062	p=0.1658	p=0.8258
July	p=0.0981	p=0.3669	p=0.8236
August	p=0.6953	p=0.0187 5<4=3	p=0.8763
September	p=0.4867	p=0.0108 1<5=4=3	p=0.9213
2011			
April	p=0.1493	p<0.0001 1=2<4=5	p=0.7802
May	p=0.3505	p=0.0052 2=1<3=4, 2<5	p=0.6460
June	p=0.4875	p=0.0841	p=0.4387
July	p=0.4946	p=0.0088 5<2=3, 4<3	p=0.5733
August	p=0.3118	p=0.5587	p=0.6926
September	p=0.0765	p=0.0765	p=0.6359
October	p=0.1005	p<0.0001 5=4<1=2=3	p=0.3451

Treatment: 1-summit, 2-shoulder, 3-backslope, 4-toeslope, 5-floodplain
Landscape position: 1-cont. corn, 2-corn-soy-triticale/soy, 3-switchgrass, 4-triticale/sorghum, 5-triticale/trees

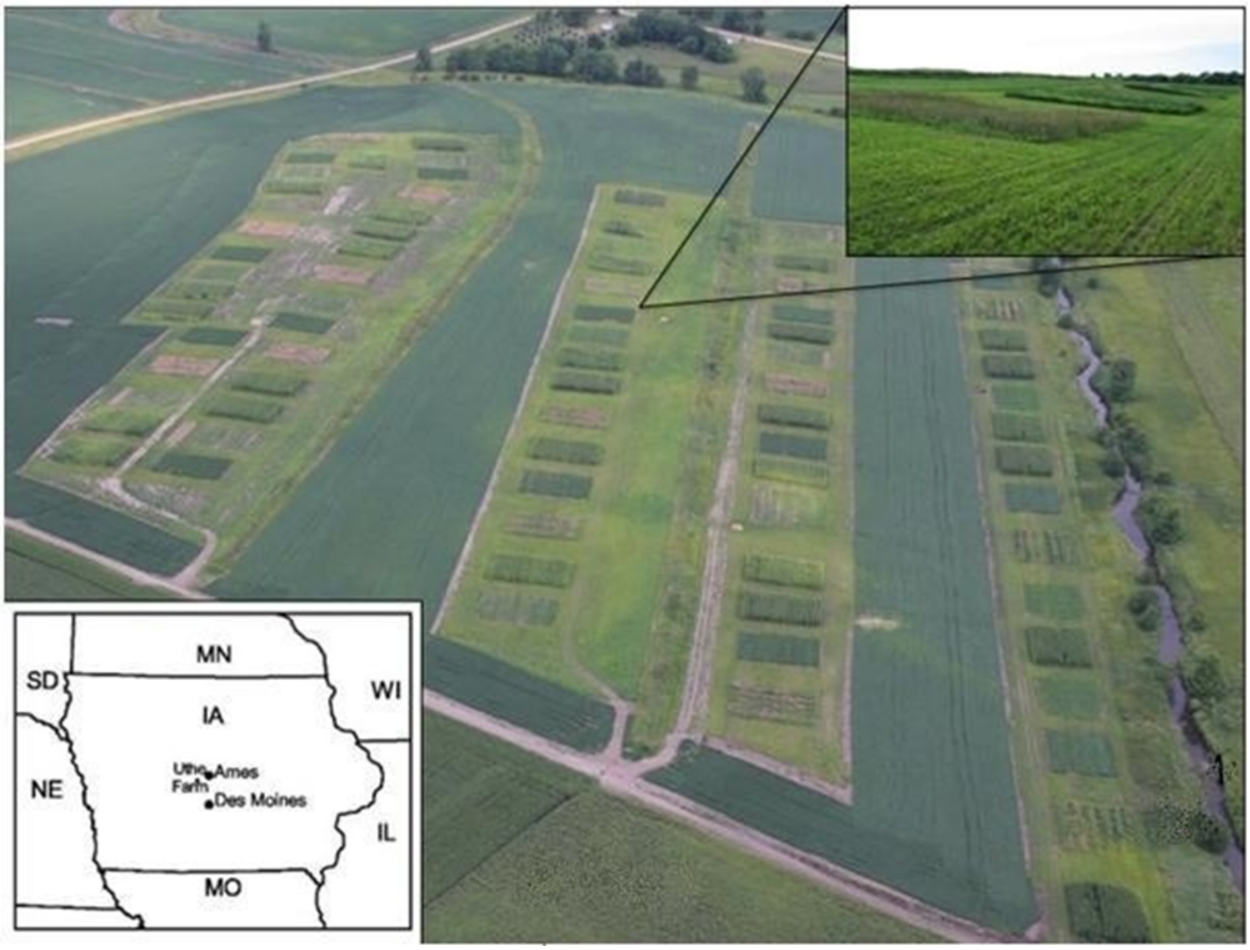


Figure 3.1. Iowa State University Uthe research farm (Schulte, 2010).

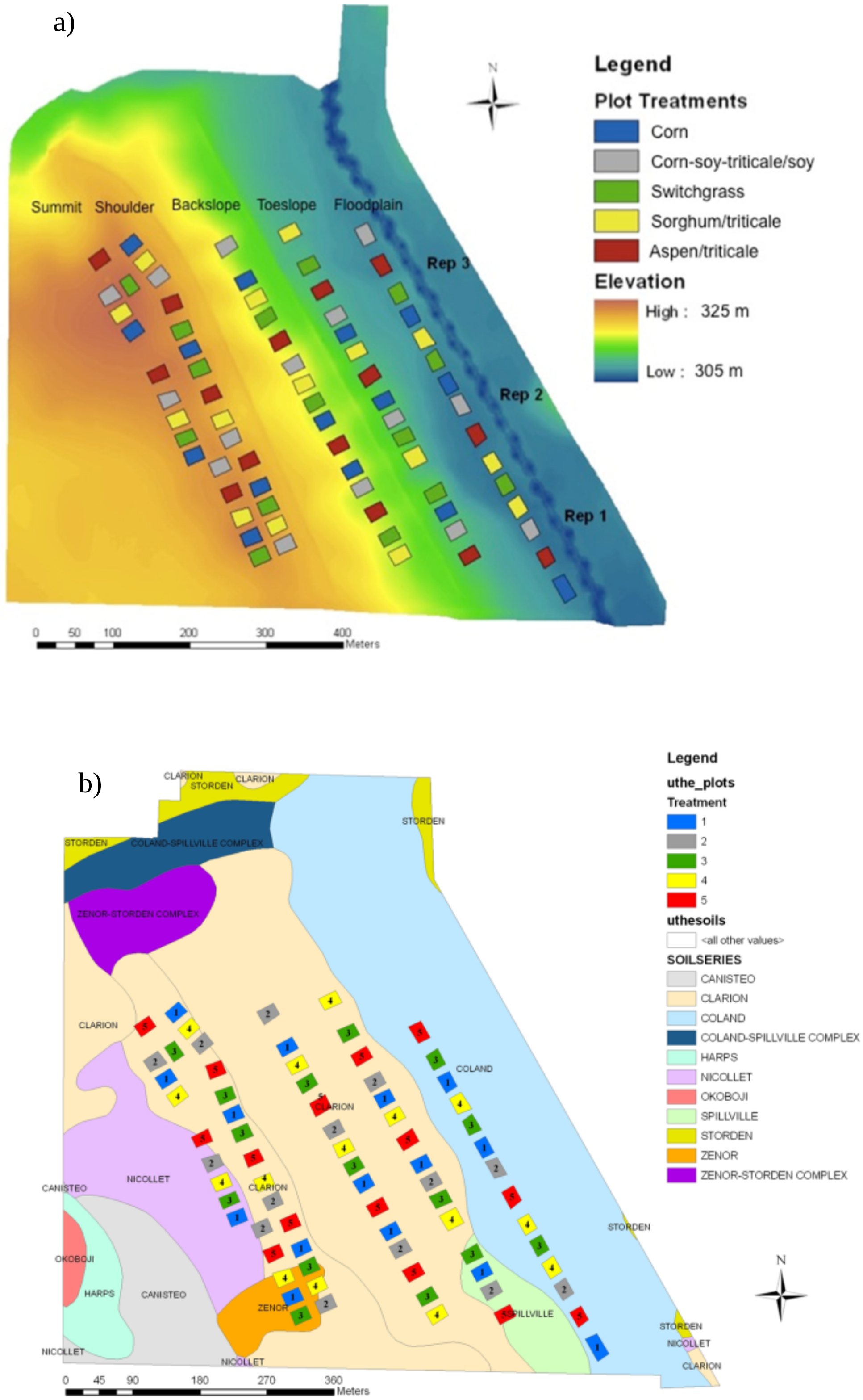


Figure 3.2a) Landscape positions and b) soils at the Uthe research farm, Ames, IA (Schulte, 2010)

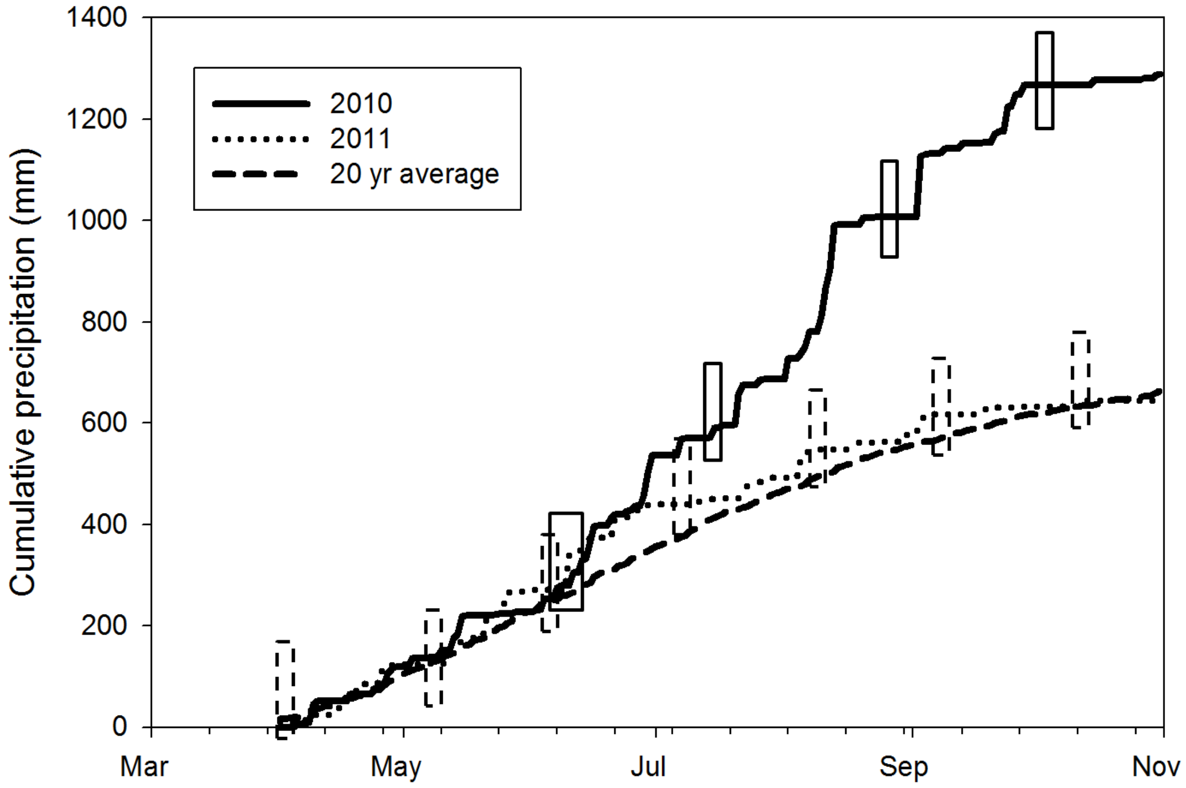


Figure 3.3. Precipitation comparison at ISU Reynoldson research site (1.5 km SE of Uthe research site). Boxes indicate sampling periods.

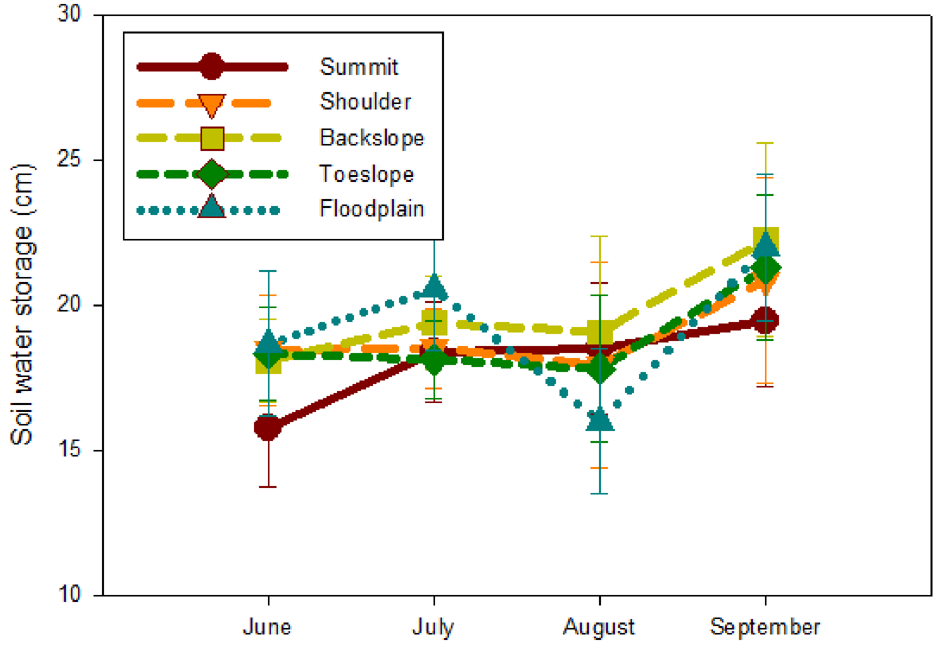


Figure 3.4. 2010 soil water storage 0-60 cm by landscape position. Error bars indicate standard deviation of soil water storage.

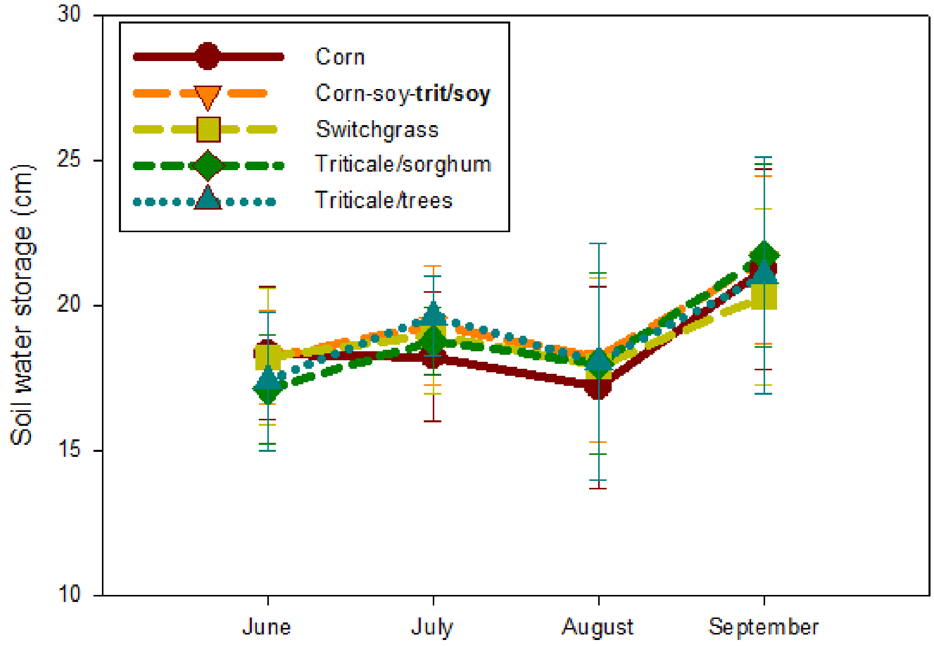


Figure 3.5. 2010 soil water storage 0-60 cm by cropping system. Error bars indicate standard deviation of soil water storage.

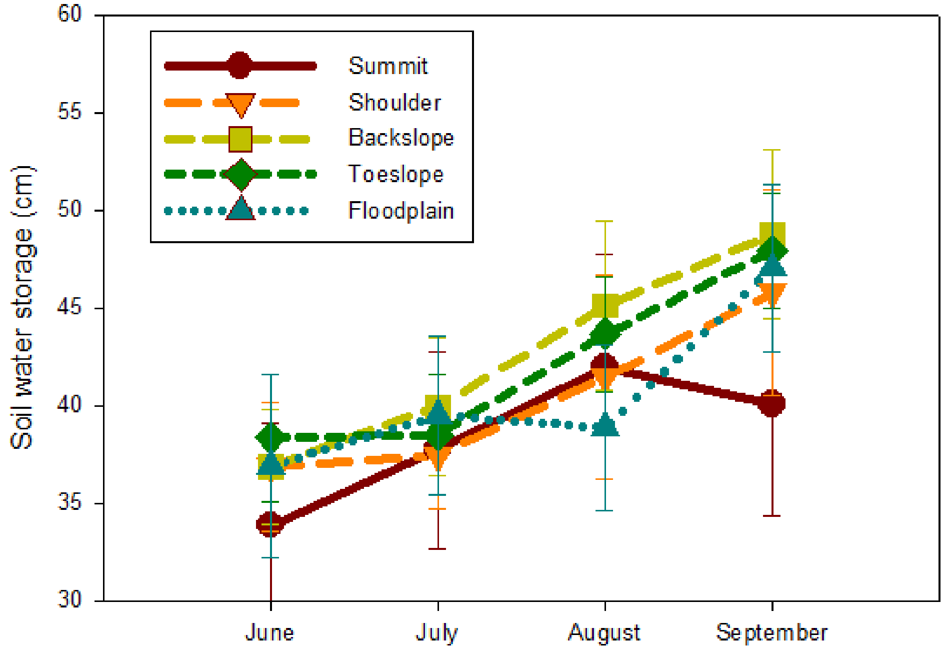


Figure 3.6. 2010 soil water storage 0-120 cm by landscape position. Error bars indicate standard deviation of soil water storage.

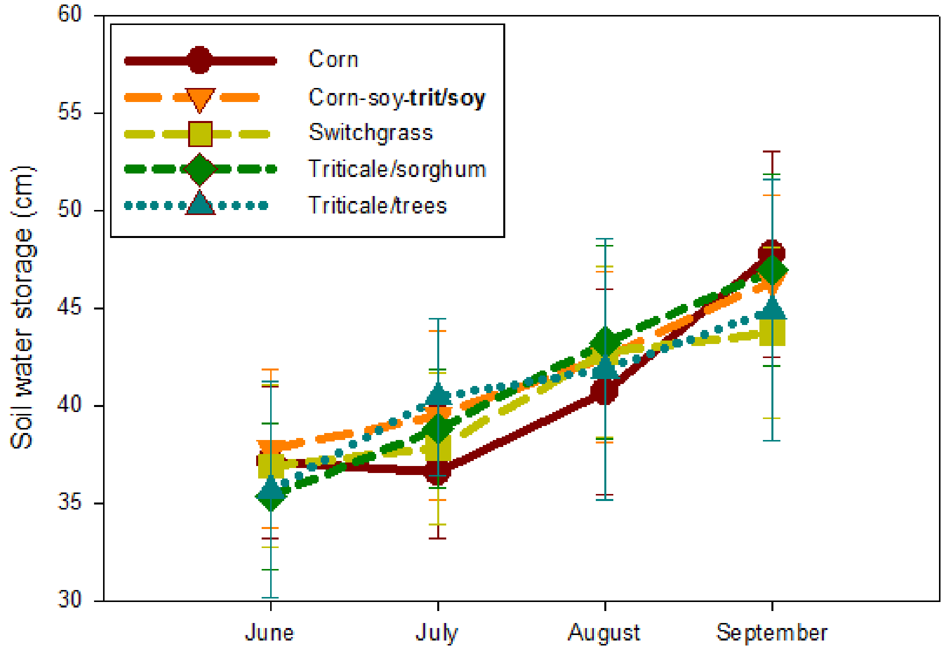


Figure 3.7. 2010 soil water storage 0-120 cm by cropping system. Error bars indicate standard deviation of soil water storage.

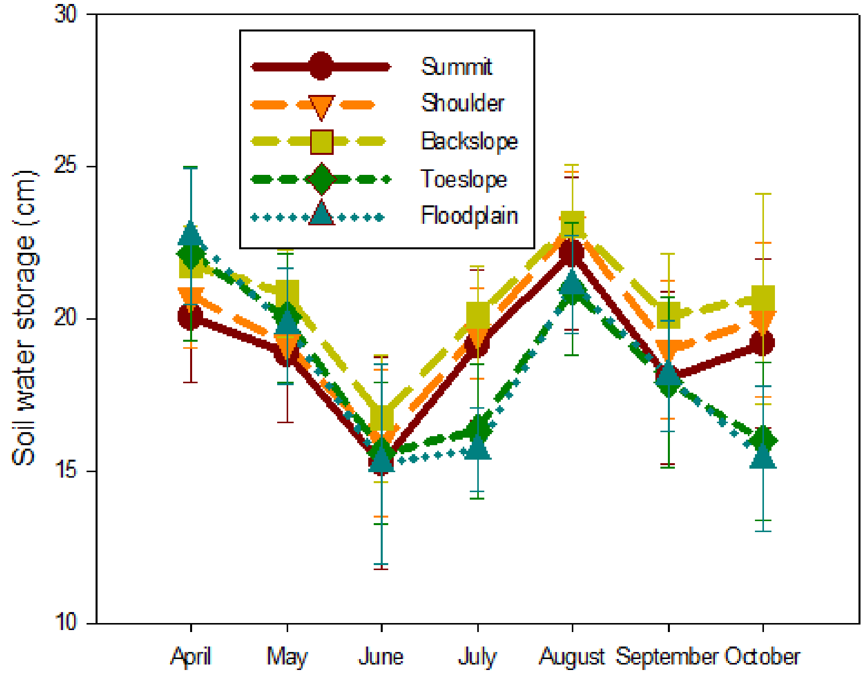


Figure 3.8. 2011 soil water storage 0-60 cm by landscape position. Error bars indicate standard deviation of soil water storage.

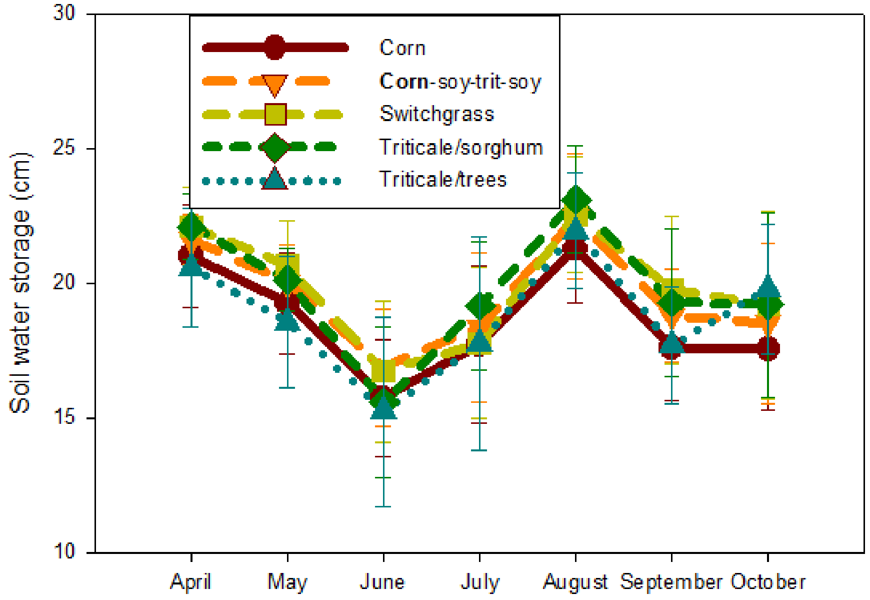


Figure 3.9. 2011 soil water storage 0-60 cm by treatment. Error bars indicate standard deviation of soil water storage.

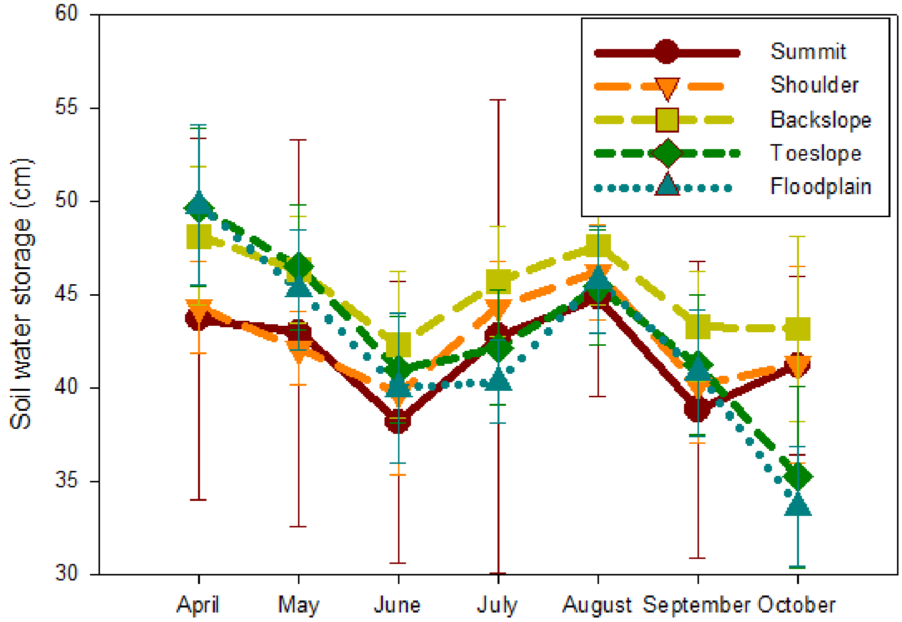


Figure 3.10. 2011 soil water storage 0-120 cm by landscape position. Error bars indicate standard deviation of soil water storage.

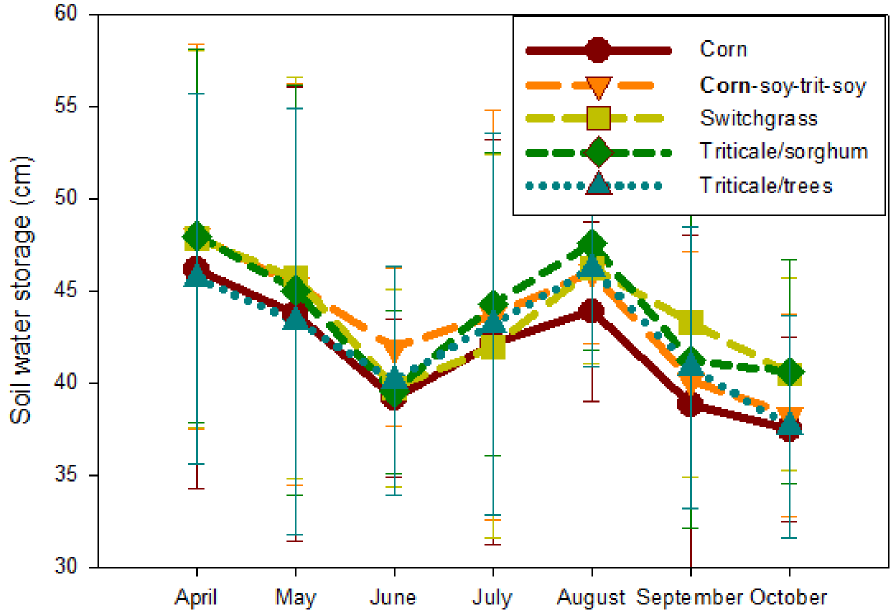


Figure 3.11. 2011 soil water storage 0-120 cm by treatment. Error bars indicate standard deviation of soil water storage.

CHAPTER 4: GENERAL CONCLUSIONS

4.1 Conclusions

As agricultural producers in the Midwest consider potentially shifting from grain-based biofuel feedstocks to second-generation, cellulosic feedstocks, it is essential that we assess the environmental impacts of these new cropping systems. We have studied the effect of various biomass production systems across landscape positions on NO_3-N concentration in the root zone and soil moisture dynamics. We observed significant differences among the cropping systems with a likely association between nitrogen fertilizer inputs to the systems containing corn and NO_3-N concentrations in the root zone. The triticale/sorghum system had consistently lower NO_3-N concentrations in the root zone than the corn systems although they received only slightly lower total N fertilizer. A rise in NO_3-N concentration in the root zone was also not observed in the switchgrass plots following a significant N input from fertilization. This may indicate that the triticale/sorghum double cropping system and the perennial switchgrass systems are more efficient at N uptake or that the NO_3-N did not get transported to the root zone. The triticale/trees system had lower moisture and soil water storage in the upper 60 cm of the soil profile than the other systems in April, May, and October 2011, which may indicate increased evapotranspirative demand. The relatively larger amount of stubble and residue in the switchgrass plots may account for the higher moisture levels at the surface in April, May and September 2011. Quantifying the water quality and soil moisture dynamics of biomass production systems will aid in optimizing deployment of biomass cropping systems across landscape positions as producers gear up to meet biomass production demand by providing part of the information needed to assess their multifunctional performance.

4.2 Recommendations

It would be beneficial to continue this study into the future to refine and fully understand observed differences among the biomass production systems. This would facilitate complete establishment of the perennial cropping systems and allow them to demonstrate their full potential. Continuous soil moisture monitors in each plot would increase the temporal data resolution and eliminate the effects of only having one data set per month. It would also remove the possibility of error from sampling over multiple days. Experiments could be conducted in the lab where rainfall rates and other variables could be controlled. If the same cropping systems were replicated in a lab we could more easily determine the fate of fertilizer and water inputs. We could use this information to determine if differences in NO_3-N concentrations and soil water in the field are due to the plants or other uncontrolled factors. This would increase our understanding of how varying amounts and timing of precipitation affect NO_3-N transport and soil moisture. Other potential biomass feedstocks (e.g., *Miscanthus* and willow) could be incorporated into the study. It would also be of benefit to expand this study to a wider variety of locations to expand on landscape impacts.

APPENDIX

Soil loss prediction of various biomass production systems across landscape positions using the Water Erosion Prediction Project (WEPP) model

Introduction

Many current agricultural practices are causing erosion rates to be much faster than soil can be generated (Montgomery, 2007 and Kort, 2009). Kort et al (1998) reviewed the soil erosion potential of biomass crops and identified that overall the change from row crops to biomass crops would likely reduce erosion, but there are several potential negative effects as well. They concluded that perennial species will lead to minimal soil erosion because of the year round soil protection they provide. They stated that perennial sod crops resulted in soil loss levels well below levels that are generally accepted for sustained productivity. They also noted that woody biomass crops generally reduce soil erosion by water and wind; however, one potential negative impact is that when woody biomass crops mature, they shade out the ground below them. This results in severe reduction of vegetative undergrowth, which could leave the soil more vulnerable to erosion if it is exposed from harvest. Another potential drawback of woody biomass crops is that they often lower the water table from their increased evapotranspirative demand. Kort et al (1998) also noted a study from Australia where a pine plantation reduced the water table level enough to change a naturally perennial stream to an ephemeral stream. While this will surely reduce water erosion, it is not necessarily beneficial to aquatic habitats and the species that rely on them. They also noted that the reduction in soil moisture from the increased water demand from the trees can leave a soil more susceptible to wind erosion.

This study investigates the effects of landscape position and cropping system on soil loss. The Water Erosion Prediction Project (WEPP) is used to estimate soil loss on Iowa crop land. Each estimate is based on the annual average soil loss over a five year simulation. Five biomass cropping systems are evaluated across five landscape positions. This paper investigates potential changes in estimated soil loss.

Biomass cropping systems and landscape positions

The five biomass cropping systems being evaluated are (1) continuous corn (*Zea mays*), (2) corn-soybean-triticale/soybean (*Zea mays-Glycine max-Glycine max*/×*Triticosecale)* (3) corn-switchgrass (*Zea mays-Pancium virgatum)*, (4) triticale/sorghum (×*Triticosecale*/*Sorghum bicolor*), and (5) triticale/trees (×*Triticosecale* / *Populus alba X P. grandidentata*) (Figure 1). Specific biomass systems were selected based on their compatibility with existing agricultural systems and their potential to provide either superior biomass yields (triticale/sorghum), some biomass yield while mitigating some negative environmental impacts (corn-soybean-triticale/soybean, corn-switchgrass), or some short-term biomass yield and superior long-term yield while strongly mitigating negative environmental impacts (triticale/trees) compared to conventional corn production systems.

A randomized, replicated experiment has been established to compare the five biomass systems across five landscape positions (summit, shoulder, backslope, toeslope and floodplain) (Fig. 4.1). All cropping systems are managed using no-till practices. The continuous corn system serves as a baseline from which to compare the alternative biomass cropping systems. Corn-switchgrass is an intercropping system in which corn provided weed control and a harvestable crop of grain and stover in the first year as the switchgrass established. Corn-soybean-triticale/soybean supplements the conventional corn-soybean rotation with a winter triticale biomass crop. Triticale is planted the September following the first soybean harvest, serves as a winter cover crop reducing exposure of soil to water and wind erosion, and is then harvested as a biomass crop in the early summer; it is followed immediately by soybean harvested for grain in the fall. Triticale/sorghum is a double-cropping system in which winter triticale planted in the fall, harvested the following June, and sorghum is planted into its stubble and harvested in September. Triticale/trees is an intercropping system in which winter triticale was planted in October before the trees are planted in May. Triticale is then harvested from between the tree rows as a biomass crop in early July, providing biomass productivity and a harvestable crop while the high-yield aspen trees (Crandon clone) are establishing. Triticale is then replanted between rows in the fall. We expect to be able to grow and harvest triticale for the first 3-5 years, as the trees establish and before full canopy closure (Schulte, 2010).

Five landscape positions (summit, shoulder, backslope, toeslope, and floodplain) are evaluated for this study. Replicate three is evaluated because of the consistent soil series among the upper four landscape positions. The soil series in all plots in all but the floodplain position is Clarion. As described by the National Cooperative Soil Survey of the United States, the Clarion series consists of very deep, moderately well drained soils on uplands. These soils were formed in glacial till and have slopes that range from 1 to 9 percent. The soil series in the floodplain is Coland. As described by the National Cooperative Soil Survey of the United States, the Coland series consists of very deep poorly drained soils formed in alluvium. These soils are on floodplains and alluvial fans in river valleys and upland drainageways in dissected till plains. Slope ranges from 0 to 5 percent. The slope shapes are uniform along each plot’s length and are as follows: summit 2%, shoulder 4%, backslope 7%, toeslope 5%, and floodplain 1%. All plots in the upper four landscape positions have slope lengths of 24.4 m (80 ft) and widths of 18.3 m

(60 ft) and those in the floodplain have slope lengths of 18.3m (60 ft) and widths of 24.4 m (80 ft).

Overview of the Water Erosion Prediction Project (WEPP)

The WEPP erosion model calculates soil loss along a hillslope as well as sediment yield at the end of a hillslope. Interrill and rill erosion processes are included in this determination of soil loss. Interrill erosion is a process of soil detachment by raindrop impact, transport by shallow sheet flow, and sediment delivery to rill channels. Sediment delivery rate to rill flow areas is assumed to be proportional to the product of rainfall intensity and interrill runoff rate. Rill erosion is described as a function of the flow's ability to detach sediment, sediment transport capacity, and the existing sediment load in the flow (USDA, 1995). For a more in depth overview of the WEPP program see Chapter 1 of USDA, 1995.

The weather generator used in WEPP is Cligen which was produced by Arlin Nicks and Gene Gander at the USDA Agricultural Research Service (ARS) lab. It is a stochastic weather generator which produces daily estimates of precipitation, temperature, dewpoint, wind, and solar radiation for a single geographic point, using monthly parameters (means, standard deviations, skewness, etc.) derived from the historic measurements (USDA, 1995). For further details about Cligen see Chapter 2 of USDA, 1995. The purpose of the surface water flow component in WEPP is to provide the erosion information with the length of rainfall excess, the rainfall intensity during the period of rainfall excess, the runoff volume, and the peak discharge rate. The sequence of calculations relevant to surface hydrology is infiltration, rainfall excess, depression storage, and peak discharge. Infiltration is computed using an implementation of the Green-Ampt Mein-Larson model for unsteady intermittent rainfall. The rainfall excess rate only applies when the rainfall rate is greater than the infiltration rate. The volume of rainfall excess is decreased to account for depression storage and runoff is assumed to begin only after this storage has been filled (USDA, 1995). For more details and explanation of each equation used see Chapter 4 of USDA, 1995. Precipitation, maximum temperature, and minimum temperature data for the years 2006to 2010 were obtained from the National Weather Service (NWS) Cooperative Observer Program (COOP) from the Boone, IA observation site. These data were used as the input to Cligen for weather generation. Other parameters used by Cligen were taken from data in the WEPP parameter files for the Boone, IA weather station. The average predicted annual precipitation for 2006-2010 was 39.87 inches.

WEPP results

The average annual soil loss across all cropping systems and landscape positions for 2006-2010 was 2.50 tons/acre. As expected, the soil loss rates increased as the slope of the landscape position increased (Figure 4.2). The soil loss was the least in the floodplain (1% slope), with an average soil loss among all cropping systems of 1.26 tons/acre. The summit (2% slope), shoulder (4% slope), and toeslope (5% slope) landscape positions had an average annual soil loss of 2.552, 2.776, and 2.859 tons/acre, respectively. The largest soil loss was found to be at the backslope landscape position (7% slope) with an annual soil loss of 3.06 tons/acre. The cropping systems differed in the amount of soil loss (Figure 4.3). The differences can likely be attributed to a combination of soil disturbance from planting/harvesting, canopy cover by the crops, root structure of the crops, and the timing of the crop growth (Kort et al, 1998). The lowest amount of soil loss was found to be in the corn-switchgrass cropping system with an average annual soil loss of 2.101 tons/acre. This is likely attributed to the perennial root system of the switchgrass stabilizing the soil. The second lowest soil loss was in the triticale/sorghum cropping system with an annual average soil loss of 2.486 ton/acre. This double cropping system maintains ground cover that stabilizes the soil year round. The greatest risk for erosion comes just after each harvest as the new crop is establishing. This risk is mitigated somewhat by the root system of the previous crop being in place to stabilize the ground. The middle value of soil loss was in the continuous corn system with an annual average of 2.587 tons/acre. The no till farming practices which leave the root system in place after harvest mitigate some of the risks of leaving the soil bare after harvesting the grain and stover in the fall. Next was the triticale/trees cropping system with an annual average soil loss of 2.625 ton/acre. The combination of no crops being planted until the fall of the first season, the larger spacing and slow growth of the trees and there being little ground cover between triticale harvest in the summer and planting in the fall may account for the comparatively large soil loss (Kort, 1998). WEPP is unable to simulate two crops growing at the same time, so the impact of the trees' reduction of soil loss is likely underestimated because they are not represented in the model until the third year. The corn-soybean-triticale/soybean cropping system showed the most erosion with an annual average soil loss of 2.715 tons/acre. The increased soil disturbance of planting and harvesting four crops in three years may negate some of the benefits of the winter cover crop of triticale in one of the winter seasons.

Summary

Soil loss estimations were obtained for various biomass cropping systems across landscape positions. It was found that landscapes with steeper slopes produced the greatest soil loss and that there are differences in the soil loss of the production systems. This study should not be assumed to represent actual soil loss quantities but rather its goal was to compare the potential erosion changes associated with specific biomass cropping systems. There are limitations to how this study should be interpreted. Cropping and management systems and agricultural implements had to be manually created in WEPP because many of these crops and management practices are not in the WEPP database. The systems that were used were manually modified from existing systems in WEPP by changing one or more of the parameters in the files. They are closer to representing actual crops and practices at the test site than the systems in WEPP but, are likely not close enough to reality to use for quantitative analysis. Rather, the results should be used only to compare the systems to each other in a qualitative way. The slope shape and actual slope percent likely vary slightly from plot to plot, so the uniform representation by landscape position also adds error. The actual shape and slope of each plot could be directly determined in future research to refine these results. Other possible sources of error include macropores (i.e., burrows, worm holes, voids from decaying roots, etc.) that are not able to be accurately represented in WEPP, small areas of local compaction (that would reduce infiltration) from foot traffic around data collection areas within the plots, and wildlife activity. Kort et al. (1998) point out several potential negative effects of planting trees for biomass production. One key effect is that herbaceous undergrowth is suppressed from competition from sunlight. This reduced undergrowth will result in the trees being the only thing that is stabilizing the soil. This is likely little concern as long as the soil is protected by the trees, but could lead to increased erosion when the trees are removed for harvest. Future research could focus on reducing the length of time the soil is exposed before new biomass growth from the woody crops protects the soil. A possible solution that could be explored would be to seed a fast growing annual such as triticale or forage oats just prior to or at the time of harvest to stabilize the soil and reduce the risk of erosion.

References

Kort, J., M. Collins, and D. Ditsch. 1998. A review of soil erosion potential associated with biomass crops. *Biomass and Bioenergy.* 14:351-359.

Montgomery, D.R. 2007. Soil erosion and agricultural sustainability. Proc. Natl. Acad. Sci. USA 13268-13272.

National Weather Service Cooperative Observer Program data was accessed at: http://mesonet.agron.iastate.edu/COOP/ ,12 March 2011.

National Cooperative Soil Survey data was accessed at: https://soilseries.sc.egov.usda.gov/OSD_Docs/C/CLARION.html, 24 March 2011.

Schulte, L.A. 2010. Developing A Portfolio Of Sustainable Regional Feedstock Production Systems For The U.S. Midwest. AFRI Project Summary.

United States Department of Agriculture (USDA).Water Erosion Prediction Project (WEPP) Hillslope Profile and Watershed Model Documentation NSERL Report #10, July 1995. available at: http://www.ars.usda.gov/Research/docs.htm?docid=18073

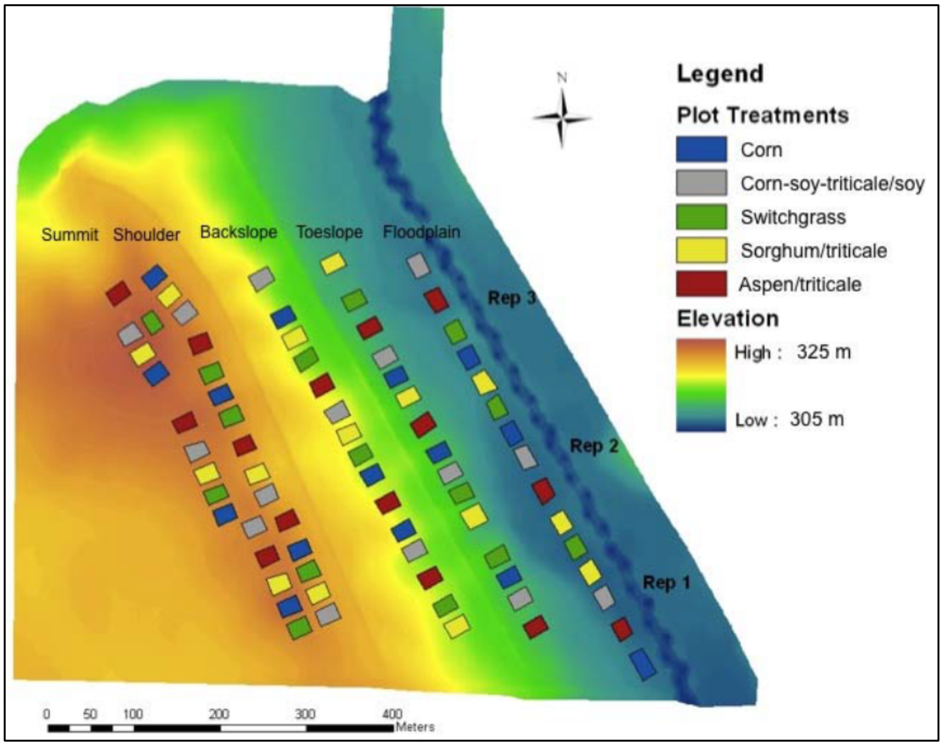


Figure 4.1. Landscape positions and cropping systems (Schulte, 2010)

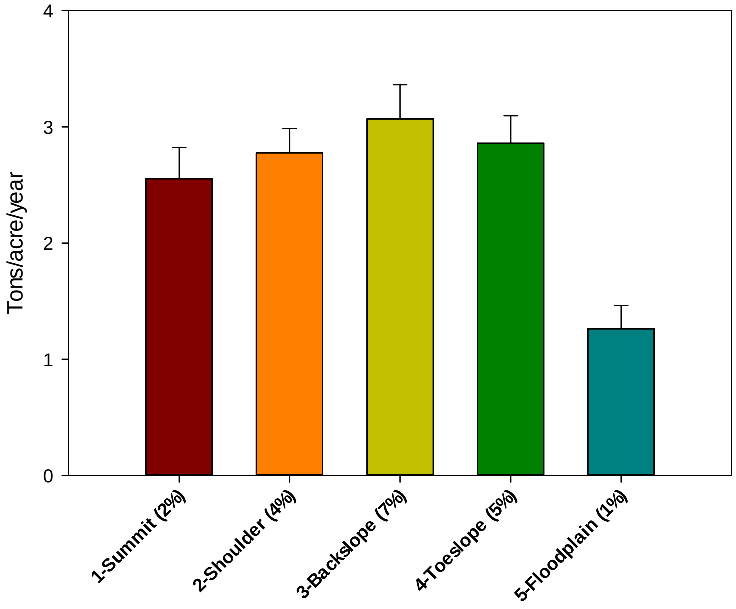


Figure 4.2. Average annual soil loss by landscape position. Error bars indicate standard deviation of soil loss.

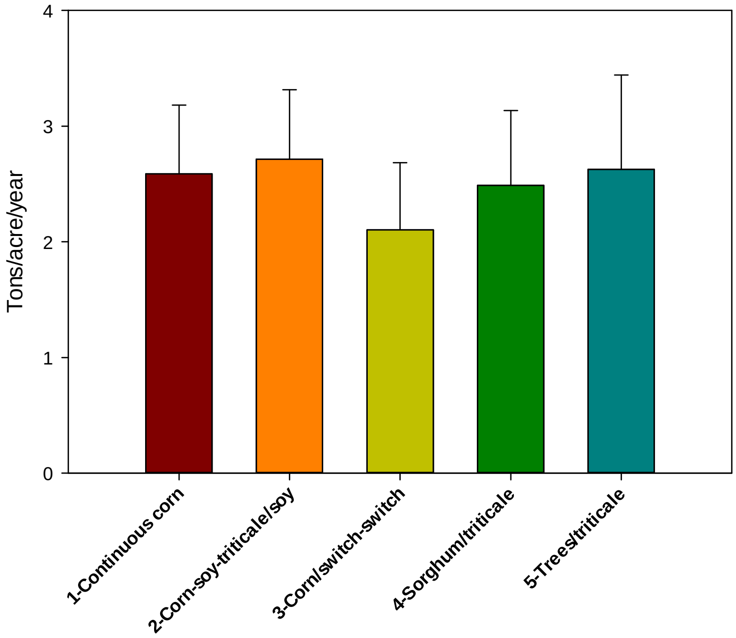


Figure 4.3. Average annual soil loss by cropping system. Error bars indicate standard deviation of soil loss.

DECAGON CALIBRATION

Methods

The ECH$_2$O EC-TM probe (Decagon Devices, Inc, Pullman, WA) was calibrated for water content measurements in site specific soils. Data was collected using the Em50 data logger (Decagon Devices, Inc, Pullman, WA). Soil samples (~10,000 cm^3) were taken from plots at the Uthe research site that were representative of the indicated soil series as shown in the USDA Web Soil Survey (www.websoilsurvey.nrcs.usda.gov). These samples were sieved through a 2 mm sieve and allowed to air dry in the lab for at least 14 days. The gravimetric water content was determined by drying a 150 g sample at 105^{o}C for 24 hours. The mass of air dry soil needed in a known volume (4000 cm^3) to maintain measured bulk density was calculated. The mass of water needed to reach volumetric water contents in 5% increments from 10% to 35% was determined. The appropriate mass of air dry soil was placed in a 4000 cm^3 container to maintain bulk density. The probe was inserted vertically into the soil at least 8 cm from the edge of the container. Care was taken to prevent air gaps around the probe. Three locations were sampled for at least five minutes each. The amount of water to reach 10% volumetric water content was added and mixed thoroughly. Bulk density was maintained by compacting, as needed, to maintain the original volume. This process was repeated until 35% volumetric water content was reached when the gravimetric water content was determined. Based on the difference between 35% volumetric water content and the measured gravimetric water content, corrections were made to account for water loss during the calibration. Calibrated equations were determined by plotting the mean raw output at each water content from the sensor with the corrected volumetric water contents (Figures 5.1-5.4). The equations for determining volumetric water content were determined to be: default $y=0.00109x-0.629$; Clarion y=0.000895x-0.4667; Coland y=0.000947x-0.48009; Spillville y=0.001045x-0.55397; Zenor y=0.000871x-0.43835, where x=raw output from sensor and y=volumetric water content.

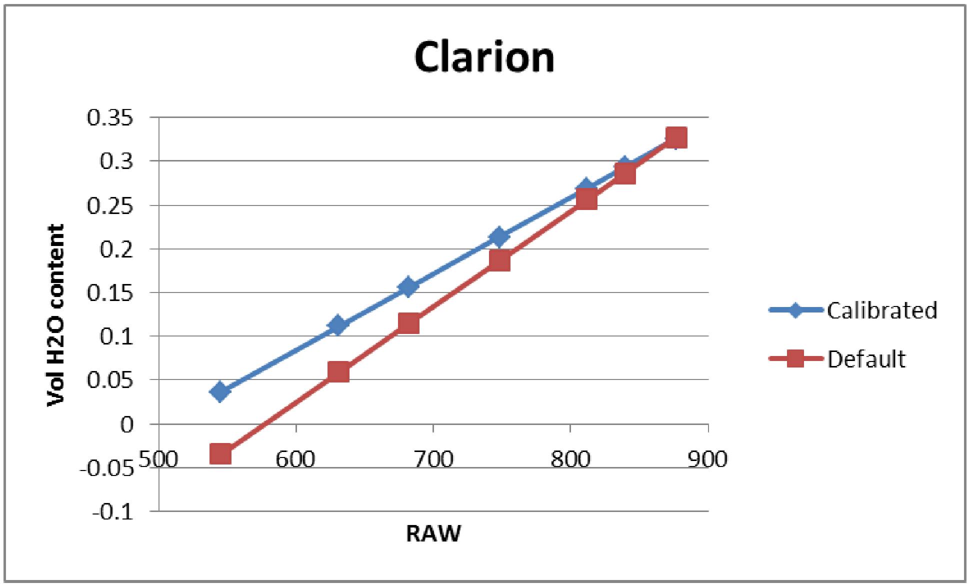


Figure 5.1. Decagon ECH$_2$O Probe calibration in Clarion soil

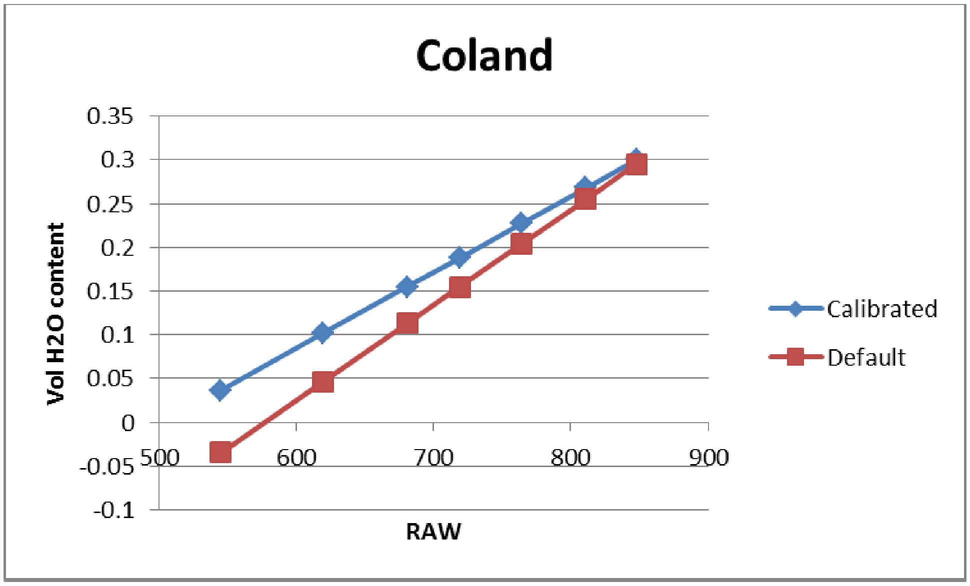


Figure 5.2. Decagon ECH$_2$O Probe calibration in Coland soil

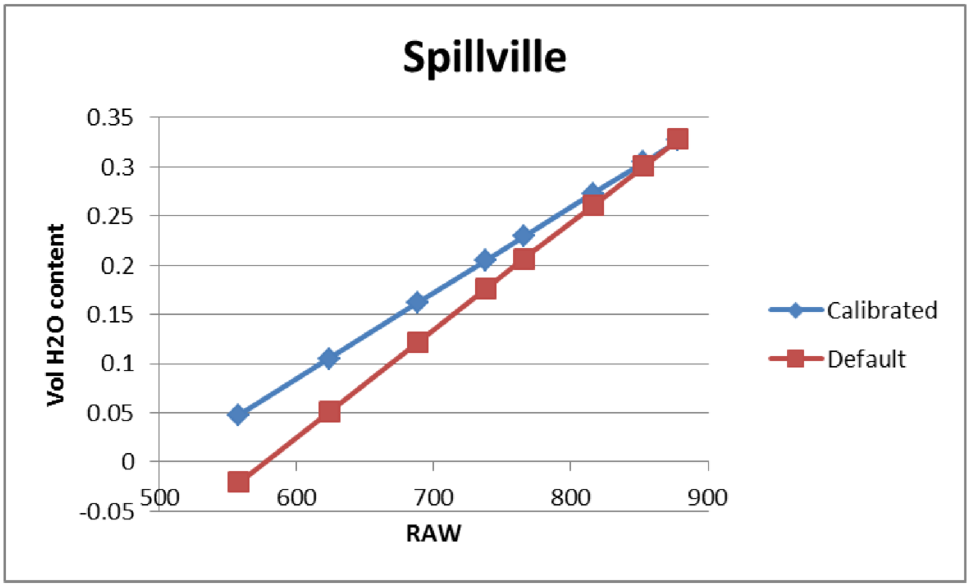


Figure 5.3. Decagon ECH$_2$O Probe calibration in Spillville soil

Figure 5.4. Decagon ECH$_2$O Probe calibration in Zenor soil

ACKNOWLEDGEMENTS

I would like to acknowledge and thank the following people for their role in the development of this thesis:

My wife, Stephanie and daughters, Whitney and Ellison

My committee: Matthew Helmers, Thomas Isenhart, Lisa Schulte-Moore

Aaron Andrews

Alan Kuuttila

Alec Anderson

Alex Steffens

Andrew Frana

Carl Pederson

Delise Lockett

Dennis Lock

Ellen White

Emily McMains

Emily Steinweg

Jeremy Sprecher

Jon Hobbs

Josh Henik

Justin Edwards

Leigh Ann Long

Ligia de Oliveira Serrano

Phillip Grandt

Rebecca Meerdink

Ryan Nelson

Sara Sloan

Sean Smith

Theo Gunther

Todd Ontl

Xiaobo Zhou