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Cover crop impacts on soil quality during Miscanthus x giganteus establishment in central Iowa

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NOMENCLATURE

SBD	Soil Bulk density
WAS	Wet aggregate stability
ASF	Aggregate size fraction
HEL	Highly Erodible Land
SAS	Statistical Analysis Software
ANOVA	Analysis of Variance
PROC GLM	General Linear Model
PROC MIXED	Mixed Model
LS MEANS	Least Square Means
TRT	Treatments
BLK	Block
C	Control
WC	White Clover
CC	Crimson Clover
BTS	Billion Ton Study
EISA	Energy Independence and Security Act

DOE	Department of Energy

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ABSTRACT

The primary goal of this thesis was to create a baseline for soil conserving Miscanthus establishment in the U.S. Since Miscanthus production is expected to occur on marginal lands with significant erosion potential, we focused our attention on soil quality indicators. The hypotheses of this study were to examine Miscanthus establishment with companion crops by studying: 1) morphological and hydrological soil parameters (soil bulk density, soil aggregate stability, and steady-state infiltration) and 2) percent soil surface cover via photogrammetry (live plant, mulch, and bare soil).

Treatments were Miscanthus (*Miscanthus x giganteus*), rye (*Secale cereale*), oat (*Avena sativa*), crimson clover (*Trifolium incarnatum*), and white clover (*Trifolium repens*). Five treatments, a control and Miscanthus with a companion crop, were studied in a randomized complete block design on a Webster soil (fine-loamy, mixed, superactive, mesic Typic Endoaquoll) in central Iowa. Measurements began in the 2nd and 3rd growing seasons after Miscanthus transplanting. Morphological soil samples were taken once annually, and hydrological and percent cover were taken monthly throughout the growing seasons. Treatments significantly ($p > 0.05$) impacted the 1.00 mm ($p > 0.0099$), 0.50 mm ($p > 0.0039$), and 0.25 mm ($p > 0.0054$) aggregate size fractions. Tukey mean comparisons between treatments for 1.00, 0.50, and 0.25 mm aggregate size fractions revealed rye and oat companion crops in all significant comparisons. A temporal effect on intermediate aggregate size fractions showed increased mean weight diameter from 2010 to 2011. Soil bulk density, steady-state infiltration, and all three percent cover parameters were not impacted by treatments. Mulch percent cover

was impacted by treatment*month, however this interaction merely suggests treatments impact mulch cover in some months and not others.

Changes in the 1.00, 0.50, and 0.25 mm aggregate size fractions indicate changes in the foundation of aggregate stability. Over time these changes influenced by companion crop and Miscanthus treatments could reduce soil bulk density and increase steady-state infiltration. Improvements to soil structure and porosity directly impact soil resistance to erosive events such as intense precipitation. By understanding soil physical parameters and processes, better management decisions can be made about producing bioenergy crops on highly erodible lands.

CHAPTER 1. GENERAL INTRODUCTION

Background

Biofuels from renewable resources has become an important research topic. In the United States legislation outlines strategies to increase renewable energy production through the adoption of perennial grasses for cellulosic ethanol (DOE, 2011; EISA, 2007). To avoid competition with traditional crops on arable land, marginal land has been suggested for dedicated energy crops production (Blanco-Canqui, 2010). The Food and Agriculture Organization (FAO) defines marginal land as land "having limitations…[and] with inappropriate management, risk irreversible degradation" (FAO, 2015). Marginal land constraints primarily describe loss of soil function (low fertility, poor drainage, and shallowness) and include steep slopes (FAO, 2015). The current estimation of marginal land in the U.S. is 10.8Mha (Mitchell, 2010). The characterization of marginal land having steep slopes and shallow soil suggests these are highly erodible lands (HEL). Marginal land and HEL will be used interchangeably for the remainder of this thesis. A 2007 National Resources Inventory revealed the amount of HEL with erosion rates above the soil loss tolerance rate is estimated to be 54 million acres in the continental U.S. (NRCS, 2010). The Inventory also found 54% of water erosion occurring in 2007 was from the Corn Belt and Northern Plains. Production on marginal land coupled with rising soil erosion concerns in the Midwest create management opportunities for dedicated bioenergy crops.

A review of long-term studies on Miscanthus indicate there are environmental benefits from perennial, herbaceous grass production (McCalmont et al., 2015). Unfortunately these grasses require up to 3 – 5 years of establishment before reaching full maturity (Karp and Shield, 2008). Low canopy cover, rainfall impact, and soil detachment on marginal land can lead to severe erosion and loss of the topsoil. Without proper establishment and root development, these grasses suffer from stand failure, overwinter kill, and low shoot and root growth (Iqbal et al., 2015).

Providing a sustainable fuel source is challenging, however with agricultural management strategies focused on conservation, dedicated bioenergy crops can be part of the solution. Cover crops have been extensively studied as multi-functional tools for conservation agriculture. The benefits of cover crops include continuous cover, improved soil structure, and nutrient additions, to name a few (Blanco-Canqui et al., 2015). Growing cover crops in conjunction with Miscanthus can mitigate potential topsoil erosion by stabilizing soil structure, intercepting rainfall impact, and improving infiltration. Additionally these crops could accelerate environmental benefits associated with dedicated bioenergy crops. In order to create a sustainable and renewable biofuel economy, management needs to address problems of marginal lands and long establishment periods. Companion crops could be the solution to successful bioenergy crop establishment.

The hypotheses of this thesis are:

1. Determine companion crop effects during Miscanthus establishment on morphological and hydrological parameters relating to soil erosion
2. Examine companion crop and Miscanthus percent cover for 3 parameters (live plant, mulch, and bare soil) during establishment

Thesis Organization

Chapter 2 is an extensive literature review on the use of companion crops to mitigate topsoil erosion. Specific soil quality indicators will be described and examined in the context of companion crop management. Chapter 3 explores companion crops influence on soil properties and processes during Miscanthus establishment. Canopy coverage from companion crops and Miscanthus also will be addressed. The experiment site is located in Central Iowa. Chapter 4 summarizes general conclusions of this thesis and connections between companion crops and sustainable bioenergy crop management. This chapter also suggests future research options for bioenergy production and soil quality. References are listed at the end of each chapter. Appendix of analyzed data collected throughout the second and third year of Miscanthus establishment will be provided. This includes a summary of a preliminary experiment on Miscanthus litter decomposition.

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CHAPTER 2. LITERATURE REVIEW

Introduction

Recent renewable fuel alternatives include warm-season perennial grasses as feedstocks. Current legislation estimates 61% and 37%, respectively, of renewable fuels are to be from dedicated bioenergy crops, which includes perennial grasses such as *Miscanthus x giganteus* (EISA, 2007; BTS, 2011). Perennial, herbaceous, C4 grasses like Miscanthus require several years following planting to reach full maturity and complete ground cover. Low shoot density and shorter plant height during establishment exacerbates soil erosion susceptibility as limited aboveground biomass leaves the soil surface exposed to raindrop impact (Iqbal et al., 2015). Minimal canopy coverage can lead to soil degradation especially if Miscanthus and other biofuel crops are produced on marginal land that is often erosion prone (Kort et al., 1998; Lal, 2001). Eroded topsoil results in organic matter and nutrient loss, weak soil structure, and reduced infiltration. Though topsoil erosion is typically greatest in the planting year, the risk from water erosion is still high until full canopy cover develops (Smeets et al., 2009). As cropping strategies change due to economic influences, it is important for producers to adapt management plans emphasizing the conservation of available natural resources. Similar to corn production where some producers use cover crops in fallow fields to support productive soils (Singer, 2008), cover crop benefits can be extrapolated to support bioenergy crop establishment.

Companion crops are types of cover crops that grow with the main crop to support it. Other terms that have been associated with companion crops are living mulch and double or inter cropping. Typically cover crops and companion crops have one thing in common – they both offer soil protection beyond that occurring with the main crop. Because companion crops grow and develop with the main crop, there are inherent obstacles between the two such as resource competition, limited space for canopy development, and extra traffic from double plantings (Huang, 2012). Resource competition from companion crops are usually short-lived and preferred over weed growth (Barker et al., 2012). Despite these obstacles, companion crops are useful management tools for conservation agriculture (Reeves, 1994). In fact anything to accelerate complete canopy cover during bioenergy crop establishment would aid in reducing exposed soil to erosion (Kort et al., 1998). Companion crops provide multi-functional uses to assist in the development and growth of main crop production.

The multi-functionality of nurse crops can be differentiated into separate categories. In this review we identify major areas of soil quality which have been directly impacted from the addition of both nurse crops and cover crops, especially as it relates to soil conservation and soil quality improvement. The primary focus will be on cover crop capabilities to protect the soil against water erosion. These areas are physiological (plant structures), hydrological (soil infiltration), and morphological (soil physical structure). By investigating factors influencing soil quality, we can understand implications surrounding changes in cover crop development over time. Although there are many other beneficial effects from these complimentary crops, the scope of this literature review will not include biological-related benefits.

Canopy Cover – cover crops, living mulches, and plant residues

The initial barrier to rainfall impact, the initial driver of the soil erosion process, is canopy cover. Canopy cover is comprised of leaves, senesced plant vegetation or decomposing residues, all of which absorb and dissipate kinetic energy of incoming raindrops. These aboveground plant structures partially or completely intercept raindrops, thereby reducing the impact to soil particles. Short rotation woody crops (SRWC) face a similar dilemma. Without any type of supportive cover, SRWCs are expected to have similar erosion rates to that of conventionally grown crops during the establishment period (Malik et al., 2000). A minimum of 40% vegetative cover is suggested to exponentially decrease water runoff and soil erosion loss in a cambisol after 2 years of study (Nunes et al., 2011). Winter annuals were observed to be more effective at reducing soil erosion than summer perennials, due to dense plant stands in the winter, a season when soil erosion is the highest in Alabama (Malik et al., 2000). Although some cover crops may not have a large effect on residue quantity, these crops can be associated with a high percentage of ground cover, which is attributed to the management technique of 'rolling' the stubble so that it lays parallel to the soil surface (Ward et al., 2012). Residues oriented parallel to the ground offers more soil cover than leaving those residues perpendicular, i.e. standing vertical.

Interrill and Rill Erosion

A lack of substantial canopy cover fails to effectively intercept raindrops resulting in soil particles becoming detached from soil aggregates. Falling rain disaggregates soil into finer particles clogging pores and developing a surface seal. This limits infiltration into the soil profile (Derpsch, 2002). Rill erosion is the transport of water, sediment, and nutrients into runoff within small channels called rills. Rye and oat cover crops reduced rill erosion by 93% and 64%, respectively, compared to the control in the 3rd year of production on a Clarion silt loam in Iowa (Kasper et al., 2001). These two small grain cover crops also reduced rill erosion in the subsequent year as well; rye by 86% and oat by 42% (Kasper et al., 2001). Rye cover crops were more effective at controlling rill development due to greater shoot mass in the spring than oat cover crops, which didn't survive the winter. While aboveground structures, such as canopy and residues, intercept rainfall, roots anchor shoots and residue to the soil surface preventing flowing water from detaching soil particles. Thus roots from covering crops minimize the formation of rills under residue cover (Kasper et al., 2001).

Interrill erosion occurs between rills and is mitigated by cover either from plant leaves or residues on the soil. In the same study by Kasper et al. (2001), rye reduced interrill erosion by 62% and 48% in the 3rd and 4th years of production. The oat cover crop reduced interrill erosion in only the 3rd year by 51%. Cover crops reduce interrill erosion by reducing sediment transport from raindrop impact. Even when cover crops don't increase surface residue cover, the additional volume of cover crop plants and residues and their attachment to the soil may reduce interrill flow velocity. In the fallow period cover crops can provide environmental benefits to the subsequent crop. During winter months when aboveground biomass is degraded, root structures remained effective at reducing soil erosion (De Baets et al., 2011).

Water and Soil Runoff and Sediment Loss

Cover crop plants and residues have been observed to intercept and reduce surface runoff leading to increased ponding, thus limiting sediment movement to rills and interrills causing localized deposition (Kasper et al., 2001). After 2 years of production, measurements revealed cover crops had significantly reduced sediment loss by 57% (Malik et al., 2000).The increased density of plant structures from cover crops slow consequential sediment movement in runoff water (De Baets et al., 2011). Over the course of the season, some cover crops senesce (deteriorate with age), but continue to mitigate soil erosion due to litter and decomposing plant residues (Curran et al., 2006).

Nutrient Retention

Depending on the regional climate, leaching of nutrients, especially nitrogen, can occur in late winter/early spring or late fall. Soil erosion and associated nutrient losses, specifically phosphorus, are alleviated with active crop growth during those seasons (Kasper et al., 2008). An actively growing cover crop absorbs a significant amount of these nutrients that otherwise could be lost by leaching and runoff processes. Retaining these nutrients helps avoid the need to replenish them for the subsequent main crop. To reduce losses of dissolved phosphorus on highly erodible lands, cover crop effectiveness is critical to reduce erosion (Kasper et al., 2008).

Morphological changes

Using cover crops facilitates subsequent stand establishment of main crops through improved soil structure formation. Organic matter from degraded cover crop residues contribute compounds which aid in the formation of aggregates. Greater aggregate stability favors soil permeability to air and water and increases water holding capacity as well as aids in seedling emergence and root growth (Curran et al., 2006). Roots of most cover crops extensively develop within the upper 30cm of soil and fibrous roots showed the highest density of roots in the topsoil (De Baets et al., 2011). These roots have the capacity to increase cohesive properties of the soil, leading to greater soil aggregate stability. Soil stability is crucial for preventing topsoil erosion that is initiated by rainfall impact.

Soil Aggregate Stability

Soil aggregate stability is fundamental to soil structural stability and is considered an indicator of soil resistance to erosion (Barthes and Roose, 2002). Aggregates form from primary particles and through various physical and chemical processes form microaggregates, which can further develop into macroaggregates. Microaggregate stability promotes soil macroaggregation and soil aggregate development (Sainju et al., 2003). Cover crops enhance pore structure and stability in the soil through increases in root biomass (Bronick and Lal, 2005; Nascente et al., 2013). Overall water-stable aggregates were 1.2 to 2 times more stable under cover crops than the control with the responsiveness of soil aggregation occurring within 3 years after cover crop introduction (Blanco-Canqui et al., 2015). Increases in aggregate stability from cover crop plots also suggest improved root penetration of the main crop will occur. Correlation between crop yield and cover crop effects on soil properties were strong and positive grown in semi-arid Spain (Nicolau et al., 1996).

Soil Bulk Density and Porosity

Bulk density is often cited as an indicator of soil compaction. Compaction reduces pore space and deforms soil structure, both effects limiting percolation and increasing the potential for water runoff and subsequently, soil erosion. Under conservation tillage cover crops improved soil structure by decreasing soil bulk density on a Tifton loamy sand (Hubbard et al., 2013). Root structures of cover crops promote the creation of continuous macro pores and improved water and gas transport. With less compaction, cover crops promote root growth, nutrient cycling, and soil structure development leading to increases in crop yield. Under 15 years of cover crop management on a Geary silt loam soil, a negative correlation was observed between increased crop yield and decreased soil bulk density (Blanco-Canqui et al., 2012). Plots without cover crops had higher bulk densities and lower yields, suggesting cover crops decrease soil vulnerability to compaction (Blanco-Canqui et al., 2012). Compared to corn with an average bulk density of 1.5 Mg/m^3, sweetgum (an SWRC) with a cover crop had a soil bulk density of 1.1 Mg/m^3 in a Decatur silt loam (Tolbert et al., 2002). Cover crop mixes decreased bulk density and soil compaction, while increasing total porosity in Ohio field trials (Islam and Reeder, 2014). Cover crops grown in a silt loam soil are observed to decrease soil bulk density while air-filled porosity, air permeability, and pore continuity have been observed to increase within the upper 4 – 8 cm of the soil profile and the 12 to 16 cm depths (Abdollah et al., 2013). Greater pore continuity and air permeability suggest fewer blocked pores. By improving porosity in the upper horizon of the soil, there is less potential for water runoff and subsequent topsoil erosion. Positive cover crop effects on pore characteristics at lower depths (18 – 27 cm) suggest decreased compaction to the plow pan (Abdollah et al., 2013). Disrupting the plow pan allows greater root growth depth which should help limit the nutrient and water mining that occurs above an intact plow pan. The improvements in permeability and pore organization are complex and take time to develop. Increased root biomass in the soil, following senescence and decomposition, can increase the number of pores available for preferential flow.

Hydrological changes

Infiltration

Infiltration is the process of water moving into the soil and is supported by water moving into deeper layers through the soil (NRCS, 1998). Factors inhibiting infiltration include discontinuous pores, reduced porosity, clogged pores, soil surface seals and crusts, and weak soil structure. Saturated soils can lead to weakened soil structure and loss of structural integrity, which limits infiltration leading to soil detachment and water runoff (NRCS, 1998). Cover crop canopies capture precipitation and through improved infiltration, increase rainfall retention for future crop growth (Blanco-Canqui et al., 2012). Vegetative cover can also slow water runoff from steeper slopes, allowing more time for infiltration to occur (Nicolau et al., 1996; Unger and Vigil, 1998). Rye cover crop reduced runoff by 10% and increased the infiltration rate by 16% compared to a control in only the 4th year of production on a Clarion silt loam in central Iowa (Kasper et al., 2001). Increased infiltration rates from cover crops occurred by increased surface ponding and allowing more time for infiltration to occur (Kasper et al., 2001). A meta-analysis on cover crops found some studies observed increased infiltration rates by 1.1 to 2.7 times (Blanco-Canqui et al., 2015). However, other hydrological parameters (saturated hydraulic conductivity and water retention) didn't exhibit measurable change in the first 5 years of production with a cover crop (Blanco-Canqui et al., 2015). In a silt loam soil, Abdollah et al. (2013) observed improved pore organization, reduced soil bulk density and greater air permeability, yet there was no effect on infiltration from cover crops, which suggests infiltration rates are affected more slowly than observed changes in soil porosity and structure.

Soil Water Content and Evaporation

Cover crop plant residue provides surface cover that has multiple implications. Soils mulched with cover crop residues resulted in greater volumetric water content and lower soil temperatures in the spring than plots without residues in a Geary silt loam in Kansas (Blanco-Canqui et al., 2012). In the previous study soils without cover were observed to increase in temperature, which accelerated evaporation and lowered soil water content. Increased residue from cover crops can create a micro-climate, which is favorable for subsequent crop growth by reducing evaporation (Blanco-Canqui et al., 2012) and increasing soil water storage, especially if the cover crop is terminated early (Ward et al., 2012). Cover crops should be terminated as early as possible to minimize transpiration losses of water, which allows for soil water recharge for the next crops. Conversely, cover crop transpiration can reduce soil water content if spring growth is not timely controlled, which impacts subsequent hydrological processes.

Disadvantages of Cover Crops

The benefits of supplemental canopy cover from cover crops aid in minimizing the risk of erosion, however nutrient and water competition can offset selected benefits supplied by cover crops. In temperate climates characteristic management of cover crops begins in late August through the winter until spring planting of the main crop. Planting cover crops prior to harvesting the summer crop allows more time for aboveground biomass development. However, the longer growing season allows cover crops to take advantage of available nutrients, creating a nutrient shortage for subsequent crops. For cover crops the amount of nutrients used is proportional to the amount of biomass grown (Kasper et al., 2008). Depending on the type of cover crop, taproots take up nutrients from deeper depths than traditional row crops. A management strategy for producers suggest terminating cover crop growth in the spring using herbicides or other means (Ward et al., 2012).

The use of cover crops as a conservation management tool is dependent on regional climate, specifically seasonal precipitation amount. A dry spring actively growing cover can lower yields of the agronomic crop if cover crops transpire crop-needed soil water. Conversely a normal spring with rainfall in the summer may produce higher yields (greater porosity, hydraulic conductivity, and water retention) with cover crops. In Mediterreanean climates during the summer, there is high potential evapotranspiration from plants and low rainfall, which results in cover crops reducing soil water storage (Ward et al., 2012). Water used by cover crops/green manures can greatly reduce available water leading to reduced yields for subsequent crops. Cover crops are less desirable in semi-arid regions. Timely cover crop termination and effective weed control are essential for minimizing the potential adverse effects on subsequent crops.

Summary

Benefits of producing cover crops in conjunction with bioenergy crops are evident based on shoot and root structures and their favorable impact on soil properties. Plant canopy cover and vegetative structures are important for protecting soil from rainfall kinetic energy and soil particle detachment, as well as facilitating soil structure development through processes associated with organic matter additions. Increased soil stability and improved soil structure reduces particle detachment from raindrop impact and dense plant stands impedes sediment loss. Root biomass from cover crop growth increases soil aggregation and decreases soil compaction resulting in lower soil bulk density values. As a consequence of cover crop impacts on soil properties and rainfall interception, increases in infiltration rate can effectively reduce soil susceptibility to erosive events. However, the success of implementing cover crops is limited by the management strategies used. Resource competition between the main crop and arid and semi-arid climates are disadvantages to cover crop use.

As bioenergy crop production rises, the need for conservation agriculture strategies will be magnified. Other sustainable options also will be required for bioenergy production on marginal lands since one option rarely is a panacea for all environmental and agricultural issues.

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CHAPTER 3: COVER CROP IMPACTS ON SOIL QUALITY PARAMETERS WITH MISCANTHUS X GIGANTEUS DURING ESTABLISHMENT

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

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Abstract

Our research intention was to identify Miscanthus management to maintain soil resources during establishment of this highly productive biofuel feedstock. Our hypotheses were to examine Miscanthus establishment with companion crops by studying: 1) morphological and hydrological soil parameters (soil bulk density, soil aggregate stability, and steady-state infiltration) and 2) percent cover (live plant, mulch, and bare soil). Five treatments were studied in a randomized complete block design on a Webster soil in central Iowa. Treatments were Miscanthus (*Miscanthus x giganteus*) and rye (*Secale cereale*), oat (*Avena sativa*), crimson clover (*Trifolium incarnatum*), and white clover (*Trifolium repens*). Measurements began in the 2^{nd} and 3^{rd} growing seasons, 2010 and 2011, after Miscanthus transplanting in spring 2009. Treatments significantly ($p > 0.05$) impacted the 1.00 mm ($p > 0.0099$), 0.50 mm ($p > 0.0039$), and 0.25 mm ($p > 0.0054$) aggregate size fractions (ASF). Tukey mean comparisons between treatments for intermediate (1.00, 0.50, and 0.25 mm) ASFs revealed rye and oat companion crops in all significant comparisons. A temporal effect on intermediate ASFs showed increased mean weight diameter from 2010 to 2011. Soil bulk density, steady-state infiltration, and all 3 percent cover parameters were not impacted by treatments. Treatments impacted the 1.00, 0.50, and 0.25 mm aggregate size fractions indicating changes in soil structure leading to aggregate

stability. Over time these changes could impact soil bulk density and steady-state infiltration. By understanding soil physical parameters and processes, better management decisions can be made about producing bioenergy crops on highly erodible lands.

Introduction

Research focusing on cellulosic biomass for ethanol-based biofuel has rapidly increased in the United States. In 2007 Congress passed the Energy Independence and Security Act (EISA) mandated that ethanol addition to gasoline “increase to 36 billion gallons by 2022" of which "21 billion gallons must be from non-cornstarch products" (EISA 2007). This means sugar and cellulosic products can be used to fill approximately 61% of the US Renewable Fuel Standard. A former study, the Billion Ton Study (BTS) by the US Department of Energy in 2005, proposed dedicated energy crops could meet over half of the proposed renewable energy needs (DOE 2005). The updated version of the BTS in 2011 from the Department of Energy indicates bioenergy crops have become a more significant resource of biomass, providing "about 37% of the total biomass available" to meet energy demand (DOE 2011). These reports show the importance of continued research on cellulosic biomass as a bioenergy resource. The recent 2012 drought in the corn production region of the US has brought increased pressure on grain ethanol industries with less corn available to meet food, feed, and fuel demands. It is becoming apparent our renewable energy needs should not be limited to one crop or feedstock source, but include alternative options such as cellulosic ethanol. Dedicated energy crops, mentioned in the 2005 BTS, are those crops which provide no food or feed purpose and can be used solely for energy. With proper management, dedicated energy crop production results in a high yielding, renewable bioenergy resource.

Recent research on dedicated energy crops has shifted focus to perennial, warm-season grasses. One of the most promising dedicated perennial bioenergy feedstock plants being studied to meet the challenges and opportunities of renewable energy production is *Miscanthus x giganteus* or hereby referred to as Miscanthus. Miscanthus is a rhizomatous grass with a broad geographic adaptation producing very high yields even in temperate environments. As a perennial, C4 herbaceous grass, Miscanthus stands have survived for over 15 years in European studies with minimal agronomic input (Lewandowski, 2000). Over time Miscanthus plants form large root masses, which could hold soil in place and alleviate potential soil erosion. In addition, the accumulation of a leaf litter layer from senescence forms a barrier to raindrop impact and basically eliminates surface soil detachment from raindrop impact. Studies in the US have promoted Miscanthus (herbaceous perennials) production on marginal or highly erodible lands (HEL) (Mitchell, 2010). These tracts of land could benefit from long-term perennial crop growth, as well as deter natural resource degradation from traditional row crop production. It is estimated there are 385 to 472 million hectares of abandoned agricultural land globally potentially suitable for this type of production (Campbell et al., 2008). Proper crop management is needed especially if these crops are produced on marginal lands. Blanco-Canqui (2010) states the "magnitude of benefits from growing warm-season grasses" will be limited by "soil types, use of fertilizers, harvest frequency..." most of which are related directly to crop management.

Current establishment methods call for planting miscanthus rhizomes or propogated shoots into tilled bare soil at 1 m plant spacings (Pyter et al., 2007) which leaves the soil surface exposed to potential erosion for the 0 – 5 years that it can take for stands of Miscanthus to reach maturity (Clifton-Brown et al., 2007). Miscanthus's long maturation phase, potential soil surface exposure, and its establishment on HELs create a unique problem for producers. Due to the long establishment period, soils on which Miscanthus is established may benefit from surface cover offered by companion or cover crops. Companion crops are crops grown in conjunction with the primary crop to support soil structure development, ground cover, and increased infiltration capacity. Cover crops grown in-between rows intercept rainfall and dissipate kinetic energy from impacting raindrops, protecting the soil surface from erosion (Mann et al., 2000). Aside from reducing the impact of rainfall, companion or cover crops also inhibit sediment runoff (Hartwig and Ammon, 2002). Additionally, companion crops aid in accelerating environmental benefits observed from mature stands of herbaceous grasses. Previous studies of bioenergy crops have shown potential soil erosion mitigation from companion crops that have been recommended for corn and switchgrass production (Torbert et al., 1996; Rinehart, 2006). Companion crops such as white clover grow early in the spring and can act as a living mulch throughout the growing season for Miscanthus. Thus, companion crops grown with bioenergy crops during establishment to help minimize soil degradation are a potentially favorable management opportunity (Kim et al, 2005). Companion crops are beneficial in maintaining and enhancing soil surface conditions, as long as they are managed properly to mitigate adverse effects from resource competition with the main crop (Hartwig and Ammon, 2002).

The primary objective of this research is to form a basic understanding of sustainable Miscanthus production under the premise of its production on marginal or highly erodible lands. In order to mitigate potential soil erosion on marginal lands, we are growing Miscanthus during its establishment phase with companion crops. Our hypotheses are companion crops positively impact soil quality parameters by: 1) determining morphological and hydrological parameter changes (soil bulk density, soil aggregate stability, and steady-state infiltration), and by 2) examining percent cover from companion crop and Miscanthus for 3 cover parameters (live plant canopy, mulch, and bare soil). These results provide the basis for understanding how Miscanthus and other bioenergy crops might be best managed.

Materials and Methods

Site characteristics

Field experiments were conducted on plots established in the fall 2008 and summer 2009 in Central, IA (Sorenson Farm 42^{o}N, 93^{o}44'W). Previously, the fields were planted in continuous corn (*Zea mays*) and soybeans (*Glycine max*) for 5 years under private ownership. Climate in this area is classified as humid continental with extremes of both hot and cold. Annual precipitation averages 836.3mm in Central Iowa. Atmospheric temperatures vary by season with -15.5^{o}C in the winter to over 37.7^{o}C in the summer (NCDC, 2001). The predominate soil series in our study is a Webster soil (Fine-loamy, mixed, superactive, mesic Typic Endoaquolls).

Field plots were arranged in a randomized complete block design with four replicates. The main treatment consisted of Miscanthus and four companion crops treatments. Companion crops grown with Miscanthus included *Secale cereal* (Rye), *Avena sativa* (Oats), *Trifolium incarnatum* (Crimson clover), and *Trifolium repens* (White clover). Five treatments including the control were observed with four replicates. Plot sizes were 18m x 20m and planted either as miscanthus only or miscanthus with one of the four companion crops.

We grew Miscanthus in fertile soil typically used for corn production with little to no slope and with or without companion crops. Miscanthus plants were transplanted from greenhouse-generated plug propagation. Miscanthus plugs were hand planted in 76.2 cm centers set apart by 38.1 cm rows in May 2009. Prior to miscanthus planting, companion crops were drilled using standard procedure. Seeding rate for the companion crops were rye (112 kg/ha), oats (112 kg/ha), crimson clover (13.5 kg/ha), and white clover (3.4 kg/ha). Oats, crimson clover (replanted), and white clover were planted in April 2009; cereal rye and crimson clover were planted earlier in September 2008. Spring companion crops were planted after strip tillage in 2009. No other tillage occurred after planting. Hand-weeding occurred within the first two weeks after planting was completed. Weeds taller than the canopy of the companion crops were mowed in June and July.

Sampling protocol

To evaluate the effects of Miscanthus establishment on selected soil quality parameters, soil samples were collected to evaluate bulk density and aggregate stability. Bulk density samples were taken at random and collected from each plot in the fall after Miscanthus senescence. Surface soil samples for bulk density were taken using an Uhland soil corer with driving hammer to a depth of 23 cm (Doran, 1984). Each fall after Miscanthus leaf senescence, aggregate stability samples were collected to a depth of 23 cm with a round point utility shovel. Samples were air-dried and passed through an 8mm sieve before wet stable aggregate analysis was conducted.

Field saturated infiltration measurements were conducted using a sprinkle infiltrometer designed by Cornell University (van Es and Schindelbeck, 2003). Measurements were taken monthly throughout the growing season (May – October) and 1.5 days after a rain event to avoid excessively dry conditions. Prior to infiltration tests, infiltrometers were calibrated to simulate rainfall intensity between 0.4 – 0.5 cm/min (van Es and Schindelbeck, 2003). Residue on the soil surface or live plant cover was not disturbed unless it directly impeded simulated rainfall from the capillary tubes. Stainless steel metal rings with a 25.4 cm diameter were hammered into the ground at a depth of 18 cm. Sprinkle infiltrometers were placed atop the metal ring for simulation of rainfall. Each treatment was measured for infiltration at random points within each plot. Time to runoff was observed and runoff volume was measured at 5 minute intervals until 60 minutes had elapsed. This provided ample time for steady-state infiltration to be measured. Some measurements didn't yield any runoff in the time period observed. Treatments without runoff could be considered 1) having porosity leading to infiltration in lower horizons or 2) ponding on the soil surface. Plots with no runoff and no observable ponding required special statistical analysis.

The amount of canopy cover in each plot was determined through photogrammetry. A digital camera (Canon Rebel Xti, New York) was used to take pictures from the height of 1 meter and perpendicular to the soil surface. The camera resolution was 10.1 Megapixels. Photos were taken on overcast days or in positions with minimal interference from cast shadows. Area of plant cover measured was within a 1m x 1m square and sites within each plot were chosen at random. GPS of the picture locations were taken for observation of plant cover changes over the growing season.

Laboratory analysis

Bulk density samples were oven dried at 105^{o}C for 2 – 3 days until the mass no longer fluctuated. Density of soil samples was determined using oven-dry weight and known volume (Blake and Hartge, 1986).

Aggregate stability was measured using the wet aggregate stability method (Marquez et al. 2004). To deter the sudden collapse of aggregates from immediate slaking, samples were re-moistened to 40% field capacity through capillary wetting for a minimum of four hours. Samples were placed on five nested sieves (4, 2, 1, 0.5, and 0.25mm openings), shaken vertically for 5 min. at 50 rpm, and subsequently oven dried at 70^{o}C (Kemper and Rosenau, 1986). Dried samples were weighed and saved for determination of sand content. To determine sand content, oven-dried stable aggregates were immersed in water and 2g/L of sodium metaphosphate and oscillated at 160 rpm for at least 3 hours (Nimmo, 2002). The samples were then passed through a 53 μm sieve and oven-dried at 50^{o}C. Oven dried samples were weighed for sand content. Wet aggregate stability was based on mean weight diameter of aggregates remaining on the nest of sieves following the wet sieving operation (van Bavel and Schaller, 1951). Sand fractionation was subtracted to avoid an artificially high amount of sand sized aggregates.

Photos of canopy cover were uploaded and digitized using ArcGIS 10. Percentage areas of canopy cover were determined by a polygon drawing method differentiating between live plants, debris, and bare soil. Live plants accounted for changing plant cover. Debris was for dead plant material, usually covering the soil surface in a given area. Bare soil accounted for exposed soil surface not covered by any plant material. For live plant cover and debris, no distinction was made between Miscanthus, the companion crops, or other plant cover (i.e. weeds).

Statistical Analysis

Bulk density and wet aggregate stability were analyzed by treatment, block, and year effects. Both bulk density and wet aggregate stability were statistically analyzed using PROC GLM (SAS Institute, 1990). Aggregate size fractions were analyzed using the same statistical code as bulk density and aggregate stability. We performed a post hoc multiple treatment means comparisons test. We performed a post hoc multiple treatment means comparisons test on intermediate (1.00, 0.50, and 0.25 mm) ASFs. The Tukey multiple comparison test was used since the data was balanced and used LS Means of each treatment for the comparison.

Infiltration rates were analyzed using the averaged steady state infiltration rate by treatment, block, and month effects. Analysis was done on data from each plot. Rates were statistically analyzed using repeated analysis in PROC MIXED Method type 3 and LSMEANS (Sas Institute, 1990). Tukey-Kramer (HSD) tests were used to differentiate between treatment means.

Areas of each three cover types were statistically analyzed using repeated measurements with PROC GLM and LSMEANS (Sas Institute, 1990). LSMEANS were sliced to differentiate between live plants, debris, and bare soil cover. Slicing provided further investigation into significant interactions between cover types and months.

Both infiltration rates and crop canopy photos had incomplete data sets. Treatments with no runoff were treated with a zero infiltration rate value. To account for incomplete data sets, we used Levene’s Test for Homogeneity of Variance. This test compares the equality of variances between populations.

Results

Table 1. Wet Aggregate Stability (ANOVA table)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	**24**	**0.56936181**	**0.02372341**	**2.34**	**0.0454**
Error	**15**	**0.15185893**	**0.01012393**		
Corrected Total	**39**	**0.72122074**			

Source	DF	Type III SS	Mean Square	F Value	Pr > F
blk	3	0.20335059	0.06778353	6.70	0.0044
trt	4	0.01420677	0.00355169	0.35	0.8394
blk*trt	12	0.27697463	0.02308122	2.28	0.0669
year	1	0.00012638	0.00012638	0.01	0.9125
trt*year	4	0.07470344	0.01867586	1.84	0.1728

Table 2. Soil bulk density, wet aggregate stability, and soil aggregate size fractions (ANOVA table)

	Bulk Density	Wet Aggregate Stability	4.00 mm size fraction	2.00 mm size fraction	1.00 mm size fraction	0.50 mm size fraction	0.25 mm size fraction
Main effects	Pr > F						
Block	0.0085	0.0044	0.4000	0.0003	<0.0001	<0.0001	<0.0001
Treatment	0.3654	0.8394	0.3356	0.2541	0.0099	0.0039	0.0054
Block*Treatment	0.0640	0.0669	0.3057	0.1910	0.0466	0.0068	0.0149
Year	<0.0001	0.9125	0.0353	0.0382	<0.0001	<0.0001	0.0016
Treatment*Year	0.7381	0.1728	0.0996	0.3368	0.1633	0.0343	0.5757

Note: p-values taken from Type III SS

Table 3. Least square means of mean weight diameters from aggregate size fractions (1.00, 0.50, 0.25 mm)

	Least square means (mm)		
Treatments	**1.00 mm**	**0.50 mm**	**0.25 mm**
Control	0.0796	0.0492	0.0195
Crimson Clover	0.0900	0.0507	0.0202
Oat	0.0730	0.0408	0.0157
Rye	0.1001	0.0513	0.0182
White Clover	0.0770	0.0453	0.0173

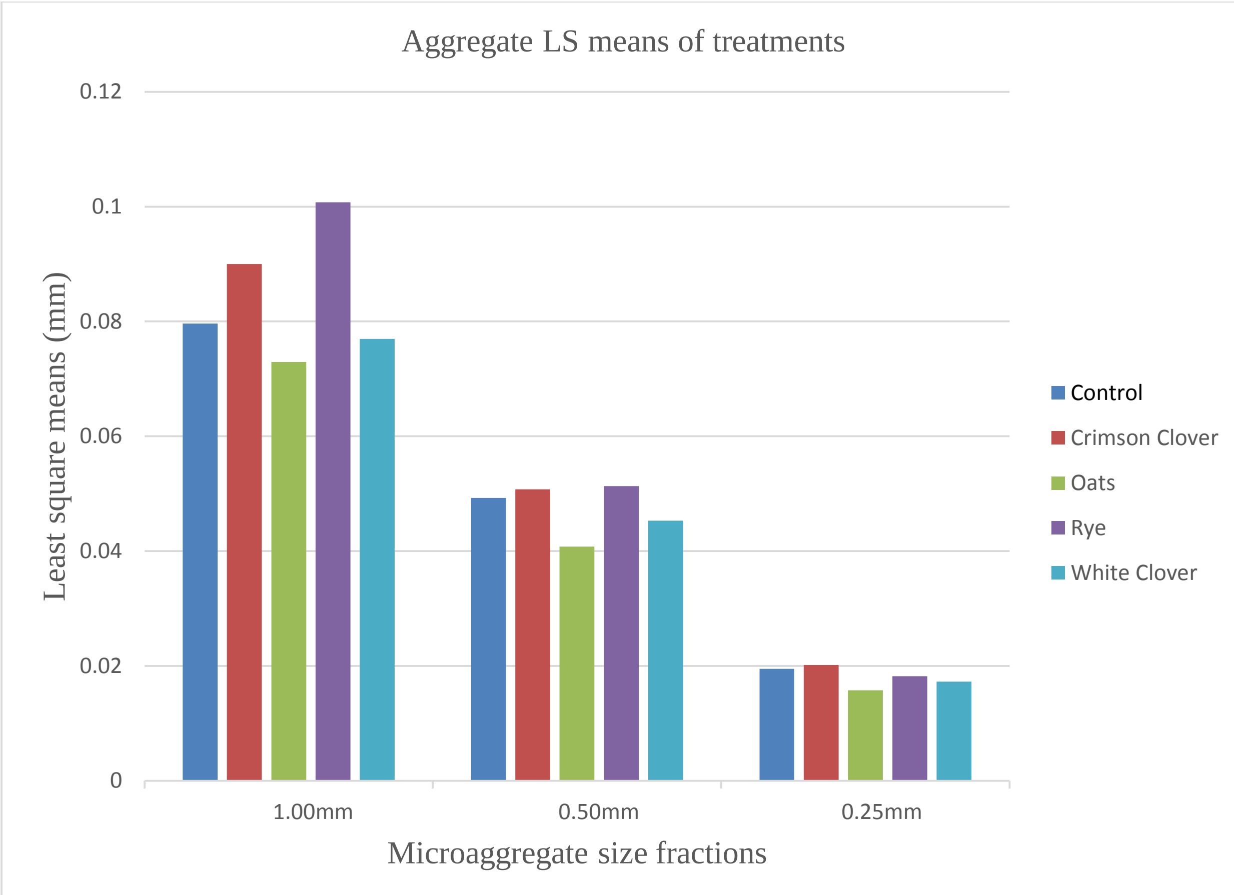

Figure 1. Least square means of mean weight diameters for 1.00, 0.50, and 0.25 mm soil aggregate size fractions

Table 4. Tukey multiple comparisons for least square treatment means of the 1.00, 0.50, and 0.25 mm soil aggregate size fractions

Soil Aggregate Size Fractions	Treatment Comparisons	P > |t|
1.00 mm	Control (Miscanthus only) vs. Rye	0.0659*
	Oat vs. Rye	0.0113**
	White Clover vs. Rye	0.0331**
0.50 mm	Control (Miscanthus only) vs. Oat	0.0303**
	Crimson Clover vs. Oat	0.0095**
	Rye vs. Oat	0.0061**
0.25 mm	Control (Miscanthus only) vs. Oat	0.0194**
	Crimson Clover vs. Oat	0.0057**
	Crimson Clover vs. White Clover	0.0854**

* indicates P > 0.10
** indicates P > 0.05

Table 5. ANOVA table for percent cover parameters (Live plant, mulch, and bare soil)

	Mulch	Bare Soil	Live Plant
Main effects	Pr > F		
Block	0.0184	0.5070	0.0078
Treatment	0.2620	0.1018	0.1927
Block*Treatment	0.4318	0.4936	0.4266
Month	0.0027	<0.0001	0.0004
Treatment*Month	0.0205	0.1538	0.0613

Note: p-values taken from Type III SS; p > 0.05

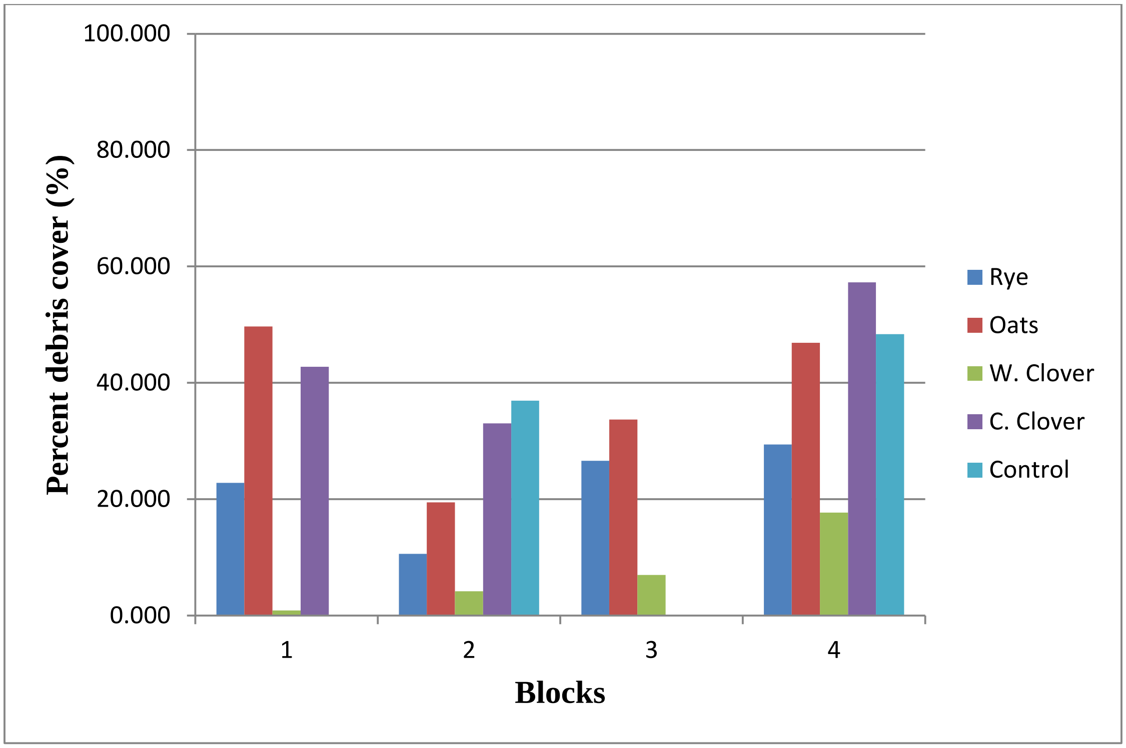

Figure 2. Percent cover parameter Mulch for the month of June

Companion crop treatments and Miscanthus had no significant impact on soil bulk density of the upper 23 cm of the soil (Table 2). Only the main effect year significantly affected soil bulk density, thus SBD changed temporally. As with soil bulk density, treatment did not significantly affect wet aggregate stability (Table 1). Correlation coefficient between soil bulk density and wet aggregate stability was not found to be significant in our study. The correlation analysis did suggest a slightly negative relationship between soil bulk density and aggregate stability. The formation of soil aggregation from microaggregates to macroaggregates necessitated separating these soil structural units into aggregate size fractions, which helped clarify treatment effects. Aggregate size fractions between 4.00 mm – 0.25 mm showed statistical significance temporally (by year). Similar to soil bulk density, macroaggregates (4.00 and 2.00 mm) were not impacted by treatment.

Companion crop treatments statistically impacted intermediate aggregate size fractions (ASF) of the 1.00, 0.50, and 0.25 mm aggregate size fractions (Table 2). Least square (LS) means from the mean weight diameters of the intermediate ASFs were calculated for post hoc treatment comparisons (Table 3; Figure 1). The Tukey multiple mean comparison test (Table 4) was conducted to identify significant ($p > 0.05$) differences among all treatment LS means in the intermediate soil aggregate size fractions. The 1.00 mm ASF resulted in 2 significant treatment comparisons. The next ASF, 0.50 mm, identified 3 significant treatment comparisons. The smallest ASF studied, 0.25 mm, found 2 significant treatment differences.

Treatments did not significantly affect steady-state infiltration rates (data not shown). Of the cover variables examined under photogrammetry, none of them were significantly affected by companion crop or Miscanthus only treatments (Table 5). Mulch was the only cover parameter significantly impacted by the treatment*month interaction (Figure 2).

Discussion

The evidence collected supports the hypothesis that companion crops treatments impacted soil quality parameters. Intermediate aggregate size fractions (1.00, 0.50, and 0.25 mm) were significantly impacted by treatments. Results from the Tukey multiple mean comparisons showed significant differences between treatments, however there was no indication of equivalence of treatments in the comparisons. Although all treatments were significant for the 1.00, 0.50, and 0.25 mm ASFs, there seems to be reoccurring significant treatments in each size fractions based on the results of the Tukey multiple comparison test. The rye companion crop was in both significant comparisons for the 1.00 mm ASF; rye had the highest LS mean for this size fraction. In the other two ASFs (0.50 and 0.25 mm), the oat companion crop reoccurred in all significant comparisons. The oat companion crop had the smallest LS mean. The trend of rye and oat companion crops in the comparisons was not well understood as both have fibrous root systems, which could impact smaller aggregate sizes. The results suggest smaller aggregate size fractions responded more quickly to changes from cover crops. Smaller aggregates could be more readily affected by treatment influences, however larger aggregates are affected on a temporally delayed time scale (Tisdall and Oades, 1982). Since aggregate formation is through the hierarchy of microaggregates developing into macroaggregates, in general, larger soil aggregate stability would respond more slowly to impacts from crop production than smaller aggregate sizes.

Wet aggregate wasn't impacted by companion crop or Miscanthus only treatments. Macroaggregates (4.00 and 2.00 mm ASFs) also weren't impacted by treatments, but this isn't surprising because macroaggregates are a component of soil aggregate stability as a whole, which wasn't impacted by treatments. Under 4 years of growth on a Bertrand silt loam in WI, greater mean weight diameter and an increased amount of macroaggregates were observed under no-till corn silage with a winter rye cover crop than in the absence of a cover crop (Jokela et al., 2009). Over a 15-year period on a Geary silt loam, cover crops increased mean weight diameter, which was 1.8 times higher with cover crops than without (Blanco-Canqui et al., 2012). In a meta-analysis by Blanco-Canqui (2015), water stable aggregates were found to be 1.2 to 2 times more stable under cover crops than a control. Additionally the responsiveness of soil aggregation occurred within 3 years after the introduction of cover crops (Blanco-Canqui et al., 2015). The results from these studies suggest the length of time required for soil aggregate stability to respond to cover crops is longer than expected to observe mean weight diameter changes. The impacts of companion crops and Miscanthus treatments on intermediate aggregate sizes were within the 3-year timeframe observed by other researchers.

The temporal effect on soil bulk density suggests natural reconsolidation of the topsoil from wetting and drying cycles (Green et al., 2003). Prior to transplanting Miscanthus, plots were minimally tilled to improve seed to soil contact. The inverse relationship between SBD and aggregate stability coincides with improvements in soil structure and porosity that as SBD decreases, aggregate stability increases. On a Decatur silt loam, cultivated corn had an average bulk density of 1.5 Mg/m^3, while sweetgum with a cover crop has an average soil bulk density of 1.1 Mg/m^3 after 3 years of growth (Tolbert et al., 2002). The previous study suggests lower average bulk densities under sweetgum with a cover crop were attributed to increases in soil organic matter. Within the soil profile on a Typic Hapludalf soil type in Denmark after 10 years of long-term tillage and rotation, cover crops were observed to decrease soil bulk density in the upper 7 cm of the topsoil (Abdollah et al., 2013). The same study at the 12 to 16 cm depth showed cover crops improved pore organization and soil bulk density. These improvements lead to less blocked pores. The 18 to 27 cm depth also showed improvement on pore organization and air permeability in the soil from cover crops (Abdollah et al., 2013). Cover crop influence at deeper depths suggest root growth resistance attributed to plow pans can be alleviated or at least partially alleviated.

Evidence from soil bulk density and wet aggregate stability data suggests we wouldn't expect treatment effects on infiltration rate. Soil bulk density and soil aggregate stability both affect porosity and weren't impacted by companion crop or Miscanthus only treatments. Thus infiltration, based on soil porosity, wouldn't be impacted by treatments. Only in the last year of a 4-year study on a Clarion silt loam in central Iowa, rye cover crop increased infiltration by 16%

and reduced runoff by 10% (Kasper et al., 2001). In the study it is hypothesized living rye cover in the spring increased infiltration rates potentially by increasing surface ponding. Infiltration is influenced by soil porosity, which changed once tillage occurred and disrupted macroaggregates and associated pores. Soil erosion also impedes infiltration as detached particles clog pores and form a surface seal (Derpsch, 2002). Runoff from highly eroded land can be intercepted by vegetative cover, resulting in increased surface ponding and possible infiltration (Nicolau et al., 1996). Increased cover crop residue can create a microcosm, which is favorable for subsequent crop growth through it increasing infiltration and reducing evaporation (Blanco-Canqui et al., 2012). By improving infiltration rates and porosity in the upper horizon of the soil, there is less potential for topsoil erosion from raindrop impact.

The interaction of treatment*month impact on mulch percent cover suggests temporal differences in treatments for vegetative cover growth. Overall, treatments likely responded similarly, thus no measureable difference among treatments were detected for all cover parameters. Cover parameter bare soil wasn't impacted by cover crop and Miscanthus only treatments, which suggests there wasn't a significant amount of exposed soil throughout the growing season. This may imply cover crops aided in reducing the percentage of exposed soil within the plots to rainfall impact. Rye and oat cover crops reduced interrill erosion by 62% and 51% in the 3rd year of a study mentioned earlier by Kasper et al. (2001). Interrill erosion occurs between rills and is closely associated with plant canopy cover and residues. Cover crop plant canopies and residues reduced interrill erosion by reducing sediment transport to channels. This led to increased runoff ponding causing sediment deposition (Kasper et al., 2001). The last year of a 2-year study on a Decatur silty clay loam in Alabama observed significant soil erosion reduction with the introduction of cover crops on a SRWC (short rotation woody coppice) plantation (Malik et al., 2000). By having a continuous cover from cover crop versus not having a cover reduced sediment loss by 57% (Malik et al., 2000).

Conclusion

The impact of cover crops on soil quality parameters during Miscanthus establishment was small. Intermediate aggregate size fractions were the only variables that significantly responded to the addition of cover crops. These size fractions indicate probable belowground changes was slowly occurring from bioenergy crop and cover crop root growth. Although small aggregates exhibited initial changes from treatments used in this study, exposed topsoil in May still shows the need for increased canopy protection. Intense precipitation events and soil detachment after planting can deter soil structural benefits observed from this study's treatments. In addition Miscanthus production on highly erodible lands is still considered a viable solution for minimizing spatial competition with agronomic crops. Until herbaceous crops grow a prominent and strong root structure, as well as accumulate a litter layer to protect the soil surface, cover crops are needed to mitigate erosion on steep slopes (Mann and Tolbert, 2000). The soil physical property impacts from cover crops, such as improved soil structure, seem to require more time to develop. Alternatively, Sanderson et al. (2012) recommends planting cover crops 1 – 2 years before establishment of the main crop. This aids in preparing the seedbed for bioenergy crop growth potentially reducing soil erosion events during bioenergy crop establishment.

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CHAPTER 4. GENERAL CONCLUSION

The interest in *Miscanthus x giganteus* as a viable bioenergy crop candidate has led to suggestions for Miscanthus production on marginal or highly erodible lands. Considering the degraded state of these lands, management strategies need to be implemented to protect these lands from further environmental degradation. Additionally temporary obstacles inherent to producing Miscanthus or similar bioenergy crops are late canopy closure and extended establishment periods of these bioenergy crops. Together production on marginal lands and a lengthy maturation phase requires conservation tools for sustainable Miscanthus growth. Although the benefits of cover crops on soil quality are numerous, research observing the production of companion crops in conjunction with bioenergy crops to prevent soil erosion are few. Our intention of conducting this research is to investigate the impact of companion crops grown with Miscanthus on soil quality parameters.

The finding of the study showed companion crops grown with Miscanthus minimally impacted soil quality. Parameters studied and were not impacted by companion crop or Miscanthus only treatments are soil bulk density, infiltration, wet aggregate stability (averaged over all size fractions), and percent cover parameters (living plant canopy, mulch, and bare soil). Intermediate aggregate sizes (1.00, 0.50, and 0.25 mm) were the only soil physical parameter measured that was significantly impacted by companion crop treatments. Since intermediate aggregate sizes form the foundation for macroaggregates and subsequently soil aggregate stability, this finding implies companion crop improve soil structure. By improving soil structure, soil particles are more resistant to erosive events such as rainfall impact.

Based on a meta-analysis by Blanco-Canqui (2015), improvements to soil aggregate stability from cover crops were observed within 3 years after cover crop introduction. Some studies in the meta-analysis cited no impact of cover crops on soil aggregate stability. The fact that we observed intermediate aggregate size fraction changes seems to coincide with the time frame of findings from other studies. The main cause to soil structural changes from cover crop production is speculated to be the root systems of cover crops. Roots assist with soil cohesion through root exudates and protect soil particles from detachment by anchoring crop residues to the soil surface. Fibrous root systems especially are dense and well-developed in the upper 30 cm of the soil (De Baets, 2011).

Recommendations for Future Research

Based on the finding from this research and literature cited in this thesis, recommendations for research on bioenergy crops and cover crops should be pursued in the following ways:

1. Studies should be conducted on marginal or highly erodible lands to investigate the commercial implications on bioenergy crop production with cover crops. This could be paired with rainfall simulations at varying intensities mimicking rainfall events within a region. Also, these studies should be conducted for at least 5 years to allow sufficient time for soil reconsolidation and Miscanthus maturity.
2. There should be studies with Miscanthus to identify ideal companion crops for production. Ideal companion crops should be able to prevent/mitigate soil erosion from rainfall impact and provide other benefits as necessary (i.e. fix nitrogen, overwinter, etc.)
3. Consider using traditional crop rotations such as cover crops grown during the winter when studying Miscanthus. Like corn or other commercial crops, Williams (2011) and

Heaton (2010) recommends winter cover crops for Giant Miscanthus. This management strategy is to prevent soil erosion and suppress weed growth, especially since Miscanthus is sensitive to weed competition during the establishment phase. Weed competition could lead to poor plant survival and/or stand failure for Miscanthus.

By producing bioenergy crops on marginal lands, there is less competition for arable land with traditional row crops, however the consequence is soil erosion including sediment and nutrient loss. Soil erosion can hinder bioenergy crop establishment by reducing plant stands and/or lead to stand failure. Cover crops are a useful conservation tool whose benefits mitigate soil erosion throughout the entire process from intercepting rainfall to increasing ponding and sediment deposition.

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APPENDIX A: ANOVA TABLE OF INFILTRATION RATES

ANOVA table for infiltration by year

	2010 infiltration	2011 infiltration
Main effects	Pr > F	
Date	0.6519	0.4215
Treatment	0.8212	0.7452
Date*Treatment	0.6332	0.1692

APPENDIX B: PHOTOGRAMMETRY COVER VARIABLES SLICED FOR MONTH EFFECTS

Percent cover parameter (Mulch)

Month	**P > 0.05**
May	0.1156
June	0.0171
July	0.5189
August	0.1222

Percent cover parameter (Live plant canopy)

Month	**P > 0.05**
May	0.0370
June	0.1793
July	0.7988
August	0.1092

Percent cover parameter (Bare soil)

Month	**P > 0.05**
May	0.0026
June	0.3476
July	0.9898
August	0.7328

APPENDIX C: LEAST SQUARE MEANS AND STANDARD ERRORS ON PHOTOGRAMMETRY COVER VARIABLES

Least square means and standard errors for Mulch percent cover

	Photogrammetry: Debris/Mulch		
Treatments	Least Square Means (average)	Standard Error	Pr > |t|
Control/MG only	21.4524289	4.9077476	<.0001
Crimson Clover	22.4721056	4.1169647	<.0001
White Clover	14.3104500	3.9056956	0.0007
Rye	16.4929063	3.9056956	0.0001
Oat	25.6596375	3.9056956	<.0001

APPENDIX D: ANOVA TABLES OF MISCANTHUS LITTER DECOMPOSITION AND SOIL VARIABLES

Miscanthus x giganteus litter decomposition and in-situ soil effects: initial chemical analysis

ANOVA table on litter structural components including total carbon and total nitrogen

	Biomass	Total Carbon (plant)	Total Nitrogen (plant)	Hemicellulose	Cellulose	Lignin
Main effect	Pr > F					
Time (weeks)	0.0526	0.0119	0.8269	0.9726	0.9623	0.9983

ANOVA table on soil sampled underneath litter bags for Miscanthus residue decomposition

	pH (soil)	Total Carbon (soil)	Total Nitrogen (soil)
Main effect	Pr > F		
Time (weeks)	0.8625	0.9171	<0.0001

Note: p-values taken from Type III SS