GROWTH, NITROGEN UTILIZATION, AND ENERGY PRODUCTION OF GRAIN AND SWITCHGRASS MANAGEMENT SYSTEMS ON VARYING TOPSOIL DEPTH OF CLAYPAN SOILS

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The undersigned, appointed by the dean of the Graduate School, have examined the thesis entitled

GROWTH, NITROGEN UTILIZATION, AND ENERGY PRODUCTION

OF GRAIN AND SWITCHGRASS MANAGEMENT SYSTEMS

ON VARYING TOPSOIL DEPTH OF CLAYPAN SOILS

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a candidate for the degree of Master of Science,

and hereby certify that, in their opinion, it is worthy of acceptance.

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ABSTRACT

With Midwest claypan soils, the soil overtop the argillic horizon is often called depth to claypan (DTC). This soil feature plays an important role in storing plant-available water for grain crop yield, but it is not well known how this same soil property affects switchgrass growth and nitrogen (N) utilization. A better understanding of plant growth, production, and production efficiency on multiple soil landscapes is needed for grain and bioenergy crops like corn (*Zea mays* L.*)*, soybean (*Glycine max* L. *Merr*.) and switchgrass (*Panicum virgatum* L.*)*. The main purpose of this research was to assess differences between grain and switchgrass productivity as influenced by the DTC. Three primary objectives of this research were: 1) to evaluate canopy-based reflectance sensing for determining the growth, N health, and yield of switchgrass as impacted by DTC; 2) to assess the N loss potential for corn and switchgrass production as affected by the DTC; and 3) to compare the impact of DTC on corn, soybean, and switchgrass yield and bioenergy production.

Research was initiated in 2009 in Columbia, MO on 160 plots with corn, soybean, and switchgrass grown on a range of DTC (0 to 80 cm). During the three years of this research (2009-11), growing season precipitation amounts were very different from each other. For 2009 and 2010 growing seasons, precipitation was well above the long-term average and in 2011it was well below average.

Canopy reflectance sensing in early summer effectively delineated management treatments of switchgrass. Reflectance sensing of the Kanlow switchgrass cultivar was less likely to be affected by DTC if 67 or 101 kg N ha^{-1} was applied. Cave-n-Rock switchgrass cultivar gave the lowest canopy reflectance readings, largely because of the

short and dense stand found with this cultivar. Canopy reflectance sensing performed early in the growing season was very effective at estimating end-of-season biomass yield ($p=<0.05$; $r^2=0.70$).

Corn yield proved to be sensitive to DTC for all three years with greater yield as DTC increased ($p=<0.06$). The DTC effect in 2009 and 2010 was attributed to lack of N and in 2011 the lack of water. Soybean yields were not affected by DTC on wet years. However in the 2011 droughty year, soybean yield increased with DTC. Switchgrass yield proved to be insensitive to DTC, unless harvested during the mid-season on a droughty year. Nitrogen that was not present in the above-ground portion of the plant at the end of the growing season was measured and called the N unaccounted for. The N unaccounted for in corn decreased as a function of increasing DTC when averaged across the three study years. The unaccounted for N in switchgrass was unaffected by DTC. Over all DTC, switchgrass recovered a much higher percentage of the applied N fertilizer than corn.

Energy grown minus N (EG-N) was the final analysis. Yields were converted to energy and N fertilizer energy was subtracted. The EG-N for Kanlow switchgrass was greater than the grain cropping system for all DTC when at least 67 kg N ha^{-1} was applied. The significance of this research is that it establishes the capabilities of claypan soils for producing energy using switchgrass, and establishes the need for site-specific management strategies for targeting crop type and N fertilizer into the landscape.

CHAPTER 1: INTRODUCTION

Interest has increased for the use of bioenergy feedstocks to meet energy needs. This has been propelled by concerns about the local and global impacts that fossil-based energy has on the environment and climate. Other concerns deal with the increasing energy costs (Hill et al., 2006). Both environmental and economic issues were key players in the U.S. federal government's 2005 mandate for the use of renewable fuels through the renewable fuel standard (RFS). The RFS requires the use of 7.5 billion gallons of renewable fuels to be blended with diesel and gasoline. The standard was then revised in 2008 to mandate the use of 36 billion gallons by 2022. Suffice it to say, these mandates create a demand for renewable fuels that generate a host of questions surrounding the production of bioenergy feedstocks.

When considering the use of crops for bioenergy, comprehensive analysis is needed in order to ensure that the amount of energy used to produce and convert the crop to fuel or byproducts is not greater than the amount of energy the crop can potentially produce. Also, growing energy on land previously used for producing food may result in increased food costs. For many years, corn (*Zea mays* L.) and soybean (*Glycine max* L. *Merr.*) have been used to produced liquid biofuels, however, there is much debate as to whether or not these crops produce a net gain in energy when converted into biofuels.

Some locations within a landscape are less productive when growing grain crops (Spomer and Piest, 1982; Jones et al., 1989; Wood et al., 1991; Mulla et al., 1992; Khakural et al., 1996; McConkey et al., 1997; McGee et al., 1997; Timlin et al., 1998).

For incidences where growing grain crops is less productive, perennial feedstock crops may be a viable alternative cropping system. If production of a bioenergy feedstock is shown to be more stable from year-to-year on soils only marginally productive for grain, the bioenergy crops might, in the long run, be more profitable for the farmer. Also, these perennial crops will have environmental benefits such as enhanced soil and water quality (Jung et al., 2008).

The claypan soils of the U.S. Midwest are soils that may be well-suited for a bioenergy feedstock production system. In many years, these soils are only marginally profitable for grain farmers (Massey et al., 2008). The central claypan soil region occupies about 4 million hectares in Missouri and Illinois and is identified as Major Land Resource Area 113 (Soil Survey Staff, 1981). Claypan soils are slowly infiltrated because of a restrictive high-clay subsoil layer usually occurring 20 to 40 cm below the soil surface. The depth of topsoil or depth to the claypan (DTC) is often greatly variable within a landscape or in a field. In some areas, the claypan may be exposed (e.g., on side-slopes) and in other areas it can be buried deeper than 40 cm (e.g., toe-slopes) by soil eroded from areas further up slope (Kitchen et al., 1999). The claypan creates a unique hydrology, controlled by a slow water flow in the soil matrix of the restrictive clay layer (Kitchen et al., 1998). Slow movement of water through the soil profile creates potential surface water quality problems. In areas within a landscape where DTC is shallow, corn yield is often reduced in dry years. This effect on yield can be explained by the unique physical and hydraulic properties of the claypan, including low hydraulic conductivity, slow recharge, poor drainage and high soil resistance for water movement to roots (Jiang et al., 2008).

Switchgrass (*Panicum virgatum* L.) has received a lot of attention as a potential bioenergy feedstock. Understanding of how switchgrass performs under different soil conditions of the claypan soil landscape is limited by a lack of research. However, previous work has shown that switchgrass can also be used to improve soil and water quality. Narrow switchgrass barriers are effective for reducing runoff sediment transport and some nutrients from concentrated field runoff flow (Blanco-Canqui et al., 2004).

The premise of my research is that some locations in claypan soil landscapes may be better suited for bioenergy feedstock production than grain production, and that economic risk will decrease by conversion of such land from grain production to perennial grasses. In addition, this conversion to switchgrass could have additional environmental benefits. One environmental risk of particular interest is associated with nitrogen (N) use by the crop and fate of N escaping from agricultural landscapes. The large energy costs associated with N fertilizer production make this input especially important when calculating the energy balance of bioenergy feedstock. Little is known for how N loss differs between grain and grass production systems across varying DTC landscapes. Further, it is not known how DTC affects N loss for growing seasons that are abnormally wet. With an increase in demand for a cleaner environment and the definite demand for bioenergy, greater understanding is needed for the production and environmental implications across landscapes made up of highly variable soils.

The main purpose of this research is to assess differences between grain and switchgrass productivity as influenced by the DTC. There are three primary objectives addressed by this thesis: 1) to evaluate canopy-based sensing for determining the growth, N health, and yield of switchgrass as impacted by DTC (chapter 2); 2) to assess the N loss potential for corn and switchgrass production as affected by the DTC horizon (chapter 3); and 3) to compare the impact of claypan soil DTC on corn, soybean, and switchgrass yield and bioenergy production (chapter 4).

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CHAPTER 2: ASSESSING MANAGEMENT AND CLAYPAN SOIL VARIABILITY EFFECTS ON SWITCHGRASS USING CANOPY REFLECTANCE SENSING

INTRODUCTION

Switchgrass (*Panicum virgatum* L.) is a warm-season, perennial grass indigenous to the Central and North American tall-grass prairie (Moser and Vogel, 1995) and has received a lot of attention as a potential bioenergy crop. It has been characterized as one of the best species for producing herbaceous biomass for bioenergy (Vogel, 1996). Unlike grain crops, a perennial herbaceous energy crop like switchgrass offers characteristics such as deep root mass that decrease erosion and improve water quality, and crop diversification and agricultural sustainability (Tolbert and Wright, 1998). Being a perennial with a deep root mass allows switchgrass to grow well in a wide range of soil textures and moistures. Various switchgrass cultivars have adapted to a wide range of climates such as eastern and southern cultivars, which are adapted to high moisture conditions; and western and northern cultivars, which are adapted to the drier conditions (Moser and Vogel 1995). Soil and climate adaptive capacity makes switchgrass a strong candidate as a herbaceous energy crop over large geographic regions of the US.

Switchgrass cultivars are categorized as being lowland (grown in the warm and wet southeastern states) and upland (grown in the colder northern states). Two common lowland cultivars are Kanlow and Alamo. These cultivars are tall plants, usually between 1 and 3 m in height, with the ability to adjust and grow well with less than ideal growing conditions, such as drought or small amounts of N availability (Stroup et al. 2003). Although these lowland cultivars are native to wet climates with mild winters, they have the ability to handle droughty conditions, which also makes them suitable for Central Midwest climate. Upland cultivars, on the other hand, are more cold and drought tolerant and are typically grown in the upper Midwest. A well-known example of an upland cultivar is Cave-n-Rock. Although well-suited to the Midwest, Cave-n-Rock yield in this region have usually been found to be less than both Kanlow and Alamo cultivars (Lemus et al., 2002).

Another advantage of switchgrass is small nutrient requirements. In most cases, N fertilizer nutrients will be needed to grow a productive switchgrass crop. Actual amounts of N will vary depending upon cultivar, soil N mineralization, and yield potential as driven by season-long temperature and plant-available water. Typically, switchgrass grown in the U.S. Midwest will need 50 to 120 kg ha^{-1} of N for optimal production (Brejda, 2000). The N requirement of warm-season grasses like switchgrass may be at least partly met through the use of N-fixing legumes in a mixed stand (Brejda et al. 1994). Nitrogen fixed by legumes will decrease the amount of commercial fertilizers needed, but legume species and competition factors will affect how much is available (Ledgard and Steele, 1992). Switchgrass needs for phosphorous (P) and potassium (K), are even less than with corn and soybean crops. With fall frosts, switchgrass leaves senesce and subsequent rainfall leaches plant nutrients back into the soil, recycled for plant use the following year (Parrish and Fike, 2005). Other nutrients and carbon are transported to the roots as storage for overwintering and next spring's growth. Thus if harvest occurs after these processes have taken place in the fall, replacement of P and K fertilize nutrients can be kept to a minimum.

Another benefit of switchgrass over grain crops is the protection offered to the soil. As a perennial grass, switchgrass provides substantial root mass to the soil; this is key in maintaining soil structure and decreasing nutrient and sediment losses through leaching and runoff. When switchgrass is harvested in the fall, there is typically 7 to 15 cm of stubble left after harvesting. Residual biomass left on the soil also decreases the amount of runoff and erosion (Vaughan et al., 1989). Where soils are erosion prone, such as in drainage ditches, a perennial grass like switchgrass can slow the flow of water and retain soil in place (Blanco-Canqui et al. 2004). A prime candidate and example is the claypan soils of the U.S. Midwest, considered to be highly-vulnerable to runoff and erosion (Nikiforoff and Drosdoff, 1943; Kitchen et al., 1998). As such, a perennial grass species like switchgrass has great potential for helping reduce erosion for these soils.

The central claypan soil occupies a region of about 4 million hectares in Missouri and Illinois and is identified as Major Land Resource Area 113 (Soil Survey Staff, 1981). This land area has many concerns because of the unique characteristics of the claypan soils. The claypan is defined as a sub-surface Bt soil horizon that is identified by the illuvial accumulation of silicate clays. The amount of clay necessary is defined in comparison with the quantity in the overlying eluvial horizon, but is at least 20 % or more. With large amounts of clay, problems such as ponding because of poor drainage (Jamison et al., 1968; Kitchen et al., 1999), a droughty nature (Larson and Allmaras, 1971) and slow water infiltration (Jamison and Thornton, 1961; McGinty, 1989) often occur. These problems result from a high-clay content subsoil layer that typically occurs from 20 to 40 cm below the soil surface (Jamison et al., 1968; Myers et al., 2007; USDA-NCRS, 1995).

Differences in landscape topographic features like slope, position, and landform have been shown to be important factors on grain crop yield (Spomer and Piest, 1982; Jones et al., 1989; Wood et al., 1991; Mulla et al., 1992; Khakural et al., 1996a; McConkey et al., 1997; McGee et al., 1997; Timlin et al., 1998). For claypan soil landscapes, depth to the claypan (DTC) can also be highly variable across the landscape. This makes managing crops on these soils difficult. In some areas of the landscape there may be no topsoil with the claypan exposed (e.g., side-slope), while in other areas the claypan can be buried with sediments moved downslope (e.g., toe-slope) (Kitchen et al., 1999). As a result of this variation, crop yield varies as a function of DTC (Thompson et al., 1991; Kitchen et al., 1999). For corn (*Zea mays* L.) production, yield with no topsoil can be half that produced with a topsoil thickness of 38 cm (Thompson et al., 1991; Sudduth et al., 1997; Kitchen et al., 1999). Kitchen et al., (1998) stated the footslope position will generally out-yield upslope position, unless early-season ponding at the footslope reduces stand. For these soils, variability in crop yield within fields usually increases with drought (Sudduth et al., 1997). Kitchen et al. (2005) found that in the months of July and August, when the precipitation amounts were below 15 cm, there was a decrease in yield mainly due to the stress placed on the plants and the lack of plant available water.

While there are many factors contributing to a decrease in yield, three main factors of these soil landscapes are known to contribute to yield reductions: 1) decreased root-zone plant-available water capacity (Gantzer and McCarty, 1987; Kitchen et al., 1999; Thompson et al., 1992; Thompson et al., 1991; USDA-NRCS, 1995); 2) restricted root penetration due to clay accumulation and poor soil structure in the Bt horizon

(Jamison et al., 1968; USDA-NRCS, 1995; Yang et al., 2003; Myers et al., 2007); and 3) small levels of soil organic matter, fertility, and early-season oxygen levels needed for root growth (Jamison et al., 1968). The hydrology of the claypan is controlled by a slow water flow in the soil matrix of the restrictive clay layer (Kitchen et al., 1998). As previously mentioned, the inability for water to move through the restrictive layer creates many of the environmental problems due to runoff, leaching, and denitrification. Furthermore, much of the water present in the clay layer is not easily retrieved by the plant roots. The inconsistency and variability of the claypan soils suggest targeted management is needed to optimize food, feed, and bioenergy production within the landscape.

"Spatial variability in soil erosion, or a surrogate measure such as depth to claypan, serves as a useful template upon which a comprehensive precision agriculture system can be developed" (Lerch et al., 2005). Technology such as apparent soil electrical conductivity (EC_a) (Kitchen et al.,1999) has the ability to do just that, and thus the method to target the high risk areas where row crop production is minimal and environmental hazards are heightened within the landscape. Due to great variability of the claypan soil landscape, the economical profit of a farmer becomes equally variable when managing uniformly in grain crops (Massey et al., 2008) A perennial grass like switchgrass, within those areas showing productivity risk to grain crops, could be a reasonable alternative to help improve productivity while also providing positive soil and water conservation outcomes.

While significant progress has been made in recent years developing agronomic practices for switchgrass, new diagnostic tools are needed to help producers in improving management decisions. One recent technology being used in row-crop production has been active-light reflectance sensors. These sensors use light emitting diodes (LEDs) to project specific visible and near infrared (NIR) light wavelengths onto the canopy of the crop, and then sense the radiation energy that is reflected back by the photodiodes (Stone et al., 1996). Reflectance sensing has been used in a number of studies for the management of N fertilizer in crops like corn (Raun et al., 2005; Dellinger et al., 2008; Kitchen et al., 2010) and wheat (*Triticum aestivum L.*)(Serrano et al., 2000). Prior to N management application, these sensors were used for weed detection and application of herbicides in agronomic and horticulture scenarios (Menges et al., 1985). Although N management is a main concept for the use of these sensors today, they have also been used for other purposes, such as biomass yield estimations (Serrano et al., 2000), grain yield estimations (Raun et al., 2001), and leaf chlorophyll concentrations (Daughtry et al., 2000).

Research using reflectance sensing in switchgrass is limited. In one study, reflectance sensing was used to indicate when switchgrass had physiologically senesced for harvesting after K^+ and Cl^- had leached out of the plant back into the soil (Jorgensen, 1997). Labbe et al., (2008) used light reflectance for examining variation of cultivars and ecotypes, variation in N fertilization, and structural components of switchgrass. Reflectance sensing has also been successfully used to predict the amount of N that is present in forages (Valdes et al. 2006) and has been related to forage compositional analysis as determined by NIR technology (Hames et al. 2003).

The purpose of this research was to further explore how reflectance sensing could be used to understand switchgrass growth and management. Specifically, the objective of this study was to investigate the relationship of active-light reflectance sensing on switchgrass stand, growth, and yield as impacted by switchgrass management and DTC variation.

MATERIALS AND METHODS

Site History

This study was conducted at the University of Missouri South Farm located near Columbia, MO on a study site known as Soil Productivity Assessment for Renewable Energy and Conservation (SPARC). This experiment was initiated in 2009, but the site was originally developed for assessing continuous corn and soybean production as affected by DTC. The research site was uniquely constructed so 32 blocks ranged in topsoil depth from 0 to 40+ cm (Gantzer and McCarty, 1987; Thompson et al., 1991; 1992). The early research was conducted from 1982 to1992. Then from 1993 to 2008 the plot area was fallowed, and native grasses and weeds occupied the site. During that period the site was usually mowed once each summer. When the SPARC project was initiated in the spring of 2009, remaining residual plant matter was burned.

Soil Assessment and Plot Layout

The 32 blocks (see Fig. 2.1) were assessed for DTC with soil EC_a using a combination of the DUALEM-2S (Dualem Inc., Milton, ON, Canada) and the Veris 2000 (Veris Technologies, Salina, KS). Three east-west transects of soil EC_a were obtained from each block to give high-resolution maps of the SPARC area. Operational procedures for obtaining EC_a is described in Sudduth et al. (2010). On the same day, three 1.2 m deep soil cores from each of the 32 block were obtained and examined by a soil scientist to determine the depth to the top of the argillic horizon. The argillic horizon depths were used to develop a regression calibration whereby all soil EC_a values could be converted to DTC, similar to procedures outlined in Kitchen et al. (1999). The 32 blocks were then separated into two experiments of 16 blocks with each experiment having a range of DTC. Experiment 1 was conducted to compare grain vs. switchgrass production on varying DTC of claypan soils. The four treatments of Experiment 1 are described in Table 2.1. Corn and soybean plots were 6.1 m wide and 10 m long, and the switchgrass plots of this experiment were 5.3 m wide and 10 m long. Experiment 2 was conducted to assess different components of management and DTC on switchgrass production. The six treatments of Experiment 2 are also described in Table 2.1. Each block allocated to Experiment 2 has six plots that are 4 m wide by 10 m long. Based on the number of treatments per block and size of plots, the assigned blocks for each experiment can be discerned in Fig. 2.1. For this investigation switchgrass treatments from both experiments were used.

Planting and Fertilization

On May 19th, 2009 all blocks were limed and fertilized with phosphorus and potassium so that each plot had an equivalent level determined to be non-limiting according to Missouri State Soil Fertility Recommendations (Buchholz, 1992) prior to switchgrass planting. After fertilization, soil was prepared for seeding using a rotary tillage operation and switchgrass was planted on June 1st using a Brillion Drop Seeder. Switchgrass was planted at 8.97 kg PLS ha^{-1}. Throughout the summer in 2009 the switchgrass plots were mowed 3 times to help control weeds. No switchgrass yield measurements were obtained in 2009. For Experiment 2 management treatments with legumes to be included, the legume seed was broadcast applied in March 2010. However, weed control on the plots were an issue in spring of 2010. In order to promote the switchgrass establishment, all switchgrass plots were sprayed on June 3, 2010 with Grazon P+D at recommended rates, which killed all broad leaf plants, including the legumes frost seeded earlier that spring. The two legume treatments (KWC and KNL) were thus altered for 2010 and were treated with 34 kg N ha^{-1}, an amount we presumed would be supplied by the legumes for the grass. The legumes were re-broadcast in early March 2011 to continue these treatments as first planned. Also in 2010, the K2cut was treated with N fertilizer the same as K67 because biomass yields this year, when the stand was still immature, did not warrant the early cutting. In 2011, Johnsongrass threatened blocks 9, 25, and 29. So as to not compromise switchgrass stand, Outrider herbicide was sprayed at recommended amounts. There corresponding blocks were not included in this analysis because of the effect of Johnsongrass on reflectance readings (Fig. 2.1). For 2011, block 17 was not used due to N application error, but will resume in 2012 as found in Figure 2.1.

Nitrogen fertilizing was done using a product called Super-U, which is 46% N and contains both thiophosphoric triamide, a urease inhibitor which prevents N loss by ammonia volatilization from urea, and dicyandiamide, an organic N material which retards nitrification. No N fertilization was done to switchgrass plots in 2009. In 2010, fertilizer was split applied to avoid stimulating weed growth while the switchgrass was getting better established (Fig. 2.2). For 2011 N was applied in full at one time, with the exception being the K2cut as shown in Fig. 2.2.

Reflectance Sensing

Canopy reflectance sensing measurements were obtained from mid-May to late-July just before plants began to set seed using a Crop Circle ACS210 (Holland Scientific, Lincoln NE) (Fig. 2.2). The sensor was held between 60 and 90 cm above the canopy and two 7-m long passes along each plot were recorded at a 10 hertz rate, giving 90-120 readings per plot. Reflectance values were averaged by plot as the inverse simple ratio (ISR):

$$ISR = VIS/NIR$$

where VIS is the reflectance of the visible wavelength (590 nm) and NIR is the reflectance of the near infrared wavelength (880 nm).

Canopy sensing, SPAD (Minolta 502 SPAD Chlorophyll Meter), and plant height measurements were taken the same day. These readings were also done within the area designated for harvest. Switchgrass population was obtained in the spring of 2010 as described by Landers, (2010).

The 2010 harvesting of the switchgrass took place on three consecutive days: December 5-7 and in 2011 on November 1-2. Two 91-cm wide passes, 7-m long were taken from the center of each plot in 2010 and in 2011 two 74-cm wide passes, 7-m long were taken. Switchgrass was harvested leaving approximately 10-16 cm of stubble. Plot yields were weighed and subsamples taken for moisture and N analysis. Subsamples were dried at 40 C^{o} for a minimum of 72 hrs and yields were adjusted for reporting on a dry matter basis.

Data Analysis

Regression analysis using PROC REG within the SAS statistical computer program was primarily used for this study. The reason a regression procedure was used was to take advantage of using DTC as a continuous variable. In the end I wanted to have mathematical relationship showing response variables as a linear function of DTC. Within the regression analysis, two procedures were used. First, response variables for each switchgrass management system were independently evaluated relative to DTC. In the second procedure, the K67 switchgrass management was used as a base reference and all other switchgrass management systems were compared against this reference. Management K67 was used because 67 kg N ha^{-1} was described as being a typical N management based on personal communication with USDA, NRCS and Plant Materials Center (Feb. 2009). Treatments were judged to be significantly different when the F-test probability was 0.05 or less. Also the SAS PROC NLIN (non-linear) regression procedure was used with a plateau-quadratic model fit to 2010 yield as a function of reflectance measurements.

RESULTS AND DISCUSSION

Canopy Reflectance as Impacted by the DTC

Switchgrass management as impacted by DTC is seen in Figures 2.3 and 2.4 (see Tables 2.2 and 2.3 for regression equations). With ISR, smaller values indicate either greater biomass, greener biomass, or both. Depth to claypan did not have an effect on sensor readings for any of the treatments in the first sensing date in 2010. As the canopy began to close for the second and third sensing dates, differences in managements were seen by reflectance measurement. For the second sensing date, ISR was affected by DTC for K67 and K101 (Table 2.2). I feel this is because sensor readings were taken shortly after fertilization of the plots and because K67 and K101 received the most N, they displayed the greatest differences in ISR readings. In 2011 as the growing season progressed and canopy began to close, DTC displayed less of an effect on reflectance values. In the first sensing date in 2011, all treatments (other than K2cut) showed a DTC effect. By the fourth sensing date, DTC had no effect on reflectance readings, other than with KWC (Table 2.3). The results support the idea that during switchgrass establishment DTC affected growth, and this was detected by reflectance sensing.

Canopy Reflectance as Impacted by Switchgrass Management

The effects of the management treatments on crop reflectance sensing are shown in Figs. 2.3 and 2.4 (see Tables 2.2 and 2.3 for regression equations). With ISR, smaller values indicate either greater biomass, greener biomass, or both. For each of the panels in Fig. 2.3 representing the three sensing dates in 2010, the ISR of different management treatments are compared using the K67 treatment as a base reference. For all these sensing dates, ISR values of CR were less than the reference K67 (Tables 2.2 and 2.3). This effect of switchgrass variety was because CR is a shorter growing, denser variety than Kanlow. Additionally, stand of CR on these plots was 50 to 100% greater than Kanlow (Lander, 2010), an effect of better seed quality. This higher density of plants seems to have contributed to the lower ISR reflectance values observed.

An understanding of the amounts of N fertilizer and timing of application is needed to interpret the differences between K67 and the other Kanlow treatments. A timeline of dates of application along with amount have been put into graphical form for both years (Fig. 2.2). For all sensing dates, switchgrass with no N (K0) gave higher ISR values. The treatment K34 was different then K67 for the first and third reading dates. The reason for a difference in the first sensing date is because K34 did not receive any N on the first application (Fig. 2.2). This treatment did, however, receive fertilizer between the first and second dates. By the time of the second sensor readings for K34, switchgrass had responded to the added N and was similar to K67. By the third reading, Kanlow switchgrass only receiving 34 kg N ha^{-1} resulted in ISR values higher than K67. I attribute these sensor reading differences to inadequate N at the time of the third sensing date. Within the third set of ISR readings, distinctions among the treatments are visible, with all significantly different from the reference.

Relative to switchgrass management treatments, the ISR values obtained in 2011 appeared very similar to those found during later readings of 2010 (Figs. 2.3 and 2.4). Differences due to N management followed the expected outcome of lower ISR values with increasing N fertilization rate. Throughout all four readings taken, the CR variety continued to have the lowest ISR readings across all sensing dates and was significantly different from the reference treatment (Table 2.3). Again CR continued to be shorter than Kanlow and very dense, a finding similar to Labbe et al, (2008). These are characteristics that would decrease ISR readings. Reflectance from K0 and KNL were significantly greater than the reference. Although the legumes were frost-seeded in the early spring of 2011, they were small and inconspicuous through the periods of reflectance measurements. As such they would have had little effect, neither on reflectance nor in contributing N to switchgrass during this first year of their establishment. The KNL management gave equivalent ISR values as the unfertilized K0 management. For the KWC management, one would expect similar outcomes as the KNL, yet for all four reading dates KWC displayed a trend of lower ISR values. I attribute this difference to the stand of white clover being dense and covering the soil surface. As expected, the reference K67 and K2cut had virtually the same ISR readings for the first three reading dates, because N management was equivalent (Fig. 2.2). The fourth reading date of K2cut deviated from K67 because the switchgrass was harvested between the third and fourth sensing dates. With biomass removed and only stubble showing, reflectance values greatly increased.

Factors Contributing to ISR Differences

To help further understand what factors may have contributed to canopy reflectance differences, ISR readings were regressed against population, height and SPAD to explore potential relationships (Figs. 2.5-2.7; respectively).

Plant Population. For 2010, ISR decreased as population increased, but the relationship was stronger early in the growing season when the first set of ISR readings were taken. This relationship could potentially be used for early season management of switchgrass to evaluate stand sufficiency. Eighteen plants m^2 has been identified as the plant-density threshold to avoid yield reductions when switchgrass is managed as a bioenergy crop (Schmer et al. 2006). Using this threshold value in the equation obtained for ISR 1 (Table 2.4), ISR values > 0.32 would indicate areas that may have marginal stands. Since reflectance values change rapidly during early season growth, using ISR to estimate switchgrass stand would require stand counts on the day of sensing for accurate calibration. For the two later reading dates as the switchgrass canopy closed, ISR was much lower and there was little effect due to population.

Reflectance values in 2011 increased as population decreased for all four dates of sensing (Fig. 2.5; Table 2.4). We attribute these findings to earlier sensing dates during the growing season. In 2010, the first sensing date was on June 22nd and the second and third sensing dates were both during the month of July. In contrast, the last sensing in 2011 was on June 22nd (Fig. 2.2). We believe for 2011, the last sensing dates did not have the full canopy closure like in 2010. Never-the-less, we see these findings supportive of using canopy reflectance sensing to assess stand density. Daily calibration will be necessary.

Plant Height. Switchgrass height was a factor that significantly impacted reflectance measurements (Fig. 2.6). As height increased, ISR readings decreased. This relationship was expected since height would be an indicator of plant biomass (Lemus, et al, (2002) although no in-season biomass measurements were taken at the time of reflectance readings in this study.

Chlorophyll Measurements. When examining 2010 and 2011 ISR as a function of SPAD chlorophyll measurements, ISR decreased as SPAD increased, although the relationship had a large predictive error (Fig. 2.7). This weak relationship is unlike what others found when looking at SPAD readings in corn under varying N fertilization rates (Raun et al., 2005; Dellinger et al., 2008; Kitchen et al., 2010). SPAD has historically been used to quantify chlorophyll content present in the leaves. It is possible that the response of switchgrass with N has more to do with stimulated biomass growth and less with N content (and therefore greenness) in the biomass. Thus SPAD readings may be less effective with switchgrass in assessing plant N health. This idea is supported by the fact that reflectance was affected by height and biomass (next section).

Yield as a Function of ISR

Another objective of this investigation was to examine canopy reflectance sensing during the growing season as an indicator of end of season switchgrass yield. Yield relative to reflectance sensing, expressed as ISR, is shown in Figures 2.8 and 2.9. In 2010, only at higher ISR values did yield vary as a function of ISR, as evidenced by the quadratic portion of the models. The joint value where the plateau and the quadratic meet represents the point where reflectance becomes saturated. The interpretation of the model is that ISR values greater than the joint of the quadratic-plateau represent less than full canopy and canopy reflectance is discerning of sub-optimal conditions for switchgrass stand and growth. Discarding the plateau section of the model, observed yield was regressed as a function of predicted yield of the model (Figs. 2.10). Based upon the root mean square error (RMSE) and coefficient of determination (r^2) (Tables 2.5 and 2.6), reflectance sensing could be reasonably used to predict yield for the sub-optimal conditions using the second two sensing dates of 2010.

Encompassed in all the yield observations are management treatments as found in Table 2.1. Generally, plots with high ISR values were from experimental units with poor stand, shallow DTC, little or no N application, or a combination of these. A possible reason the ISR to yield relationship was poorer for ISR 1 was because N application occurred after the sensor readings.

The reflectance sensor measurements in 2011 were highly related to yield (Fig. 2.9; Table 2.7). When examining the relationship it was apparent that two separate populations existed from this study. Upon investigation, it was found that the CR observations were separate from the Kanlow observations. Therefore regression equations were done by cultivar (Table 2.7). For all sensing dates, both Kanlow and CR yield showed a relationship to canopy reflectance. The r^2 values decreased for both cultivars with later canopy readings (ISR 3-4; Fig. 2.2). I believe this is because canopy closure later in the growing season occurred with all treatments, making it more difficult to discriminate yield. However, canopy reflectance continued to predict end-of-season yield.

CONCLUSION

Switchgrass grown on varying DTC was evaluated using reflectance sensing. Labbe et al, (2008) produced models to predict N rate applied to a field using reflectance sensing. Similarly, we found the canopy sensors were able to detect differences in N management during late June and early July. When looking at factors that contributed to differences in reflectance readings, population and height seemed to be the most influential. For population, reflectance sensing was able to detect where stand densities might be too low. If actual population counts are taken on the same day as sensing, a calibration relating reflectance to stand can be made. The effects of management on reflectance were more pronounced than the effects of DTC.

For the year after establishment, canopy reflectance could be used to determine where switchgrass would be suboptimal. The best relationship to yield came from management treatments that did not receive N, because switchgrass growth was suppressed when N was suboptimal. For more mature stands of switchgrass canopy reflectance early in the growing season could be used to predict yields with high predictability. For this study, the relationship of reflectance sensing to yield was cultivar specific.

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TABLES

Table 2.1 Management treatment descriptions for both Experiments 1 and 2.

Treatment Identification	Annual vs. Perennial	Cropping System	Species	N Fertilizer (kg/ha^{-1})
Experiment 1				
G1	Annual	Corn - Soybean	Corn odd yrs / Soy even yrs	168
G2	Annual	Soybean - Corn	Soy odd yrs / Corn even yrs	0
K0	Perennial	Switchgrass	Kanlow	0
K67	Perennial	Switchgrass	Kanlow	67
Experiment 2				
CR	Perennial	Switchgrass	Cave-n-Rock	67
K67	Perennial	Switchgrass	Kanlow	67
K101	Perennial	Switchgrass	Kanlow	101
K2cut	Perennial	Switchgrass	Kanlow	67 + 34
K+WC†	Perennial	Switchgrass	Kanlow + White Clover	0
K+NL†	Perennial	Switchgrass	Kanlow + Native Legumes	0

† Legumes were frost seeded in the spring of 2011. Therefore in 2010, 34 kg N ha^{-1} was applied to these two treatments and for that year only, is represented by K34.

Table 2.2 Switchgrass reflectance in 2010 as affected by management and depth to claypan (DTC). In the regression equations Y=ISR and X=DTC(cm).

Sensing Date	Treatment	Regression Equation	Statistical Effect: DTC†	Statistical Effect: Management Comparison††		r^2
			Linear	Intercept	Linear	
			-------------------probability-------------------			
6/22						
	K67 (Ref)	Y= 0.303 - 0.000002*X*	0.98	<0.0001	0.98	0.00
	K0	Y= 0.328 + 0.00055*X*	0.63	<0.01	0.64	0.02
	K34	Y= 0.325 + 0.0003*X*	0.07	<0.001	0.16	0.10
	K101	Y= 0.310 - 0.0003*X*	0.06	0.34	0.15	0.23
	CR	Y= 0.277 - 0.0001*X*	0.55	<0.001	0.61	0.03
7/13						
	K67 (Ref)	Y= 0.213 + 0.0003*X*	0.01	<0.0001	<0.01	0.14
	K0	Y= 0.277 - 0.0003*X*	0.38	<0.0001	0.04	0.06
	K34	Y= 0.203 + 0.0002*X*	0.07	<0.01	0.47	0.10
	K101	Y= 0.211 + 0.0002*X*	0.02	0.79	0.68	0.33
	CR	Y= 0.193 + 0.0002*X*	0.19	<0.01	0.69	0.12
7/28						
	K67 (Ref)	Y= 0.194 + 0.0004*X*	<0.001	<0.0001	<0.001	0.25
	K0	Y= 0.267 + 0.0001*X*	0.86	<0.0001	0.26	0.002
	K34	Y= 0.220 + 0.0003*X*	0.001	<0.0001	0.91	0.31
	K101	Y= 0.183 - 0.00001*X*	0.94	<0.0001	0.02	0.00
	CR	Y= 0.170 + 0.0004*X*	<0.01	0.04	0.02	0.47

† Treatments analyzed with a two-tailed T test where $H_o : B_L = 0$. B_L is the linear (i.e. slope) term of the regression equation.
†† The reference (K67) was analyzed with a two-tailed T test where $H_o : B_i = 0$. B_i represents both the intercept and linear term of the regression equation. For the other management treatments, intercept and linear terms are analyzed with a two-tailed test where $H_o : B_{i(treatment)} = B_{i(reference)}$.

Table 2.3 Switchgrass reflectance in 2011 as affected by management and depth to claypan (DTC). In the regression equations Y=ISR and X=DTC(cm).

Sensing Date	Treatment	Regression Equation	Statistical Effect: DTC†	Statistical Effect: Management Comparison††		r^2
			Linear	Intercept	Linear	
			------------------probability------------------			
5/17						
	K67 (Ref)	Y = 0.317 - 0.0009*X*	<0.01	<0.0001	<0.01	0.28
	K0	Y = 0.364 - 0.0014*X*	0.01	0.001	0.37	0.36
	KNL	Y = 0.353 - 0.0010*X*	0.03	<0.01	0.80	0.35
	KWC	Y = 0.336 - 0.0015*X*	0.01	0.17	0.26	0.49
	K101	Y = 0.301 - 0.0013*X*	0.03	0.29	0.54	0.34
	K2cut	Y = 0.334 - 0.0012*X*	0.06	0.22	0.54	0.27
	CR	Y = 0.249 - 0.0010*X*	0.03	<0.0001	0.83	0.33
6/1						
	K67 (Ref)	Y = 0.245 - 0.0003*X*	0.10	<0.0001	0.31	0.09
	K0	Y = 0.351 - 0.0010*X*	0.22	<0.0001	0.04	0.10
	KNL	Y = 0.340 - 0.0007*X*	0.05	<0.0001	0.17	0.28
	KWC	Y = 0.305 - 0.0009*X*	0.04	<0.0001	0.07	0.34
	K101	Y = 0.221 - 0.0003*X*	0.30	0.08	0.90	0.09
	K2cut	Y = 0.252 - 0.0005*X*	0.18	0.29	0.50	0.14
	CR	Y = 0.183 - 0.0004*X*	0.07	<0.0001	0.70	0.24
6/8						
	K67 (Ref)	Y = 0.229 - 0.0005*X*	0.01	<0.0001	0.07	0.22
	K0	Y = 0.342 - 0.0009*X*	0.23	<0.0001	0.31	0.10
	KNL	Y = 0.323 - 0.0008*X*	0.06	<0.0001	0.36	0.26
	KWC	Y = 0.286 - 0.0010*X*	0.10	<0.0001	0.25	0.23
	K101	Y = 0.197 - 0.0004*X*	0.44	0.03	0.93	0.05
	K2cut	Y = 0.224 - 0.0005*X*	0.27	0.82	0.96	0.10
	CR	Y = 0.174 - 0.0006*X*	0.02	<0.0001	0.78	0.35
6/22						
	K67 (Ref)	Y = 0.213 - 0.0002*X*	0.20	<0.0001	0.45	0.06
	K0	Y = 0.307 - 0.0007*X*	0.12	<0.0001	0.18	0.16
	KNL	Y = 0.286 - 0.0004*X*	0.18	<0.0001	0.53	0.15
	KWC	Y = 0.263 - 0.0004*X*	0.05	<0.0001	0.56	0.30
	K101	Y = 0.183 + 0.0001*X*	0.89	0.03	0.72	0.002
	K2cut	Y = 0.319 + 0.0004*X*	0.62	<0.0001	0.19	0.02
	CR	Y = 0.170 - 0.0005*X*	0.21	<0.001	0.85	0.13

† Treatments analyzed with a two-tailed T test where $H_o : B_L = 0$. B_L is the linear (i.e. slope) term of the regression equation.

†† The reference (K67) was analyzed with a two-tailed T test where $H_o : B_i = 0$. B_i represents both the intercept and linear term of the regression equation. For the other management treatments, intercept and linear terms are analyzed with a two-tailed test where $H_o : B_{i(treatment)} = B_{i(reference)}$.

Table 2.4 Switchgrass reflectance in 2010 and 2011 as affected by population. In the regression equations Y=ISR and X=the switchgrass population in plant m^{-2}.

Sensing Date	Treatment	Regression Equation	Statistical Effect: Intercept	Statistical Effect: Linear	r^2
			-----------probability----------		
2010					
6/22					
	Switchgrass	Y= 0.350 - 0.0018*X*	<0.0001	<0.0001	0.25
7/13					
	Switchgrass	Y= 0.214 - 0.0001*X*	<0.0001	0.64	0.002
7/28					
	Switchgrass	Y= 0.225 - 0.0009*X*	<0.0001	<0.01	0.08
2011					
5/17					
	Switchgrass	Y= 0.387 - 0.0040*X*	<0.0001	<0.0001	0.48
6/11					
	Switchgrass	Y= 0.343 - 0.0040*X*	<0.0001	<0.0001	0.37
6/8					
	Switchgrass	Y= 0.321 - 0.0040*X*	<0.0001	<0.0001	0.35
6/22					
	Switchgrass	Y= 0.302 - 0.0034*X*	<0.0001	<0.0001	0.38

Table 2.5 Non-linear quadratic equations for switchgrass reflectance in 2010 as affected by yield. In the regression equations Y=yield (kg ha^{-1}) and X=ISR.

Year	Response Variable	Plateau Value	Joint Value	Quadratic Regression Equation	RMSE	R^2
		(kg ha^{-1})	(ISR)		(kg ha^{-1})	
2010						
	6/22	6365	0.293	$Y= -24711 + 212206X - 362268X^2$	1128	0.13
	7/13	6310	0.227	$Y= -35921 + 371745X - 818085X^2$	968	0.36
	7/28	6387	0.204	$Y= -10767 + 168025X - 411461X^2$	982	0.34

Table 2.6 Predicted yield model fit for 2010 non-linear quadratic equations (Table 2.5) pertaining to the portion less than or equal to joint values. In the model Y=observed yield (kg ha^{-1}) and X=the predicted yield (kg ha^{-1}).

Year	Sensing Date	Model of Observed Yield vs. Predicted Yield	RMSE (kg ha^{-1})	r^2
2010				
	6/22	Y = -1327 + 1.244*X*	1091	0.22
	7/13	Y = -90 + 1.022*X*	795	0.68
	7/28	Y = -446 + 1.098*X*	912	0.53

Table 2.7 Yield in 2011 for Kanlow and CR as a function of canopy reflectance.   In the regression equations Y=yield (kg ha^{-1}) and X=ISR.

Sensing Date	Treatment	Regression Equation	Statistical Effect		r^2
			Intercept	Linear	
			-----------probability----------		
Kanlow					
5/17	Switchgrass	Y= 32024 - 67380*X*	<0.0001	<0.0001	0.45
6/11	Switchgrass	Y= 26938 - 59444*X*	<0.0001	<0.0001	0.73
6/8	Switchgrass	Y= 24207 - 53058*X*	<0.0001	<0.0001	0.72
6/22	Switchgrass	Y= 21563 - 42954*X*	<0.0001	<0.0001	0.40
Cave n Rock					
5/17	Switchgrass	Y= 18175 - 41640*X*	<0.0001	<0.01	0.57
6/11	Switchgrass	Y= 27013 - 104823*X*	<0.0001	<0.0001	0.76
6/8	Switchgrass	Y= 18110 - 58776*X*	<0.0001	0.02	0.40
6/22	Switchgrass	Y= 22003 - 81413*X*	<0.001	0.02	0.43

FIGURES

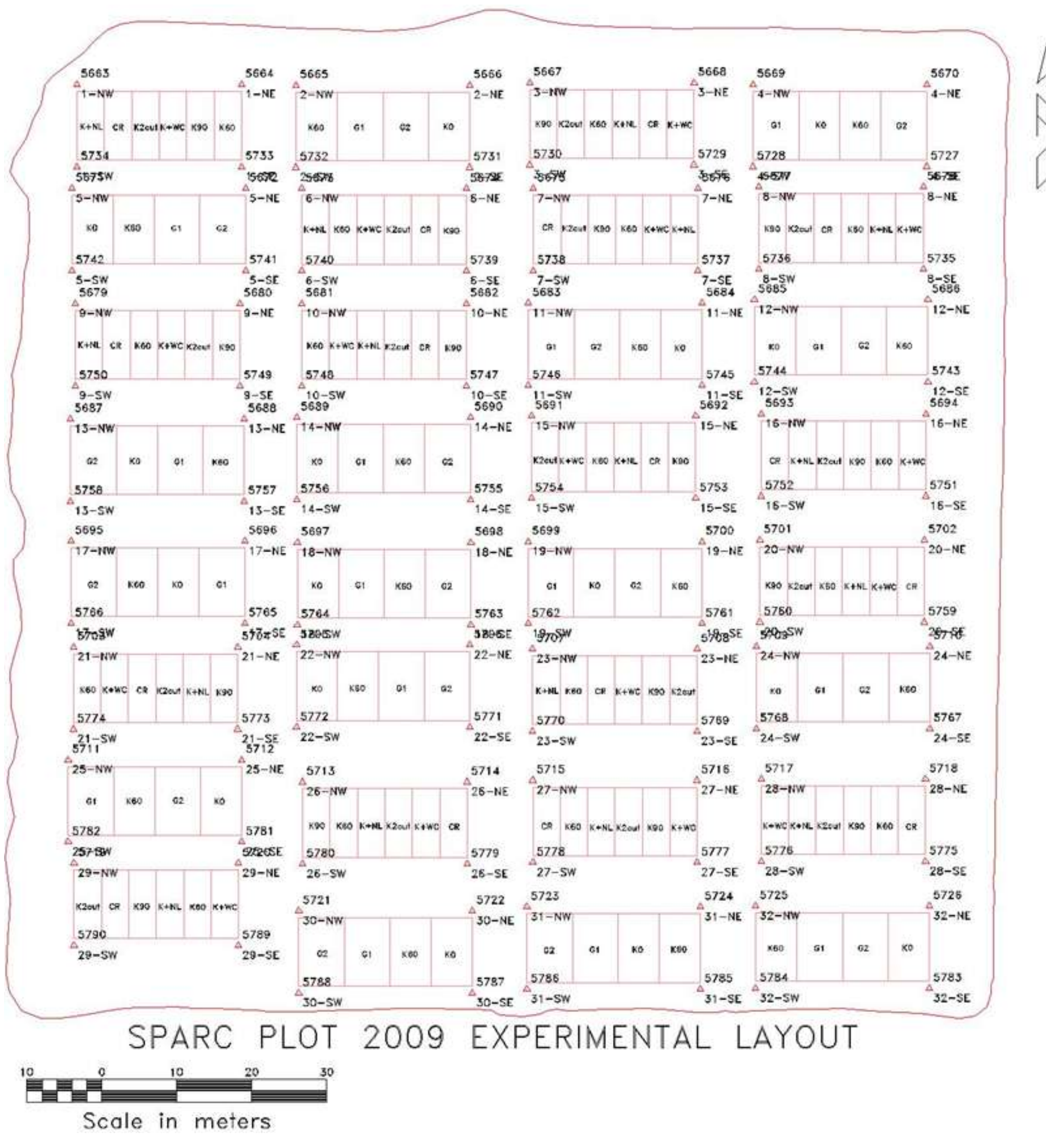

Figure 2.1 SPARC plot layout with treatments.

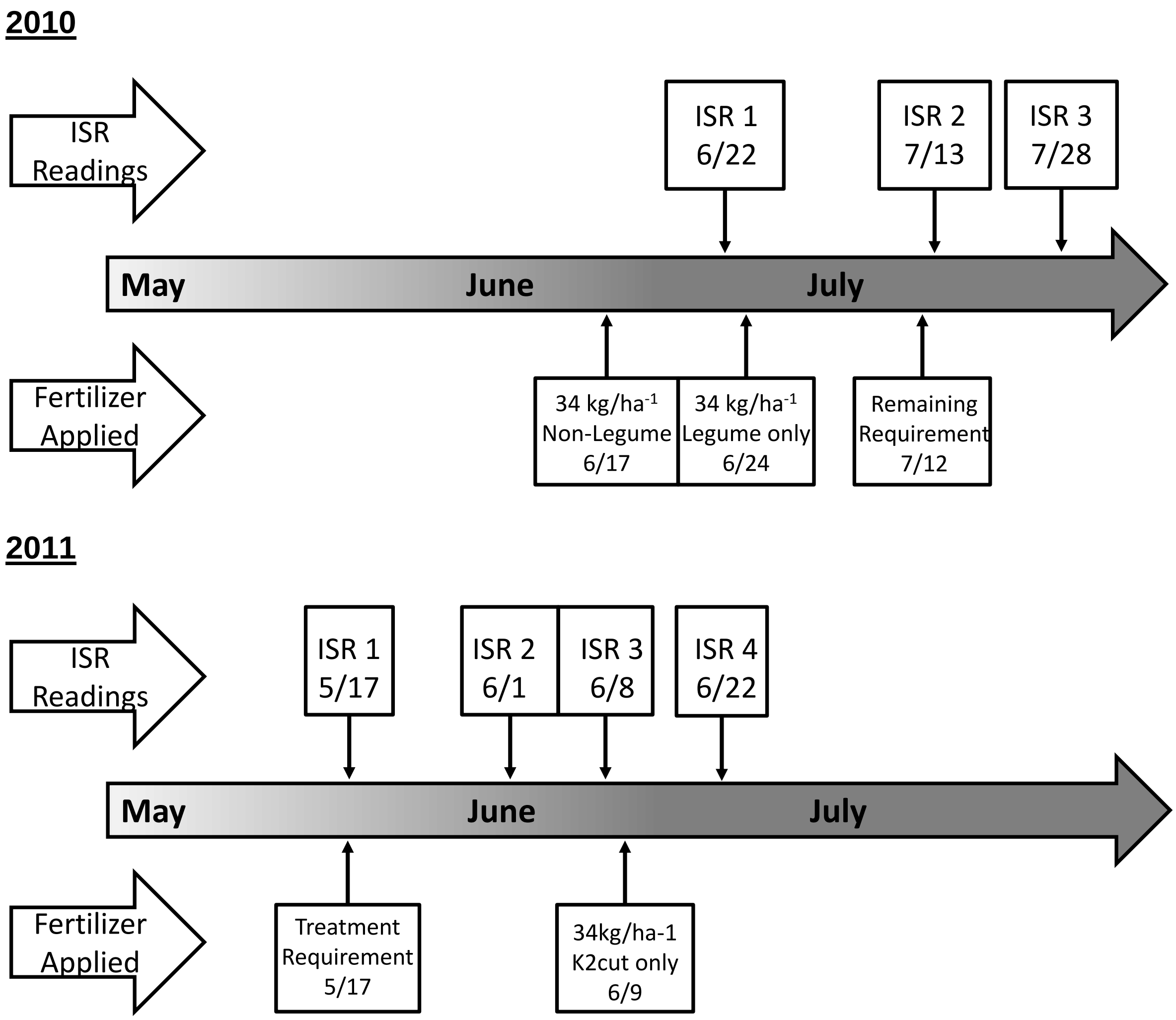

Figure 2.2 Timeline for 2010 and 2011 reflectance readings shown in relation to N fertilizer application.

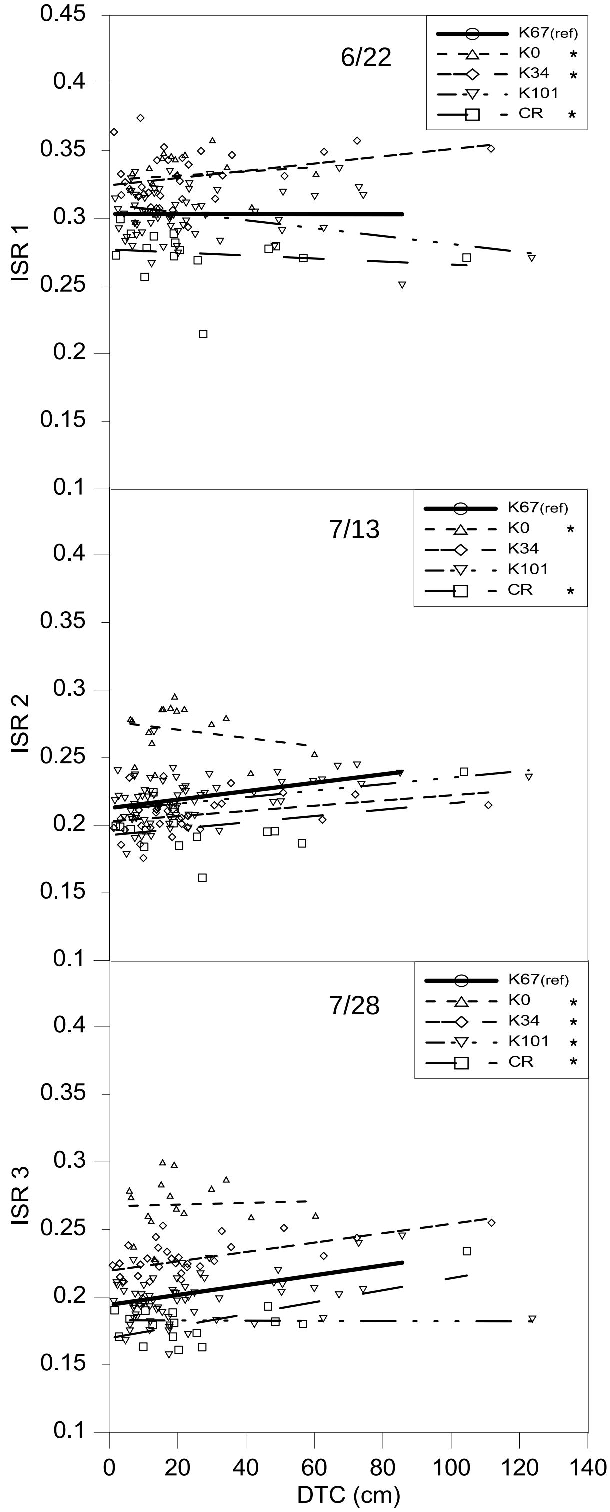

Figure 2.3 Switchgrass reflectance (ISR) readings for three dates in 2010 by management, as a function of DTC. (See Table 2.2 for regression equation.)

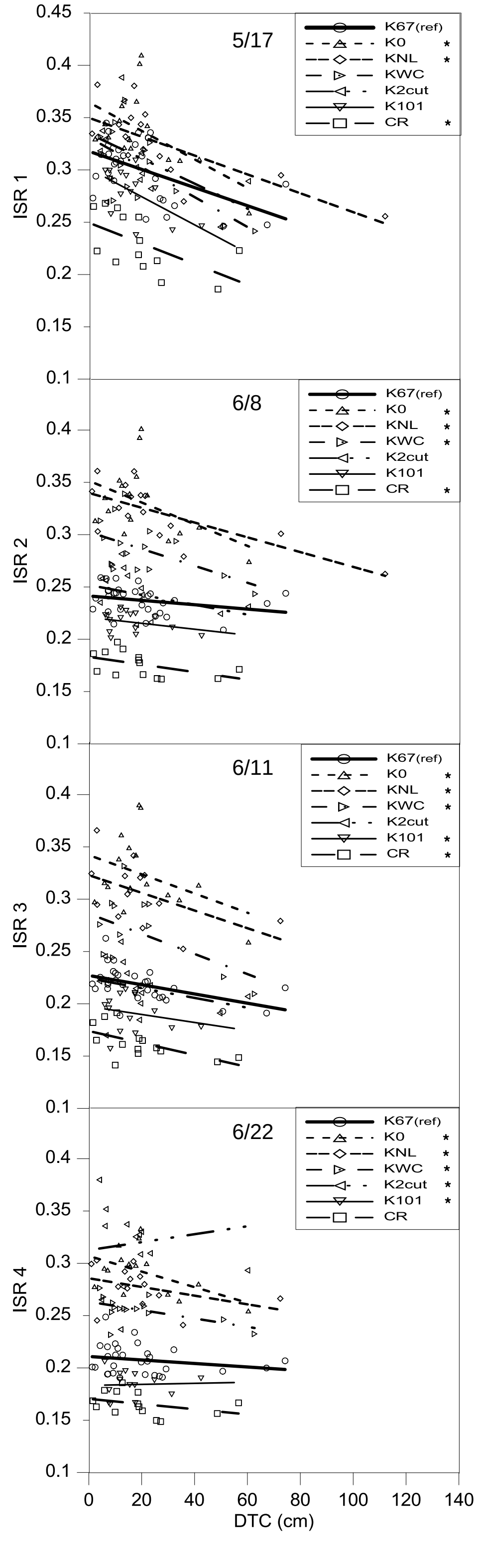

Figure 2.4 Switchgrass reflectance (ISR) readings for four dates in 2011 by management, as a function of DTC. (See Table 2.3 for regression equation.)

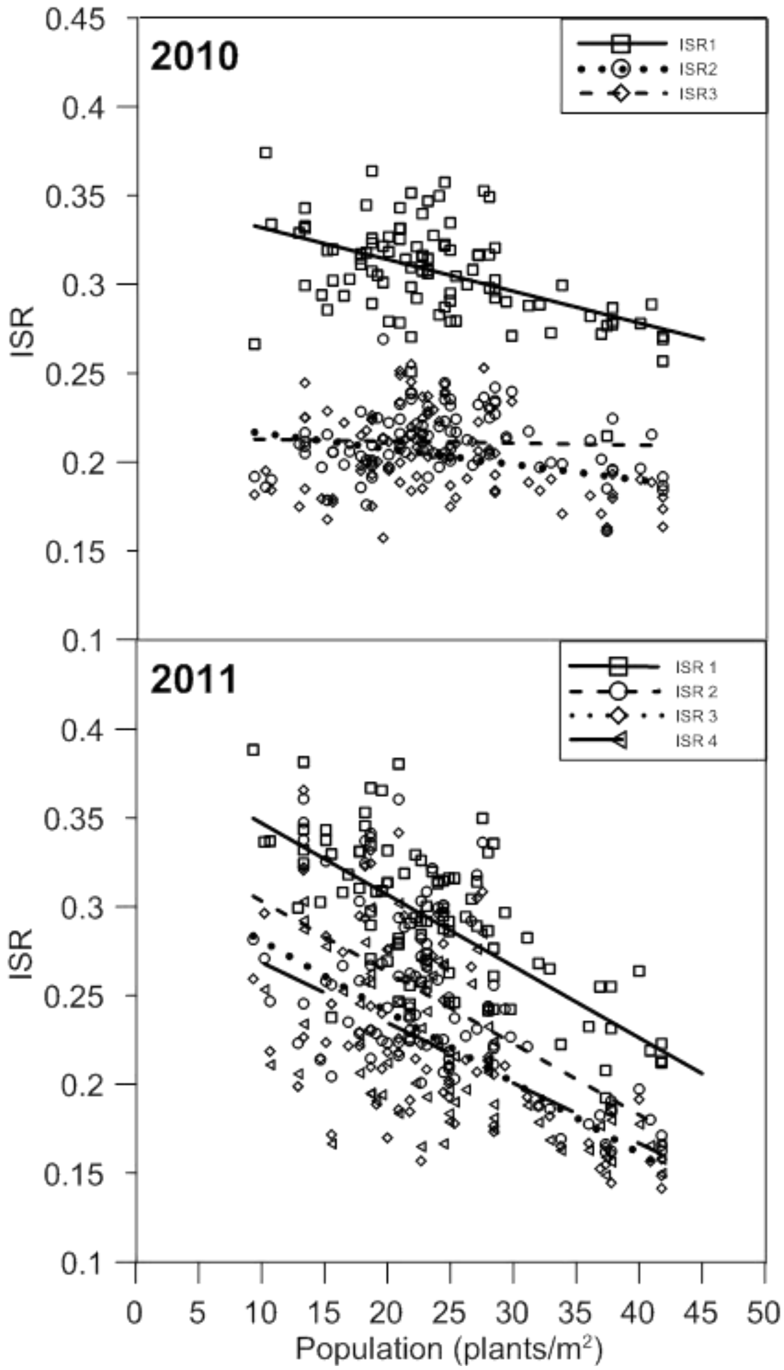

Figure 2.5 Switchgrass reflectance (ISR) as a function of population for 2010 and 2011. (See Table 2.4 for regression equation.)

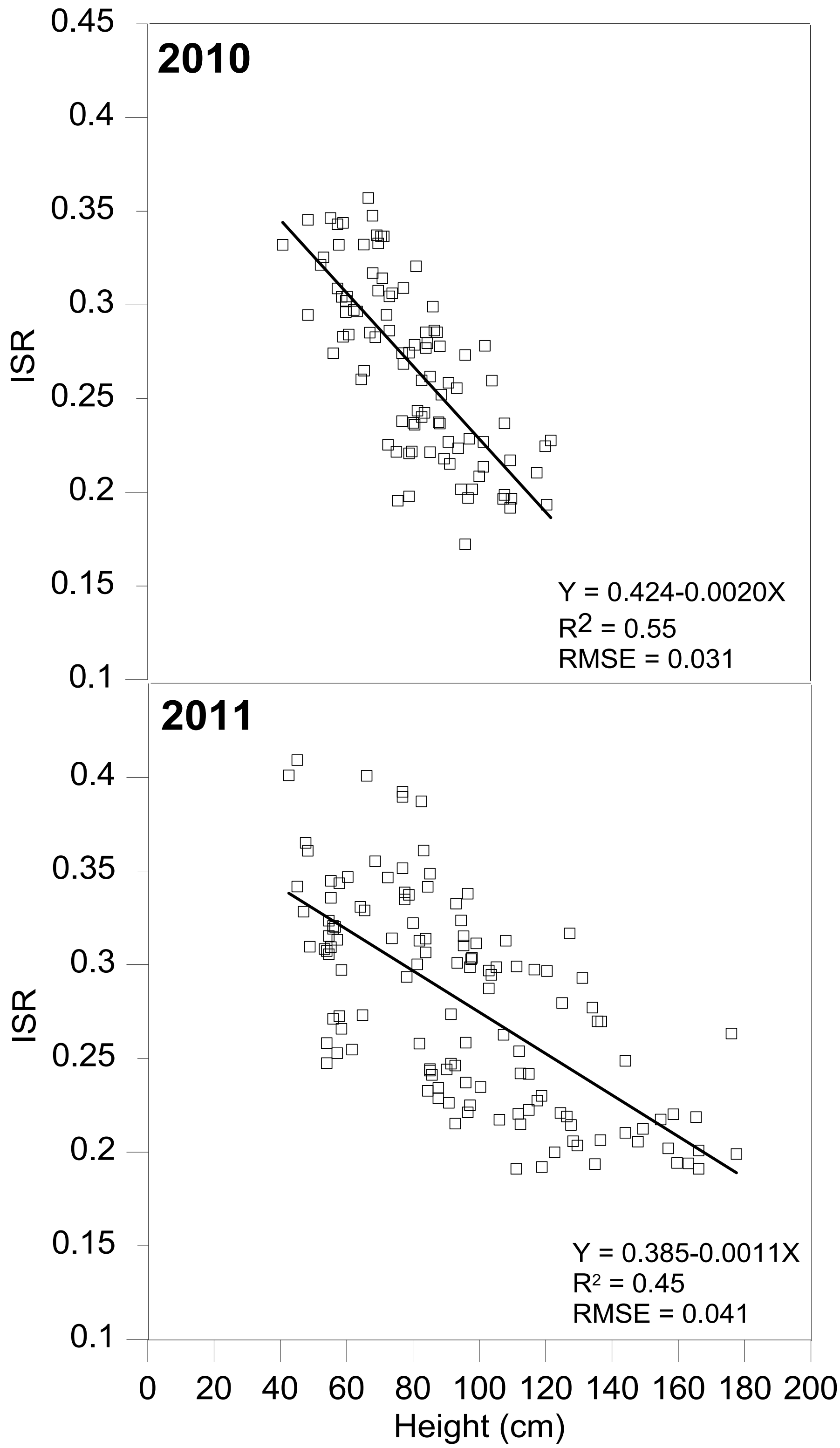

Figure 2.6 Switchgrass reflectance (ISR) as a function of height for 2010 and 2011.

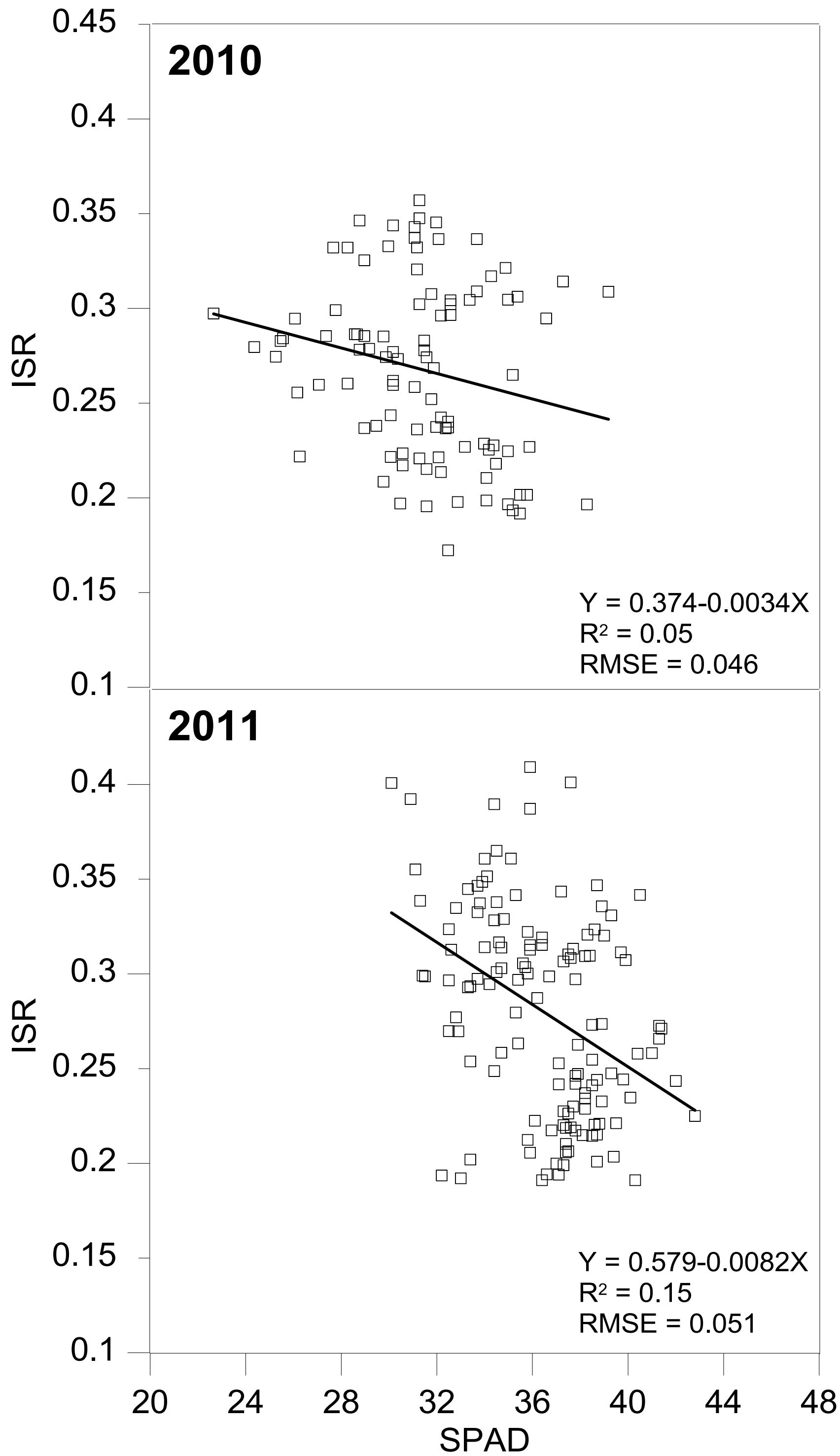

Figure 2.7 Switchgrass reflectance (ISR) as a function of chlorophyll content as measured by the SPAD Chlorophyll Meter for 2010 and 2011.

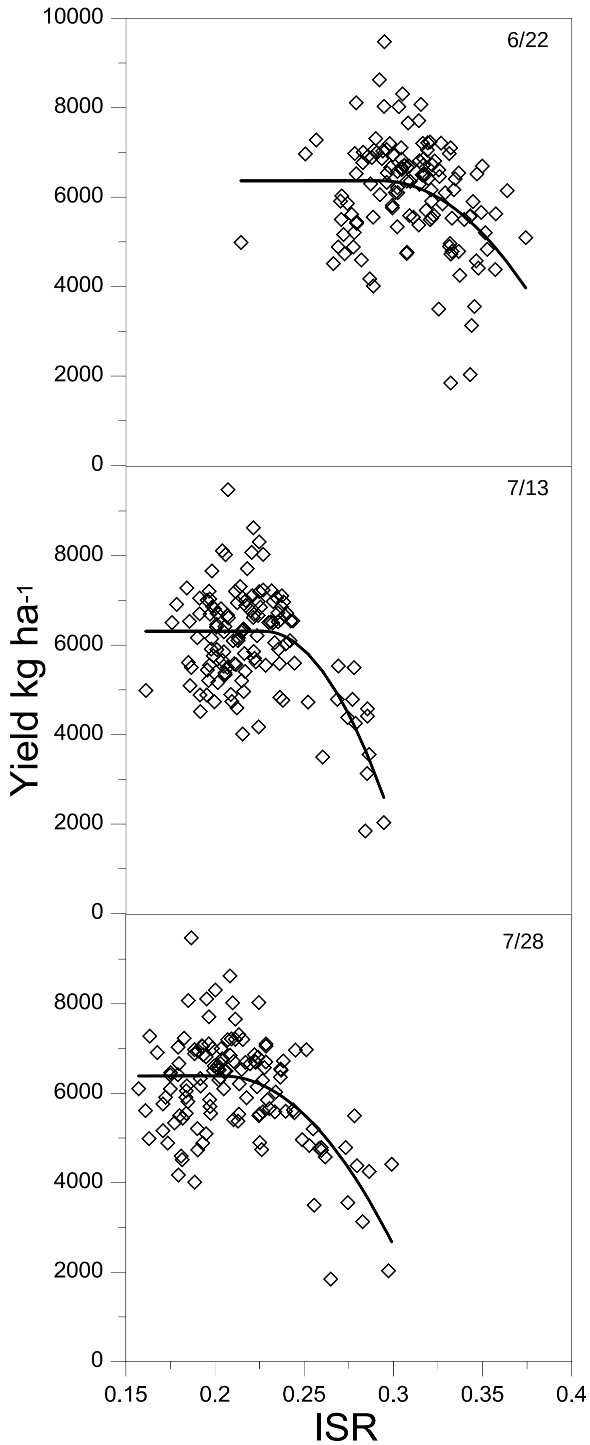

Figure 2.8 Switchgrass yield in 2010 as a function of canopy reflectance taken on three separate sensing dates (see Fig. 2.2). (See Table 2.5 for Plateau-Quadratic regression equation.).

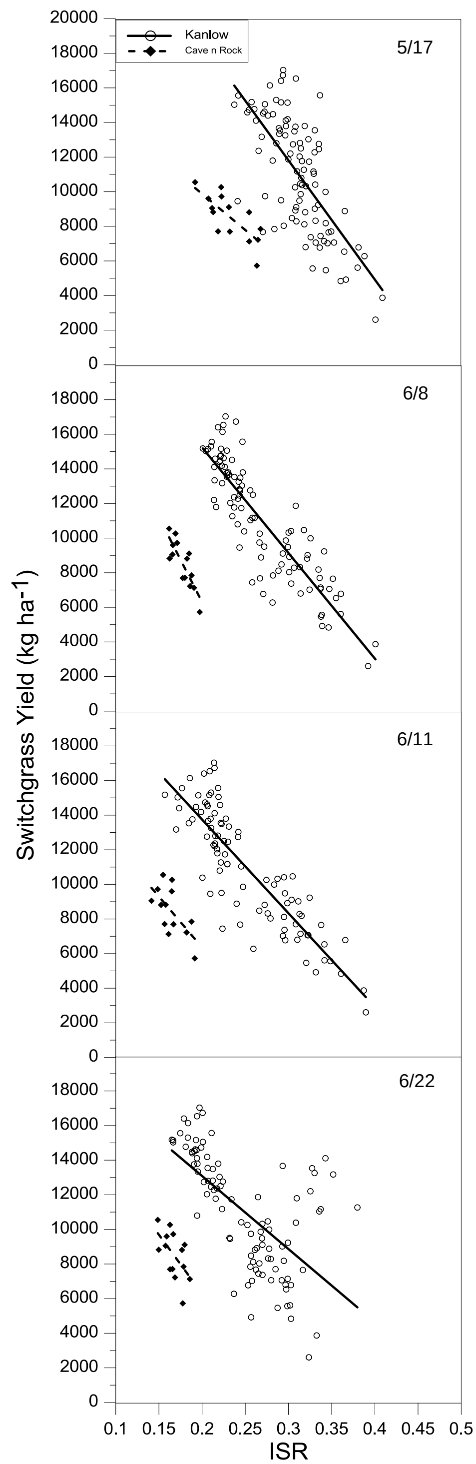

Figure 2.9 Switchgrass yield in 2011 as a function of canopy reflectance taken on four separate sensing dates (see Fig. 2.2). (See Table 2.7 for regression equation.).

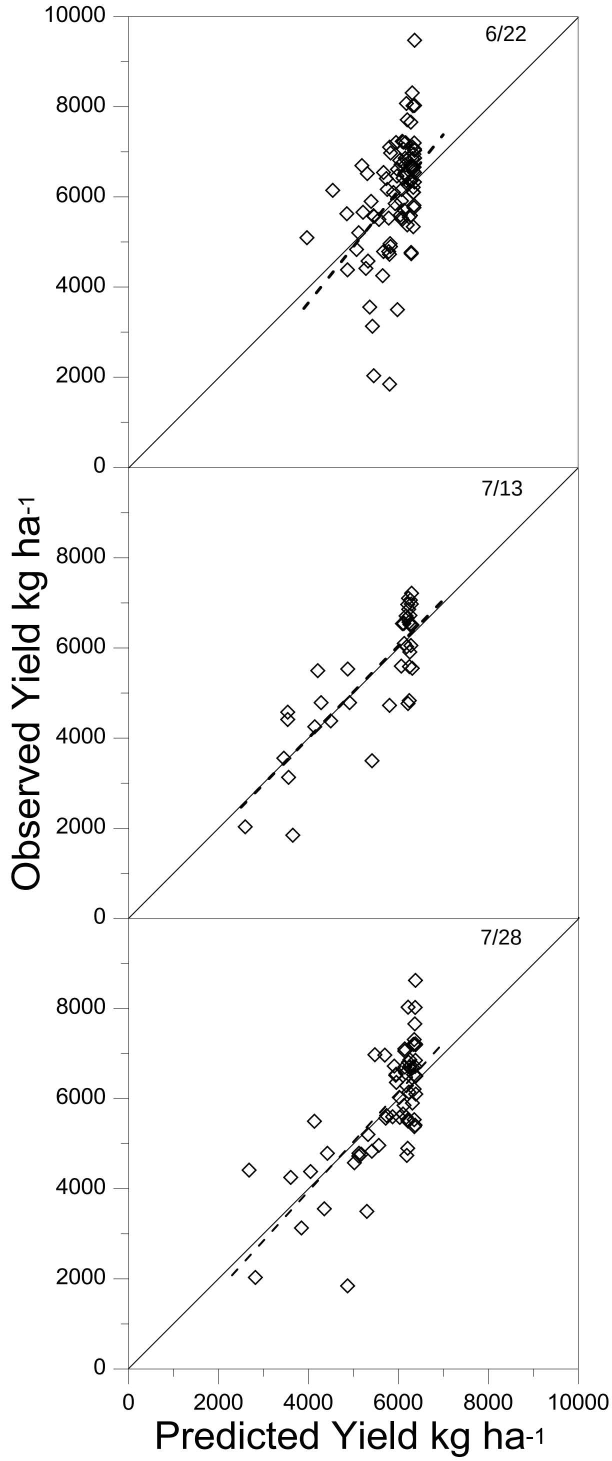

Figure 2.10 Observed 2010 switchgrass yield shown in relationship to predicted yield for reflectance readings (see Table 2.6 for regression equation). Only reflectance values greater than the model joint values were used (see Table 2.5 for joint values).

CHAPTER 3: NITROGEN USE IN CORN AND SWITCHGRASS PRODUCTION VARIES AS A FUNCTION OF TOPSOIL DEPTH

INTRODUCTION

Nitrogen (N) losses from volatilization, denitrification, and leaching may result in poor crop performance, and increase the risk of environmental contamination (Cassman et al., 2002). These N losses can be influenced by a number of factors including, crop rotation, fertilization practices, precipitation and other weather factors, and soil properties. Udawatta et al, 2006 found N losses in corn (*Zea mays* L.) to be nearly six times greater than that of soybean (*Glycine max* L. *Merr*.). Loss of N is also a concern with large amounts of precipitation. Careful management of N can help in decreasing the amount lost to the environment; however, there are elements like excessive rainfall over an extended period for which management cannot compensate.

One U.S. Midwest soil that is especially challenging for crop N management is the slowly permeating alfisols often called claypan soils. Nitrogen loss potential on claypan soils for abnormally wet years is not well known and a better understanding could improve N management decisions. Further, identifying problematic areas within the claypan landscape where losses of grain crop N are greatest allow for the identification of possible site-specific locations where a perennial crop could be grown to help decrease N losses, particularly for those abnormally wet seasons. Understanding the complexity of the claypan soils relative to N management will help highlight why and how these soils should be managed.

The central claypan soil region occupies about 4 million hectares in Missouri and Illinois and is identified as Major Land Resource Area 113 (Soil Survey Staff, 1981). This area has many concerns because of the unique characteristics of the claypan soils, such as ponding because of poor drainage (Jamison et al., 1968; Kitchen et al., 1999), a droughty nature (Larson and Allmaras, 1971) and usually slow permeability (Jamison and Thornton, 1961; McGinty, 1989). These characteristics are result of a high-clay content subsoil layer which typically occurs from 20 to 40 cm below the soil surface (Jamison et al., 1968). This argillic layer has a sharp increase in clay content compared with the overlying horizon, causing these listed characteristics (Myers et al., 2007; USDA-NCRS, 1995).

The hydrology of the claypan is controlled by a slow water flow in the soil matrix of the restrictive clay layer (Kitchen et al., 1998). As previously mentioned, the inability for water to move through the restrictive layer creates many of the environmental problems due to runoff, leaching, and denitrification. Furthermore, much of the water present in the clay layer is not easily retrieved by the plant roots. The inconsistency and variability of these soils suggest targeted management is needed to optimize food, feed, and bioenergy production within the landscape; specifically N management.

Nitrogen lost to the environment can occur through leaching and runoff, although these have not been shown to be a significant loss pathway for claypan soils. For normal to wetter than normal growing seasons, loss by runoff is less than 5% of total available to the crop (Blevins, et al., 1996). In-season N loss by leaching for these soils is generally less than 10% of the total available to the crop (Kitchen, et al., 1998). However, because these soils have poor internal drainage, denitrification becomes the largest loss component to consider. Denitrification being the greatest N loss pathway for claypan soils was also the conclusion of Blevins (1996).

The dominant N fertilizer management system is application of uniform rates over whole fields (Scharf et al., 2006). Further, many corn acres in the U.S. Midwest have N applied before the crop is planted. Uniform pre-plant N applications across fields and farms with varying N needs lead to frequent spatial and temporal mismatches between fertilizer-N applied and crop N needs.

While applying a equal amount of N over a field that appears to have a relatively uniform soil seems like the ideal way to farm, this practice has been documented to have economic and environmental loss. Recent research has shown that the amount of N needed often varies widely within individual corn fields (Davis et al., 1996; Blackmer and White, 1998; Schmidt et al., 2002; Mamo et al., 2003; Scharf et al., 2005; Scharf et al., 2006). Plant N need across fields is not uniform (Scharf et al., 2005) and uniform N applications over variable landscapes is a major deficiency in current farming systems that create conditions for N loss to ground and surface waters (Power et al., 2001; Scharf et al., 2006). Claypan soils have a unique and complex hydrology that cause N to be vulnerable to denitrification during extended wet periods of the spring and early summer. A better understanding of N loss potential under these conditions is needed.

Claypan soil landscape variation along with anthropologic influences have caused the depth to the claypan (DTC) to also be greatly variable. Plant N needs not being uniform across fields is evidence of the variability of the claypan landscape. This makes efficiently managing crops on claypan soils difficult. In some areas of the landscape, there can be no topsoil with the claypan exposed (e.g., side-slope), while in other areas the claypan can be buried with sediments moved downslope (e.g., toe-slope) (Kitchen et al., 1999). As a result of this variation, crop yield varies as a function of DTC, a point that has been well documented (Thompson et al., 1991; Kitchen et al., 1999). In corn production, yield with no topsoil was half that produced with a topsoil thickness of 38-cm (Thompson et al., 1991; Sudduth et al., 1997; Kitchen et al., 1999). Kitchen et al., (1998) stated the footslope position will generally out-yield upslope position, unless early-season ponding at the footslope reduces stand. For these soils, variability in corn yield within fields usually increases with drought (Sudduth et al., 1997). Kitchen et al., (2005) found that for the months of July and August, when the precipitation amounts were below 15 cm there was a decrease in yield, mainly due to the stress placed on the plants and the lack of plant available water. Although yield reductions are noted for dry years, understanding yield reductions on wet years and its association with N is also needed.

Perennial grasses like switchgrass (*Panicum virgatum* L.) offer an alternative to row crop systems to help in the management of N on claypan soils. Besides requiring relatively low amounts of N, switchgrass offers contrasting characteristics, like deep root mass that decrease erosion and improve water quality, while offering crop diversification and agricultural sustainability (Tolbert and Wright, 1998). Being a perennial and having a deep root mass allows switchgrass to grow well in a wide range of soil textures and moistures; this will be needed for the variability found in the claypan. A deep root mass is also key in maintaining soil structure and decreasing nutrient and sediment losses through leaching and runoff. When switchgrass is harvested in the fall, there is typically 7 to 15 cm of stubble left after harvesting. Residual biomass left on the soil after harvest also decreases the amount of runoff and erosion (Vaughan et al., 1989). Where soils are erosion prone, such as in or near drainage ditches, switchgrass is a good alternative for slowing the flow of water and retaining soil in place (Blanco-Canqui et al. 2004).

In most cases, N fertilizer additions will be needed to grow a productive switchgrass crop. Actual amounts of N will vary depending upon cultivar, soil N mineralization, and yield potential as driven by season-long temperature and plant-available water. Typically switchgrass grown in the U.S. Midwest will need 50 - 120 kg N ha^{-1} for optimal production (Brejda, 2000). It is assumed that switchgrass would be an efficient user of N but little is known for how N loss varies when comparing grain and grass production systems across varying DTC landscapes.

The understanding of how varying DTC for Midwest claypan soils impacts N loss potential in corn and switchgrass crops is needed. The main purpose of this study is to evaluate the effect that DTC on claypan soil landscapes has on crop N use for corn and switchgrass cropping systems.

MATERIALS AND METHODS

Site History

This study was conducted at the University of Missouri South Farm located near Columbia, MO on a study site known as Soil Productivity Assessment for Renewable Energy and Conservation (SPARC). This particular experiment was initiated in 2009, but the site was originally developed for assessing continuous corn and soybean production as affected by DTC. The research site was uniquely constructed so 32 blocks ranged in topsoil depth from 0 to 40+ cm (Gantzer and McCarty, 1987; Thompson et al., 1991;

1992). The early research was conducted from 1982 to1992. Then from 1993 to 2008 the plot area was fallowed, and native grasses and weeds occupied the site. During that period the site was usually mowed once each summer. When the SPARC project was initiated in the spring of 2009, remaining residual plant matter was burned.

Soil Assessment and Plot Layout

The 32 blocks (see Fig. 3.1) were assessed for DTC with soil EC_a using a combination of the DUALEM-2S (Dualem Inc., Milton, ON, Canada) and the Veris 2000 (Veris Technologies, Salina, KS). Three east-west transects of soil EC_a were obtained from each block to give high-resolution maps of the SPARC area. Operational procedures for obtaining EC_a is described in Sudduth et al. (2010). On the same day, three 1.2-m deep soil cores from each block were obtained and examined by a soil scientist to determine the depth of the argillic horizon. The argillic horizon depths were used to develop a regression calibration whereby all soil EC values could be converted to DTC, similar to procedures outlined in Kitchen et al. (1999).

The 32 blocks were then separated into two experiments of 16 blocks with each experiment having a range of DTC. Experiment 1 was conducted to compare grain vs. switchgrass production on varying DTC of claypan soils. The four treatments of Experiment 1 and the six treatments of Experiment 2 are described in Table 3.1. Corn and soybean plots were 6.1-m wide and 10-m long, and the switchgrass plots of this experiment were 5.3-m wide and 10-m long. Experiment 2 was conducted to assess different components of management and DTC on switchgrass production. Each block allocated to Experiment 2 has six plots that are 4-m wide by 10-m long. Based on the number of treatments per block and size of plots, the assigned blocks for each experiment can be discerned in Figure 3.1. For this investigation, I will only be using the corn phase of the grain crop system (G1) and the K67 treatment from both Experiment 1 and 2 (Table 3.1). Kanlow67 was used because 67 kg N ha^{-1} was described as being a typical recommended N management based on personal communication with USDA, NRCS and Plant Materials Center (Feb. 2009).

Planting, Fertilization, and Harvesting

Switchgrass. On May 19th, 2009 all blocks were limed and fertilized with phosphorus and potassium so that each plot had an equivalent level determined to be non-limiting according to Missouri State Soil Fertility Recommendations (Buchholz, 1992). Shortly after fertilization, soil was prepared for seeding using a rotary tillage operation and switchgrass was planted on June 1st using a Brillion Drop Seeder. Switchgrass was planted at 8.97 kg PLS ha^{-1}. Throughout the summer in 2009 the switchgrass plots were mowed 3 times to help control weeds. No switchgrass yield measurements were obtained in 2009.

Nitrogen fertilization of the treatments was done using a product called Super-U (46% N) which contains both thiophosphoric triamide, a urease inhibitor which prevents N loss by ammonia volatilization from urea, and dicyandiamide, an organic N material which retards nitrification. No N fertilization was done to switchgrass plots in 2009 (establishment year). In 2010 fertilizer was split applied to avoid stimulating weed growth while the switchgrass was getting better established (Fig. 3.3). For 2011, N was applied on application date (Fig. 3.3). Weed control on the blocks were an issue in spring of 2010. In order to promote the switchgrass establishment, all switchgrass plots were sprayed with Grazon P+D on June 3, 2010 at recommended amounts which killed all broad leaf plants. In 2011, Johnson grass threatened some of the blocks 9, 25, and 29. So as to not compromise switchgrass stand, Outrider herbicide was sprayed at recommended amounts. These corresponding blocks were not included in this analysis because of the effect of Johnsongrass on reflectance readings (Fig. 3.1). For 2011, block 17 was not used due to N application error, but will resume in 2012 as found in Figure 3.1.

The 2010 harvesting of the switchgrass took place on three consecutive days: December 5-7 and in 2011 on November 1-2. Two 91-cm wide passes, 7 m long were taken from the center of each plot in 2010 and in 2011 two 74-cm wide passes, 7 m long were taken. Switchgrass was harvested leaving approximately 10-16 cm of stubble. Plot yields were weighed and subsamples taken for moisture and N analysis. Subsamples were dried at 40 C^o for a minimum of 72 hrs and yields adjusted for reporting on a dry matter basis. Subsamples were ground in a Wiley Mill and analyzed using a LECO total N auto-analyzer (Yeomans and Bremner, 1991).

Corn. Planting, fertilizer, and harvest dates are found in Table 2.3. Eight rows of corn were planted using a no-till 4-row planter and planted with a target population of 69,000 seeds ha^{-1}. Significant rainfall in May of 2009 prevented earlier planting for that year. Corn was fertilized with 168 kg N ha^{-1} as ammonium nitrate in 2009 and Super U (46%) for both 2010 and 2011. Weeds were controlled with Round Up herbicide applied one time at label recommended amounts. The middle four rows were harvested using a two-row harvester when grain moisture was between 15% and 18%. Yield was corrected to 15.5% moisture.

Prior to combine harvest, eight corn plants were randomly hand-harvested for determining grain and stover plant N uptake. The grain was removed and oven-dried for

48 hours at 40 C° and ground in a Wiley Mill and analyzed for total N. Stover was dried then put through a chipper shredder and a subsample was further dried and ground in a Wiley Mill and analyzed for total N content. Nitrogen analysis was done using a LECO total N auto-analyzer (Yeomans and Bremner, 1991).

Given the chlorotic condition of the corn leading up to the 2009 and 2010 harvest, I presumed little inorganic soil N was available at the end of the growing seasons. However in 2011, due to the droughty conditions, I feel there could be some N still present in the soil which would be available for the 2012 soybean crop.

A partial N accounting was determined for the corn and switchgrass by the following equations:

Available N = MN + FN + AN

Unaccounted N (UN) = (FN + MN +AN) – PN

Potential denitrified N = UN- LN- RN

Where: MN=Estimated soil Mineralized N (22.4 kg ha^{-1})(UMC Soil Test Interpretations and Recommendations Handbook, 1983. Revised 2004), FN=Fertilizer N (see Table 3.1), AN=Estimated Atmospheric N (10 kg ha^{-1}), PN=Above-ground Plant N, UN=Unaccounted for N, LN=estimated Leaching N (Kitchen et al. 1998), RN=estimated Runoff N (Blevins et al. 1996)

Data Analysis

Regression analysis using Proc Reg within the SAS statistical computer program was primarily used for this study. The reason a regression procedure was used was to take advantage of the continuous DTC variable. In the end, I wanted to have a mathematical relationship of the response variables as a function of DTC. Treatments were judged to be significantly different when the F-test probability was 0.05 or less.

RESULTS AND DISCUSSION

Yield as a Function of DTC

Corn. The effect of DTC on corn yield is shown in Figure 3.4 (see Table 3.3 for regression equations). When looking at yield across the three years, 2009 and 2010 both yielded more than 2011. I attribute the decrease in yield in 2011 to be due to small amounts of growing-season precipitation (Fig. 3.3). For all three years, corn yield increased as DTC increased ($p=0.06$ for 2010; Fig. 3.4 and Table 3.3) Precipitation differences between these years illustrate that regardless of being excessively wet (2009 and 2010) or dry (2011) DTC had a similar effect on yield. Drought conditions caused lowest yields to occur in 2011. For the wet years, I conclude the relationship of yield and DTC was caused by a continually saturated soil with excessive water causing N to be lost. Typical N deficient chlorosis was visible during the growing season. I attribute the loss of N for the two wet years to be due to denitrification, although actual measurements were not taken. Loss of N from denitrification on claypan soils was also a conclusion of Blevins et al. (1996). Importantly, the trend observed across multiple years and climates was as DTC increased, yield also increased.

Switchgrass. Switchgrass yield was assessed similarly to see if DTC impacted yield. Depth to claypan did not affect the yield of switchgrass for 2010 and 2011 (Fig.

3.5; Table 3.3). Because perennial grasses lay dormant in the winter with established root systems, spring allows for quicker growth and use of nutrients and water much earlier than an annual grain crop like corn, resulting in biomass accumulation early in the growing-season. In addition, the deep root mass switchgrass offers optimization of whole soil-profile water use during droughty years. This was particularly evident in 2011 because the drought period began early to mid-June (Fig. 3.3) but switchgrass had already produced approximately 4000 kg ha^{-1} dry weight (data not included).

The results demonstrate that switchgrass is much less sensitive to DTC than corn, from the stand point of both water and N stress. As such, I would conclude that switchgrass would provide more stable yield than corn in claypan soil fields that have variable DTC throughout the landscape.

Plant Nitrogen Concentration as a Function of DTC

Corn grain N content was not affected by DTC (Fig. 3.6; Table 3.4). Grain N content of 2009 was approximately 3-4 g kg^{-1} less than 2010 and 2011. While I cannot be certain of the reason for this lower N content, 2009 yielded more. Further, a different N source was used and time of application was later in the growing season (Table 3.2). This along with moisture conditions in June and July may have been contributing factors. Additional investigation is warranted to explore the plant N-content to N fertilizer source and timing relationship. Stover N content was not affected by DTC for 2010 or 2011, however in 2009 it did show a slight increase with increasing DTC (Table 3.4). Again N fertilizer source and timing of application may have been a factor.

Switchgrass N content for 2010 was comparable to corn stover N content (Fig. 3.7; Table 3.4). In 2011 the switchgrass N content was about half that of 2010. This difference in N content could be the result of greater plant maturity in 2011, when biomass quantity was considerably greater than in 2010. When comparing corn to switchgrass, the averaged grain and stover N contents were approximately three times that of switchgrass. Switchgrass N content slightly increased with DTC in 2010 (Table 3.4). Depth to claypan did not have an effect on N content for 2011 switchgrass. The mature stand of switchgrass in 2011 may have also influenced the lack of DTC relationship.

Unaccounted for Nitrogen as a Function of DTC

By multiplying the N content and yield for the two crops, and subtracting this from the amount of N available to the crops, the amount of N unaccounted for can be examined and compared for the corn and switchgrass cropping systems (Fig. 3.8 and 3.9; Table 3.5). This unaccounted for N can presumably be attributed to four different loss pathways or pools: leached N, runoff N, denitrified N, and N left in the soil as organic or inorganic N.

Corn. Unaccounted for N in corn slightly decreased with increasing DTC, though this was only statistically significant for 2009 at the 0.05 probability level (Fig. 3.8; Table 3.5). Precipitation for 2009 and 2010 was similar yet somewhat greater than the 50 year average. Although having similar amounts of precipitation, unaccounted for N was different for both years. I attribute these results to be caused by a few possible reasons: N source, planting date (Table 3.2), and fertilizing date (Table 3.2). In 2009, ammonium nitrate was applied at planting. In 2010, Super-U was applied two weeks after planting. Nitrogen from ammonium nitrate quickly became plant-available causing large amounts of N to be available when the plant required little. This allowed for a greater chance of loss to the environment. On a wet year, I attribute this loss mainly to denitrification. The DTC relationship for the wet 2009 year would suggest that on shallow DTC, the soil stayed wetter longer favoring conditions for denitrification. This outcome demonstrates the need for soil specific N management. In contrast, N applied in 2010 and 2011 as Super-U became available much more slowly, and was less likely to be lost. Depth to claypan did not show a significant effect on unaccounted for N for 2010 and 2011.

For the 2011 growing season, unaccounted for N was notably greater than the two previous years. Due to the especially dry conditions in 2011, the corn crop was water stressed, and therefore N uptake was suppressed when compared to the two previous years. Significant amounts of available N was likely located in the soil after harvest, although no measurements were taken to verify this. Again, while only 2009 was significant at the 0.05 level, all three years were statistically significant at the 0.15 level and suggest that a similar trend of increased unaccounted for N with decreased DTC (Tables 3.3 and 3.5).

Switchgrass. Unaccounted for N in switchgrass was much more stable across DTC conditions than corn for all years (Fig. 3.9; Table 3.5). Depth to claypan did not have an effect on the amount of N unaccounted (Fig. 3.9; Table 3.5). Switchgrass actively puts nutrients back into the soil before senescence in the fall. I attribute most of the unaccounted for N to be within the root mass of the plant to be used the following spring. Evidence of this is found when looking at both the yield and unaccounted for N. Although there were large yield differences between years, the amount of N unaccounted were practically the same, suggesting the plant had moved similar amounts back into the soil. It is unlikely that similar amounts of unaccounted for N would occur on two very different climate years had the plant not actively moved N back into the ground.

Averaged Unaccounted for Nitrogen

Unaccounted for N averaged for the three corn years and the two switchgrass years are compared in Figure 3.10. At approximately 30-cm DTC, the unaccounted for N of these two systems is the same. With less than 30 cm, corn grown on claypan soils gives a greater unaccounted for N. This concurrently shows that on shallow DTC, a switchgrass system would minimize the amount of N that is not accounted for. Furthermore, if switchgrass is actively putting N back into the soil, the difference between the two cropping systems is exacerbated (Fig. 3.10). As perennial grasses move nutrients back into the soil the roots contain between 30-50 kg N ha^{-1} more than with corn at the end of the growing season (Risser and Parton, 1982). Switchgrass not showing a DTC relationship on both a wet and a dry year compared to the trend seen with corn would suggest switchgrass is a much more stable system from the standpoint of N utilization and yield. Further, switchgrass is less likely to create environmental issues associated with N fertilizer management as seen with grain cropping systems.

CONCLUSION

The three years of the study were very different from the 50 year average (Fig. 3.2). In 2009 and 2010 above average rainfall during the growing season was experienced, while in 2011 a drought occurred from mid-June through mid-August. When assessing the affects DTC has on unaccounted for N and yield within corn and switchgrass cropping systems for these abnormal climate years, there were some similar trends. Corn tended to yield better as DTC increased for both wet and dry years while switchgrass yielded the same across all DTC. Switchgrass showed the ability to recover N better than corn for DTC < 30 cm. When including the 30-50 kg N ha^{-1} likely left in the roots for a switchgrass crop, switchgrass is more efficient regardless of DTC.

The major focus of grain cropping systems today is the ability to obtain larger yields. In corn production, better genetics and better fertilizer inputs help in achieving these high yielding goals; however, with non-predictable weather conditions, the loss of nutrients to the environment becomes inevitable. This research demonstrates the importance of proper location within the landscapes where specific cropping systems can be implemented to preserve nutrients like N which potentially enter water sources or leave as gasses harmful to the environment. The weaknesses of corn are increased erosion, large amounts of fertilizer inputs, and high sensitivity to water and N stress, all of which typically result in decreased yield and loss of nutrients to the environment. The placement of perennial grasses on highly eroded areas of the landscape that do not produce the desired high yields in corn, help preserve and restore the soils and are much less sensitive to the differences in weather from year-to-year. I feel that through the use of specific crops on specific landscapes, there will be increase profitability for farmers and a decrease in nutrient loss to the environment.

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TABLES

Table 3.1 Management treatment descriptions for both Experiments 1 and 2.

Treatment Identification	Annual vs. Perennial	Cropping System	Species	N Fertilizer (kg/ha^{-1})
Experiment 1				
G1	Annual	Corn - Soybean	Corn odd yrs / Soy even yrs	168
G2	Annual	Soybean - Corn	Soy odd yrs / Corn even yrs	0
K0	Perennial	Switchgrass	Kanlow	0
K67	Perennial	Switchgrass	Kanlow	67
Experiment 2				
CR	Perennial	Switchgrass	Cave-n-Rock	67
K67	Perennial	Switchgrass	Kanlow	67
K101	Perennial	Switchgrass	Kanlow	101
K2cut	Perennial	Switchgrass	Kanlow	67 + 34
K+WC†	Perennial	Switchgrass	Kanlow + White Clover	0
K+NL†	Perennial	Switchgrass	Kanlow + Native Legumes	0

† Legumes were frost seeded in the spring of 2011. Therefore in 2010, 34 kg N ha^{-1} was applied to these two treatments for that year only.

Table 3.2 Planting, fertilizing, and harvest dates for corn and soybeans hybrids and their respective populations.

Crop/Year	Planting date	Fertilized date	Harvest date	Hybrid used	Population
Corn					Plants ha^{-1}
2009	June 1	June 1	Oct. 28	MC-590VT3 RR	69,000
2010	April 19	May 3	Sept. 13	MC-550GT RR	69,000
2011	May 5	March 23	Sept. 8	MCT-583 QUAD RR, LL	69,000
Soybeans					
2009	June 3	N/A	Nov. 11	NK S39-A3 RR	370,000
2010	June 5	N/A	Oct. 15	NK S37-F7 RR	370,000
2011	May 25	N/A	Oct. 7	NK S38-H8 RR	370,000

Table 3.3 Corn and Switchgrass yield as affected by depth to claypan DTC. In the regression equations Y=yield (kg ha^{-1}) and X=DTC(cm).

Year	Crop	Regression Equation	Statistical Effect: Intercept	Statistical Effect: Linear	r^2
			------------probability-----------		
2009					
	Corn	Y= 6922 + 124.5*X*	<0.0001	<0.001	0.58
	Switchgrass	Establishment Year	N/A	N/A	N/A
2010					
	Corn	Y= 7565 + 29.8*X*	<0.0001	0.06	0.23
	Switchgrass	Y= 6882 - 10.7*X*	<0.0001	0.14	0.07
2011					
	Corn	Y= 2955 + 79.2*X*	<0.001	0.02	0.32
	Switchgrass	Y= 13663 - 16.0*X*	<0.0001	0.38	0.03

Table 3.4 Nitrogen concentration found in grain, stover, and switchgrass as affected by DTC. In the regression equations Y=N concentration (g kg^{-1}) and X=DTC(cm).

Year	Treatment	Regression Equation	Statistical Effect		r^2
			Intercept	Linear	
			-----------probability-----------		
2009					
	Grain	Y= 8.2 + 0.03*X*	<0.0001	0.24	0.10
	Stover	Y= 5.5 + 0.01*X*	<0.0001	0.03	0.28
	Switchgrass	Establishment Year	N/A	N/A	N/A
2010					
	Grain	Y= 12.2 + 0.001*X*	<0.0001	0.88	0.001
	Stover	Y= 5.1 - 0.01*X*	<0.0001	0.16	0.13
	Switchgrass	Y= 3.9 + 0.02*X*	<0.0001	0.01	0.20
2011					
	Grain	Y= 11.3 + 0.01*X*	<0.0001	0.41	0.05
	Stover	Y= 4.8 + 0.01*X*	<0.0001	0.80	0.005
	Switchgrass	Y= 2.2 - 0.01*X*	<0.0001	0.51	0.02

Table 3.5 Nitrogen unaccounted for in corn and switchgrass as affected by DTC. In the regression equations Y=N unaccounted for (kg ha^{-1}) and X=DTC(cm).

Year	Treatment	Regression Equation	Statistical Effect		r^2
			Intercept	Linear	
			-----------probability-----------		
2009					
	Corn	Y= 105.9 - 1.79*X*	<0.0001	0.001	0.55
	Switchgrass	Establishment Year	N/A	N/A	N/A
2010					
	Corn	Y= 85.8 - 0.39*X*	<0.0001	0.15	0.14
	Switchgrass	Y= 72.7 - 0.07*X*	<0.0001	0.18	0.06
2011					
	Corn	Y= 132.6 - 0.83*X*	<0.0001	0.16	0.13
	Switchgrass	Y= 77.1 - 0.03*X*	<0.0001	0.85	0.001
Study Average	Corn	Y= 104.3 - 0.75*X*	<0.0001	0.01	0.15
	Switchgrass	Y= 75.3 - 0.06*X*	<0.0001	0.38	0.01
	Root Adjusted†	Y= 45.3 - 0.06*X*			

† Adjustment made because N stored in warm-season grass roots greater than corn (Risser and Parton, 1982).

FIGURES

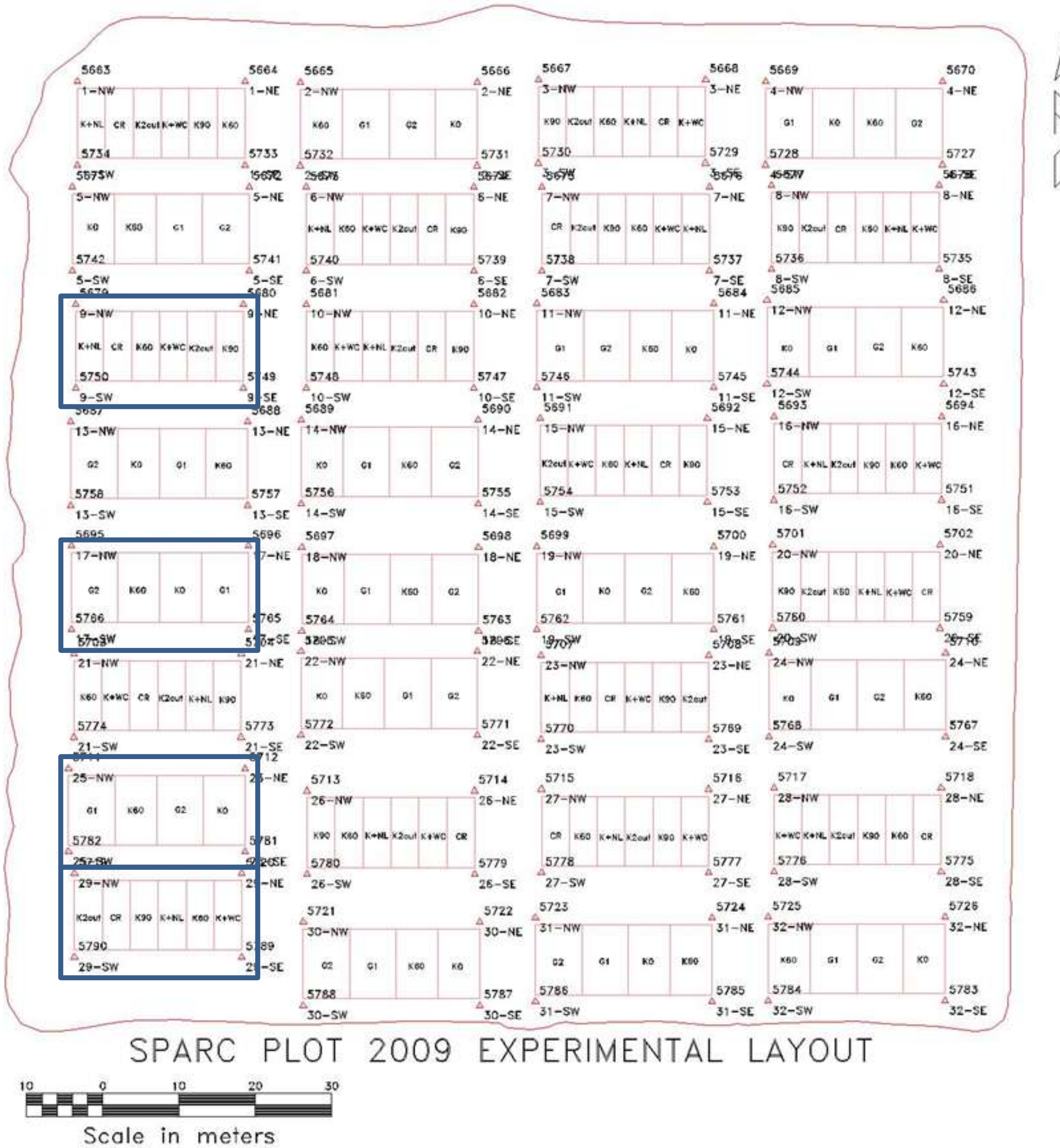

Figure 3.1 SPARC plot layout with treatments. Those plots highlighted with a box were not used in the 2011 analysis due to weed and fertilizer error issues. (see text for more details)

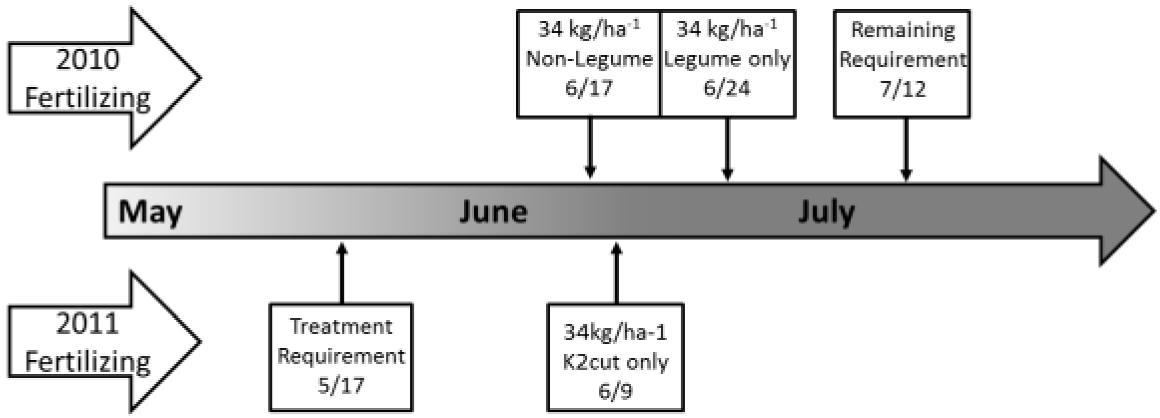

Figure 3.2 Timeline of N fertilizer application dates and amounts for switchgrass in 2010 and 2011.

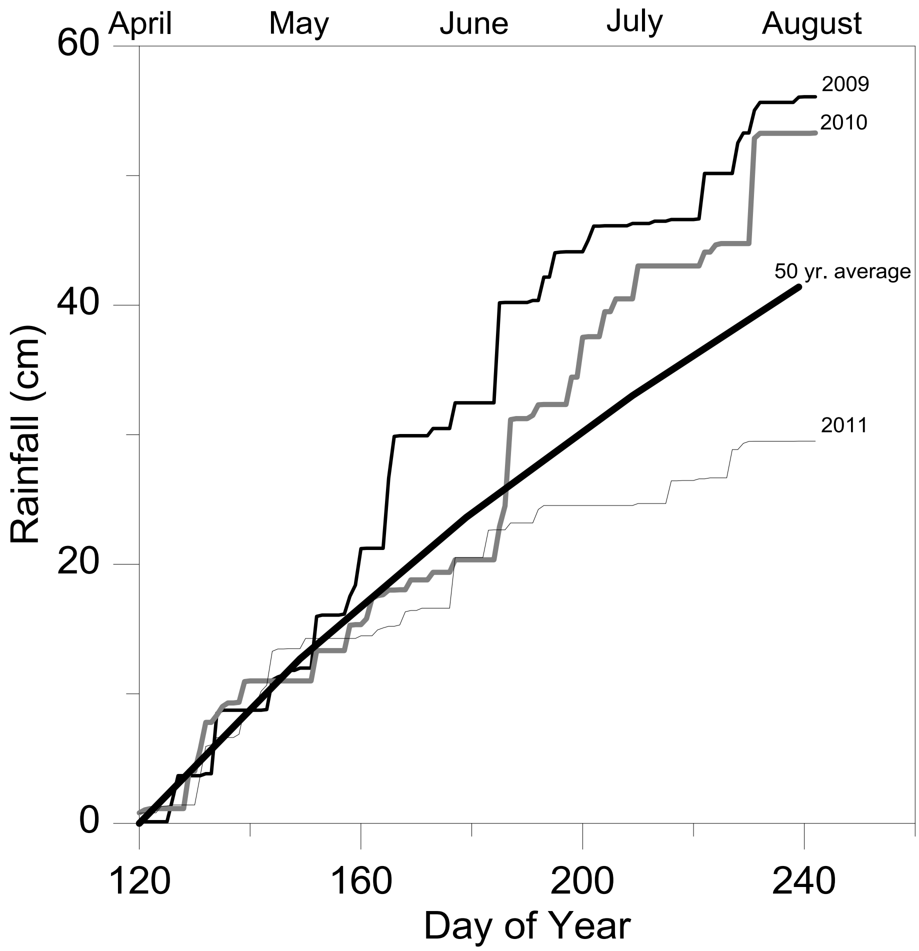

Figure 3.3 Accumulative precipitation from April to August for 2009, 2010, 2011 compared to the 50-year average.

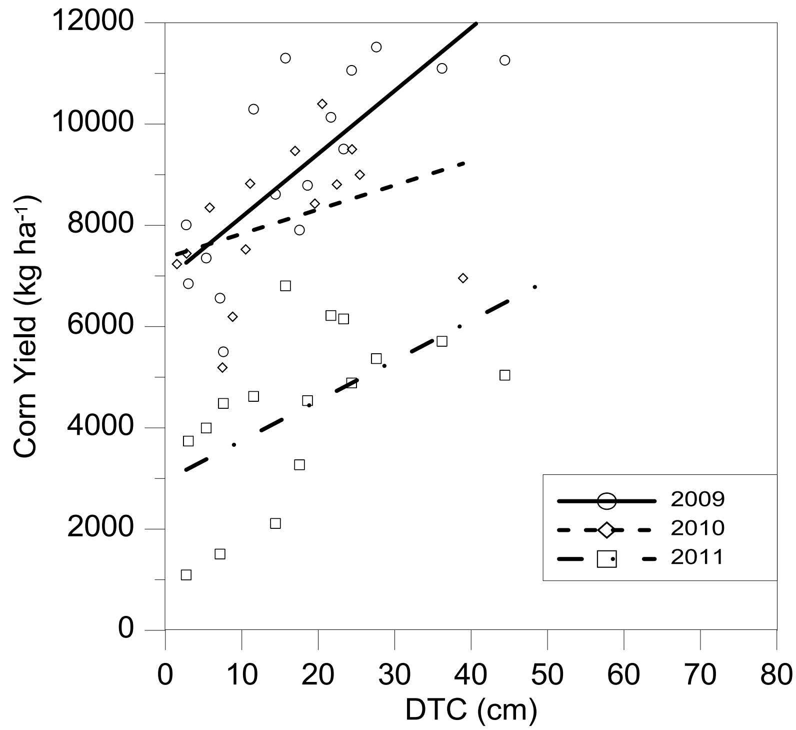

Figure 3.4 Corn yield for 2009, 2010, and 2011 as a function of DTC. (see Table 3.3 for regression equations)

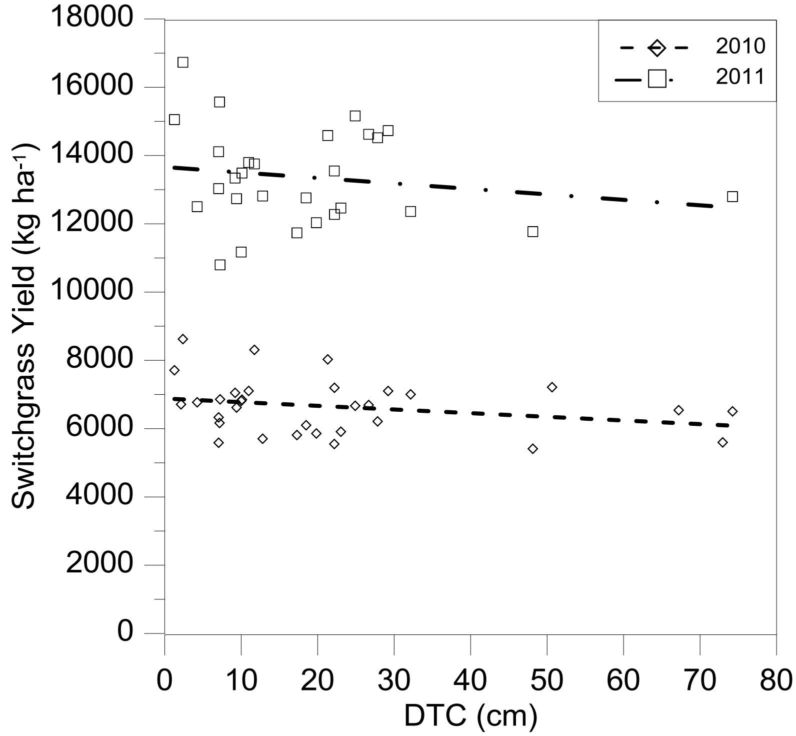

Figure 3.5 Switchgrass yield for 2010 and 2011 as a function of DTC. (see Table 3.3 for regression equations)

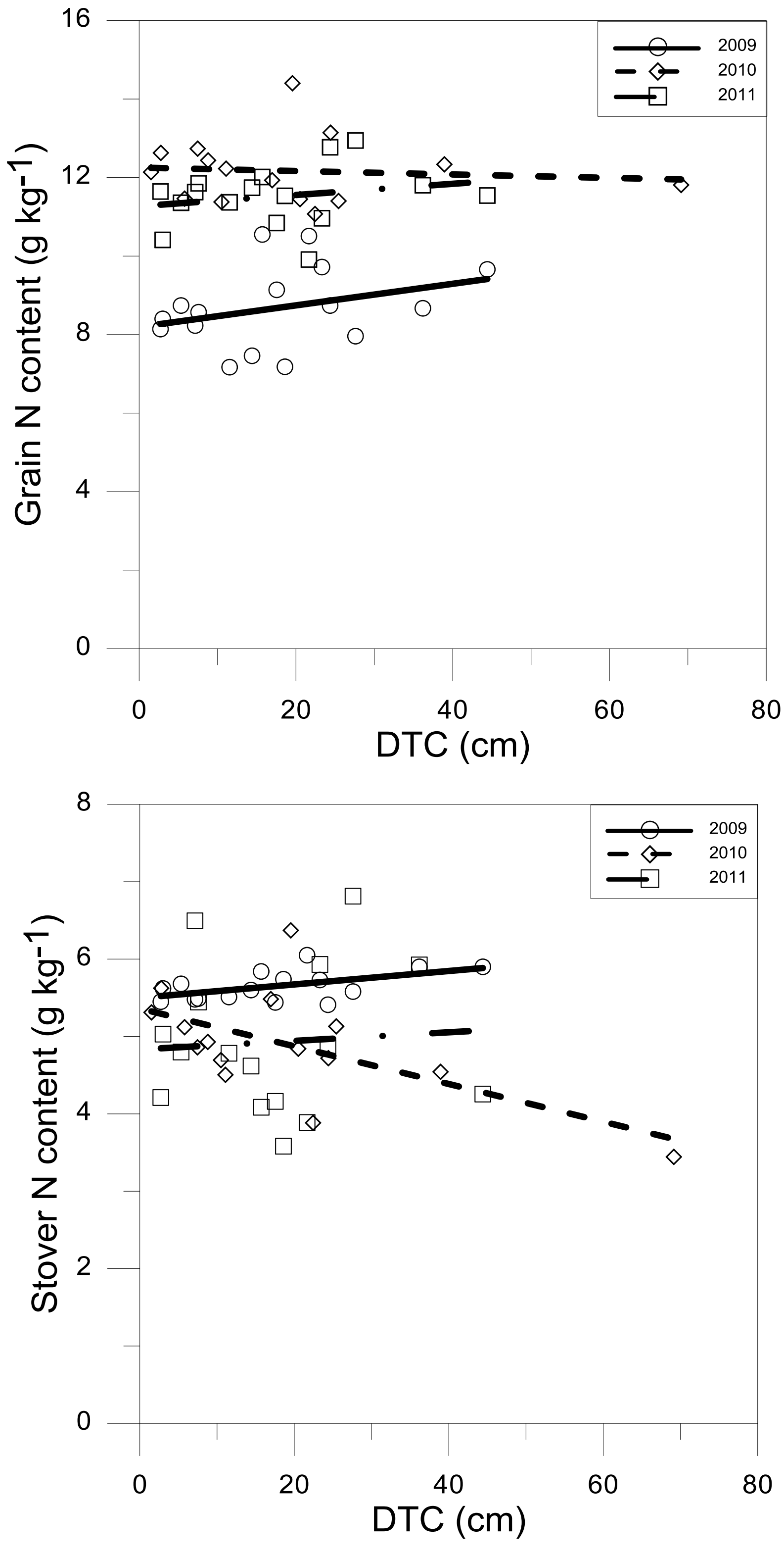

Figure 3.6 Corn grain and stover N content for 2009, 2010, and 2011 as a function of DTC. (see Table 3.4 for regression equations)

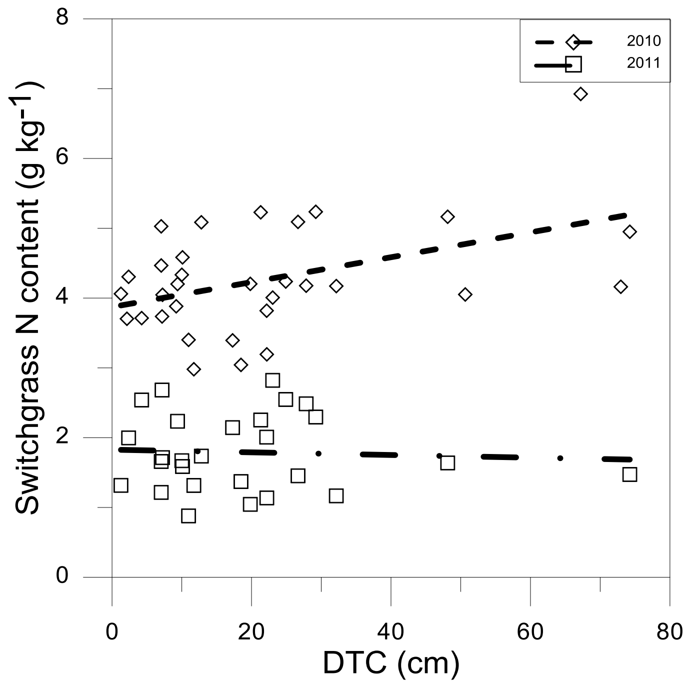

Figure 3.7 Switchgrass N content for 2010 and 2011 as a function of DTC. (see Table 3.4 for regression equations)

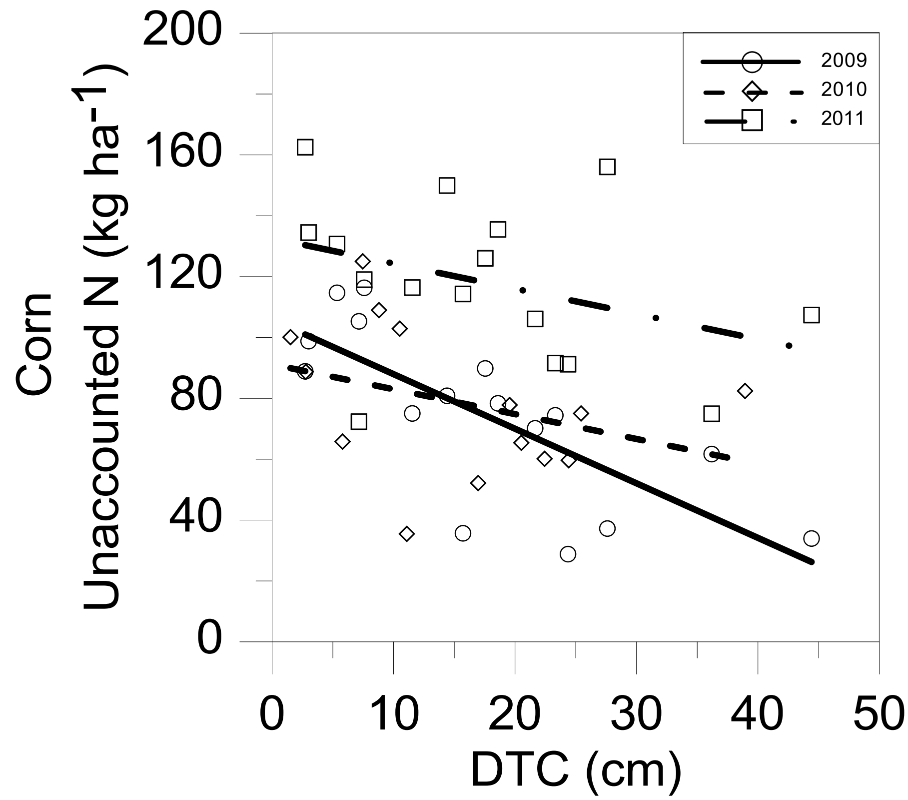

Figure 3.8 Unaccounted for N in corn for 2009, 2010, and 2011 as a function of DTC. (see Table 3.5 for regression equations)

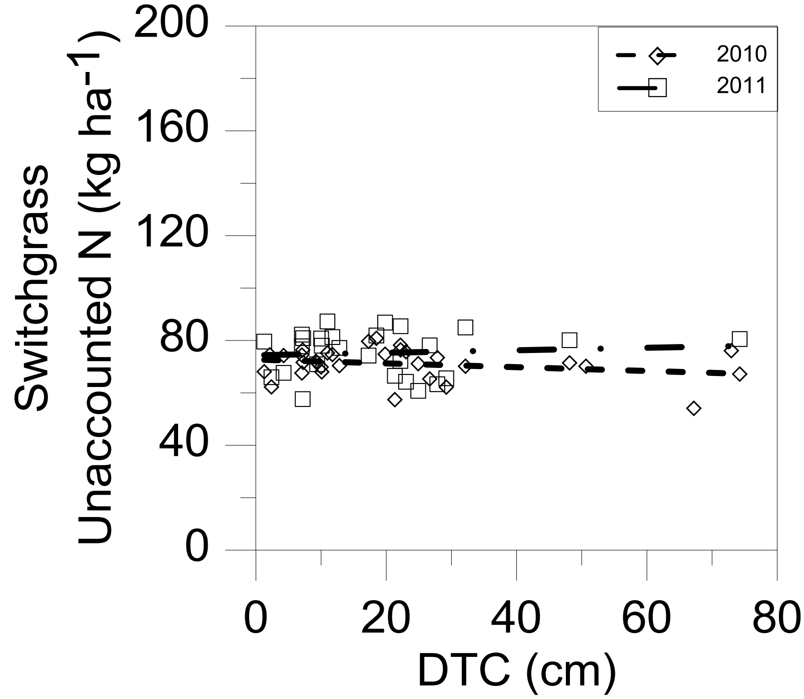

Figure 3.9 Unaccounted for N in switchgrass for 2010 and 2011 as a function of DTC. (see Table 3.5 for regression equations)

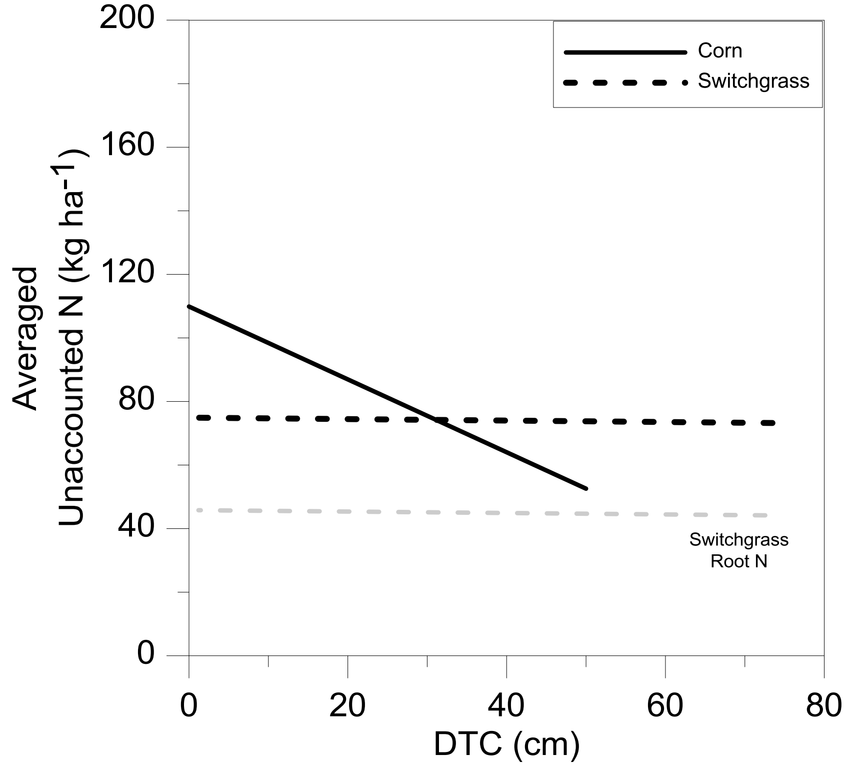

Figure 3.10 Averaged across years, unaccounted for N in corn and switchgrass are shown as a function of DTC. From other research (Risser and Parton, 1982) the amount of N in switchgrass roots has been estimated to be 30-50 kg N ha^{-1} more than what is found in grain crops roots at the end of the growing season. The dashed gray line represents an adjusted (30 kg N ha^{-1}) unaccounted for N of switchgrass given this expected larger N content in switchgrass roots (see Table 3.5 for equations).

CHAPTER 4: CORN, SOYBEAN, AND SWITCHGRASS YIELD AND BIOENERGY PRODUCTION AS A FUNCTION OF TOPSOIL DEPTH

INTRODUCTION

Interest has increased for the use of bioenergy feedstocks to meet energy needs. This has been propelled by concerns about the local and global impacts that fossil-based energy has on the environment and climate. Other concerns deal with the increasing energy costs (Hill et al., 2006). Both environmental and economic issues were key players in the U.S. federal government's 2005 mandate for the use of renewable fuels through the renewable fuel standard (RFS). The RFS requires the use of 7.5 billion gallons of renewable fuels to be blended with diesel and gasoline. The standard was then revised in 2008 to mandate the use of 36 billion gallons by 2022. Suffice it to say, these mandates create a demand for renewable fuels that generate a host of questions surrounding the production of bioenergy feedstocks.

When considering the use of crops for bioenergy, comprehensive analysis is needed in order to ensure that the amount of energy used to produce and convert the crop to fuel or byproducts is not greater than the amount of energy the crop can potentially produce. Also, growing energy on land previously used for producing food may result in increased food costs. For many years, corn (*Zea mays* L.) and soybean (*Glycine max* L. *Merr.*) have been used to produced liquid biofuels, however, there is much debate as to whether or not these crops produce a net gain in energy when converted into biofuels.

While many processes in producing biofuels have become more efficient, the large amounts of inputs associated with biofuel production causes the life-cycle analysis of energy production to become very difficult to monitor. This difficulty stems from the inability of those parties doing bioenergy research to reach consensus of all the factors and processes to consider. For example, some advocating corn to be used in ethanol production suggest a net energy gain from its production (Shapouri, et al., 2002) while others would say that some input cost were excluded in the analysis and that their analysis shows a net energy loss which displaces very little amounts of fossil fuels, if any (Pimentel and Patzek, 2005). Soybean have also been assessed for the production of biodiesel. It too has been calculated to have a net negative production of energy when converted to biofuel (Pimentel, 2001; Sheehan, et al., 1998). With confounding results, no clear understanding of the amount of energy gained or lost from the production of biofuels from corn and soybean. At the same time other crops (such as perennial grasses) are projected to come on line in the near future for bioenergy production. The use of a perennial grass could potentially decrease dependence on foreign oil and eliminate the food vs fuel debates. One such perennial grass is switchgrass (*Panicum virgatum* L.).

Switchgrass is a warm-season, perennial grass indigenous to the Central and North American tall-grass prairie (Moser and Vogel, 1995) and has received a lot of attention as a potential bioenergy crop. It has been characterized as one of the best species for producing herbaceous biomass for bioenergy (Vogel, 1996). Key to the use of a perennial crop for bioenergy is its ability to produce large amounts of biomass. This biomass has the potential to be burned, processed into a liquid fuel or a gas fuel. Whatever the process may be, large amount of biomass will be essential and is an important driving factor in bioenergy feedstock production. While actual yield for switchgrass will vary depending on cultivar and location in which it is grown, yields can average between 8-15 Mg ha^{-1} yr^{-1} (Heaton et al., 2003; Mclaughlin and Kszos, 2005).

Unlike grain crops, a perennial herbaceous energy crop such as switchgrass offers characteristics such as deep root mass that decreases erosion and improves water quality, crop diversification, and agricultural sustainability (Tolbert and Wright, 1998). A deep root mass allows switchgrass to grow well in a wide range of soil textures and moisture regimes. Various switchgrass cultivars have adapted to a wide range of climates such as eastern and southern cultivars, which are adapted to larger moisture conditions. Western and northern cultivars have adapted to drier conditions (Moser and Vogel 1995). Soil and climate adaptive capacity makes switchgrass a strong candidate as a herbaceous energy crop over larger geographic regions of the US.

Switchgrass cultivars are categorized as being lowland (grown in the more southeastern states) and upland (grown in the colder northern states). Two common lowland cultivars are Kanlow and Alamo. These cultivars are tall, usually between 1 and 3 m in height, with the ability to adjust and grow well with less than ideal growing conditions, such as drought or low N availability (Stroup et al. 2003). Although these lowland cultivars are native to wet climates with mild winters, they have the ability to handle droughty conditions, which also makes them suitable for Central Midwest climate. Upland cultivars on the other hand are more cold and drought tolerant and are typically grown in the upper Midwest. A well-known example of an upland cultivar is Cave-n-Rock. Although well-suited to the Midwest, Cave-n-Rock yield in this region have usually been found to be less than both Kanlow and Alamo cultivars (Lemus et al., 2002).

Another advantage of switchgrass is small nutrient requirements. In a study by Varvel et al., (2008) corn and switchgrass were compared for N use efficiency. Switchgrass produced equal or more energy than corn with equal or less amounts of N. Actual amounts of N needed for switchgrass will vary depending upon cultivar, soil N mineralization, and yield potential, as driven by season-long temperature and plant-available water. Typically switchgrass grown in the U.S. Midwest will need 50 to 120 kg ha^{-1} of N for optimal production (Brejda, 2000). The N requirement of warm-season grasses may be at least partly met through the use of N-fixing legumes in a mixed stand (Brejda et al. 1994). Nitrogen fixed by legumes will decrease the amount of commercial fertilizers needed, but legume species and competition factors will affect how much N is available (Ledgard and Steele, 1992).

While N efficiency is important for the use of feedstocks for bioenergy, minimal inputs of other nutrients like phosphorous (P) and potassium (K) allows for less expensive production cost. The perennial nature of switchgrass offers many beneficial processes to keep inputs minimal. Before the plant has become dormant nutrients are actively translocated down stems into the crown of roots and stored for the subsequent year (Parrish and Fike, 2005). Also, once the plant has gone dormant, leaves fall to the soil surface and nutrients are mineralized from the leaves and contribute to the nutrient pool. In addition, with fall frost cells are ruptured and subsequent rainfall weathers nutrients out of plant tissues into the soil (Parrish and Fike, 2005). Thus if harvest occurs after these processes have taken place in the fall, replacement P and K fertilize nutrients can be kept to a minimum.

Along with nutrient recycling, another advantage of switchgrass over grain crops is the protection offered to the soil. As a perennial grass, switchgrass provides substantial root mass to the soil; this is key in maintaining soil structure and decreasing nutrient and sediment losses through leaching and runoff. When switchgrass is harvested in the fall, there is typically 7 to 15 cm of stubble left after harvesting. Residual biomass left on the soil helps prevent runoff and erosion (Vaughan et al. 1989). Where soils are erosion prone, such as in drainage ditches, a perennial grass like switchgrass can slow the flow of water and retain soil in place (Blanco-Canqui et al. 2004). A prime candidate and example is the claypan soils of the U.S. Midwest, considered to be highly-vulnerable to runoff and erosion (Nikiforoff and Drosdoff, 1943; Kitchen et al., 1998). As such, a perennial grass species like switchgrass has great potential for helping soil and water conservation for these soils.

The central claypan soil occupies a region of about 4 million hectares in Missouri and Illinois and is identified as Major Land Resource Area 113 (Soil Survey Staff, 1981). This land area has many concerns because of the unique characteristics of the claypan soils. The claypan is defined as a sub-surface Bt soil horizon that is identified by the illuvial accumulation of silicate clays. The amount of clay necessary is defined in comparison with the quantity in the overlying eluvial horizon, but is at least 20 % or more. With large amounts of clay, problems such as ponding because of poor drainage (Jamison et al., 1968; Kitchen et al., 1999), a droughty nature (Larson and Allmaras, 1971) and slow water infiltration (Jamison and Thornton, 1961; McGinty, 1989) are common. These characteristics result from a high-clay content subsoil layer that typically occurs from 20 to 40 cm below the soil surface (Jamison et al., 1968; Myers et al., 2007; USDA-NCRS, 1995).

Differences in landscape topographic features like slope, position, and landform have been shown to be important factors on grain crop yield (Spomer and Piest, 1982; Jones et al., 1989; Wood et al., 1991; Mulla et al., 1992; Khakural et al., 1996a; McConkey et al., 1997; McGee et al., 1997; Timlin et al., 1998). For claypan soil landscapes, depth to the claypan (DTC) can also be highly variable across the landscape. This makes managing crops on these soils difficult. In some areas of the landscape there may be no topsoil with the claypan exposed (e.g., side-slope), while in other areas the claypan can be buried with sediments moved downslope (e.g., toe-slope) (Kitchen et al., 1999). As a result of this variation, crop yield varies as a function of DTC (Thompson et al., 1991; Kitchen et al., 1999). For corn (*Zea mays* L.) production, yield with no topsoil was half that produced with a topsoil thickness of 38 cm (Thompson et al., 1991; Sudduth et al., 1997; Kitchen et al., 1999). Kitchen et al., (1998) stated the footslope position will generally out-yield upslope position, unless early-season ponding at the footslope reduces stand. For these soils, variability in corn yield within fields usually increases with drought (Sudduth et al., 1997). Kitchen et al. (2005) found that in the months of July and August, when the precipitation amounts were below 15 cm, there was a decrease in yield mainly due to the stress placed on the plants and the lack of plant-available water.

While there are many factors contributing to a decrease in yield, three main factors of these soil landscapes are known to contribute to yield reductions: 1) decreased root-zone plant-available water capacity (Gantzer and McCarty, 1987; Kitchen et al., 1999; Thompson et al., 1992; Thompson et al., 1991; USDA-NRCS, 1995); 2) restricted root penetration due to clay accumulation and poor soil structure in the Bt horizon (Jamison et al., 1968; USDA-NRCS, 1995; Yang et al., 2003; Myers et al., 2007); and 3) small levels of soil organic matter, fertility, and early-season oxygen levels needed for root growth (Jamison et al., 1968). The hydrology of the claypan is controlled by a slow water flow in the soil matrix of the restrictive clay layer (Kitchen et al., 1998). As previously mentioned, the inability for water to move through the restrictive layer creates many of the environmental problems due to runoff, leaching,and denitrification. Furthermore, much of the water present in the clay layer is not easily retrieved by the plant roots. The inconsistency and variability of the claypan soils suggest targeted management is needed to optimize food, feed, and bioenergy production within these landscape.

The need to be less dependent on foreign oil and more environmentally friendly is at hand. “A Nation that destroys its soil, destroys itself.” (Franklin D. Roosevelt) This statement suggest, President Roosevelt had similar feelings as Hugh Hammond Bennett, the father of soil conservation. Understanding the importance of soil conservation, H. H. Bennett started the Soil Conservation Service, now the Natural Resources Conservation Service in the U.S. Department of Agriculture. Hugh Hammond Bennett and Franklin D. Roosevelt knew that there was a problem and that there would be a problem in the future. With the prices of corn and soybean increasing as compared to the past, it is safe to say that the number of acres being put into continuous corn or soybeans is increasing. This problem can only become more and more compounded as the U.S. federal government subsidizes billions of dollars for ethanol, causing demand to increase and leading to land that is not suitable for a row crop to be put into that system. While looking at the increased need and interest for bioenergy, saying that both these men would advocate for a more soil friendly bioenergy feedstock like switchgrass, is not far-fetched.

There are two purposes to this research: 1) to assess corn, soybean and switchgrass yields as affected by DTC; and 2) to assess grain and switchgrass bioenergy production as affected by DTC.

MATERIALS AND METHODS

Site History

This study was conducted at the University of Missouri South Farm located near Columbia, MO on a study site known as Soil Productivity Assessment for Renewable Energy and Conservation (SPARC). This particular experiment was initiated in 2009, but the site was originally developed for assessing continuous corn and soybean production as affected by DTC. The research site was uniquely constructed so 32 blocks ranged in topsoil depth from 0 to 40+ cm (Gantzer and McCarty, 1987; Thompson et al., 1991; 1992). The early research was conducted from 1982 to1992. Then from 1993 to 2008 the plot area was fallowed, and native grasses and weeds occupied the site. During that period the site was usually mowed once each summer. When the SPARC project was initiated in the spring of 2009, remaining residual plant matter was burned.

Soil Assessment and Plot Layout

The 32 blocks (see Fig. 4.1) were assessed for DTC with soil EC_a using a combination of the DUALEM-2S (Dualem Inc., Milton, ON, Canada) and the Veris 2000 (Veris Technologies, Salina, KS). Three east-west transects of soil EC_a were obtained from each block to give high-resolution maps of the SPARC area. Operational procedures for obtaining EC_a is described in Sudduth et al. (2010). On the same day, three 1.2-m deep soil cores from each block were obtained and examined by a soil scientist to determine the depth of the argillic horizon. The argillic horizon depths were used to develop a regression calibration whereby all soil EC_a values could be converted to DTC, similar to procedures outlined in Kitchen et al. (1999).

The 32 blocks were then separated into two experiments of 16 blocks with each experiment having a range of DTC. Experiment 1 was conducted to compare grain vs. switchgrass production on varying DTC of claypan soils. The four treatments of Experiment 1 and the six treatments of Experiment 2 are described in Table 4.1. Corn and soybean plots were 6.1-m wide and 10-m long, and the switchgrass plots of this experiment were 5.3-m wide and 10-m long. Experiment 2 was conducted to assess different components of management and DTC on switchgrass production. Each block allocated to Experiment 2 has six plots that are 4-m wide by 10-m long. Based on the number of treatments per block and size of plots, the assigned blocks for each experiment can be discerned in Figure 4.1. For this investigation, I will only be using the corn phase of the grain crop system (G1) and the K67 treatment from both Experiment 1 and 2 (Table 4.1). Kanlow67 was used because 67 kg N ha^{-1} was described as being a typical recommended N management based on personal communication with USDA, NRCS and Plant Materials Center (Feb. 2009).

Planting, Fertilization, and Harvesting

Switchgrass. On May 19^{th}, 2009 all blocks were limed and fertilized with phosphorus and potassium so that each plot had an equivalent level determined to be non-limiting according to Missouri State Soil Fertility Recommendations (Buchholz, 1992) prior to planting. Shortly after fertilization, soil was prepared for seeding using a rotary tillage operation and switchgrass was planted on June 1st using a Brillion Drop Seeder. Switchgrass was planted at 8.97 kg PLS ha^{-1}. Throughout the summer in 2009 the switchgrass plots were mowed 3 times to help control weeds. No switchgrass yield measurements were obtained in 2009.

Nitrogen fertilization of the treatments was done using a product called Super-U (46% N) which contains both thiophosphoric triamide, a urease inhibitor which prevents N loss by ammonia volatilization from urea, and dicyandiamide, an organic N material which retards nitrification. No N fertilization was done to switchgrass plots in 2009 (establishment year). In 2010, fertilizer was split applied to avoid stimulating weed growth while the switchgrass was getting better established (Fig.4.2). For 2011, N was applied on application date (Fig. 4.2). Weed control on the blocks were an issue in spring of 2010. In order to promote the switchgrass establishment, all switchgrass plots were sprayed with Grazon P+D on June 3, 2010 at recommended amounts which killed all broad leaf plants. In 2011, Johnson grass threatened some of the blocks 9, 25, and 29. So as to not compromise switchgrass stand, Outrider herbicide was sprayed at recommended amounts. These corresponding blocks were not included in this analysis because of the effect of Johnson grass on reflectance readings (Fig. 4.1). For 2011, block 17 was not used due to N application error, but will resume in 2012 as found in Figure 4.1.

The 2010 harvesting of the switchgrass took place on three consecutive days: December 5-7 and in 2011 on November 1-2. Two 91-cm wide passes, 7 m long were taken from the center of each plot in 2010 and in 2011 two 74-cm wide passes, 7 m long were taken. Switchgrass was harvested leaving approximately 10-16 cm of stubble. Plot yields were weighed and subsamples taken for moisture and N analysis. Subsamples were dried at 40 C^o for a minimum of 72 hrs and yields adjusted for reporting on a dry matter basis. Subsamples were ground in a Wiley Mill and analyzed using a LECO total N auto-analyzer (Yeomans and Bremner, 1991).

Grain. Planting, fertilizer, and harvest dates can be seen in Table 4.2. Eight rows of corn and soybeans were planted using a no-till 4-row planter. Significant rainfall in May of 2009 prevented earlier planting for that year. Corn was fertilized with 168 kg N ha^{-1} as ammonium nitrate in 2009 and Super U for both 2010 and 2011. Weeds were controlled on grain plots with Round Up herbicide applied one time throughout the growing season at label recommended amounts. The middle four rows were harvested using a two-row harvester when grain moisture was between 15% and 18%. Yield was corrected to 15.5% moisture in corn and 13.5% for soybeans. Prior to combine harvest, eight corn plants were randomly hand-harvested for determining stover weight. Stover was dried then put through a chipper shredder and a subsample was further dried to find adjust for moisture content.

For this study the energy grown minus the N energy (EG-N) was used for the three crops. The EG-N was calculated using yields converted to energy values. Corn yield included both grain and stover, while soybean included only the grain portion. Switchgrass came from above-ground biomass yield. The energy needed to produce the N applied to crops was subtracted from the energy values found for the respective crops. Energy conversion values are as follows:

Corn: 0.0163 GJ kg^{-1} (National Research Council, 1984).

Stover: 0.0194 GJ kg^{-1} (Scurlock, J. 2001).

Soybeans: 0.0186 GJ kg^{-1} (USDA-ARS Nutrient Data Laboratory)

Switchgrass: 0.0202 GJ kg^{-1} (Scurlock, J. 2001).

N fertilizer: 0.065 GJ kg^{-1} (Hood, C.F. and Kidder, G. 1992).

Data Analysis

Regression analysis using PROC REG within the SAS statistical computer program was primarily used for this study. The reason a regression procedure was used was to take advantage of using DTC as a continuous variable. In the end I wanted to have mathematical relationship showing response variables as a linear function of DTC. Within the regression analysis, two procedures were used. First, response variables for each switchgrass management system were independently evaluated relative to DTC. In the second procedure, the K67 switchgrass management was used as a base reference and all other switchgrass management systems were compared against this reference. Management K67 was used because 67 kg N ha^{-1} was described as being a typical N management based on personal communication with USDA, NRCS and Plant Materials Center (Feb. 2009). Treatments were judged to be significantly different when the F-test probability was 0.05 or less.

RESULTS AND DISCUSSION

Yield as a function of DTC

Yield values for corn, soybean, and switchgrass can be observed in Figures 4.4-4.7 (see Table 4.3 and 4.4 for regression equations). For all three years, as DTC increased the yield in corn increased (in 2010 p=0.06). This DTC relationship occurred for both wet and dry years (Fig. 4.3). Variability in yield for multiple climate years further explains the need for site specific management of these soils by targeting of crops into the landscape. Soybean yield is known to be less sensitive to climate and soil differences because of the indeterminate flowering. Soybean yield was not affected by the DTC in 2009 and 2010 (Fig.4.5; Table 4.3) of this study; however, drought conditions in 2011resulted in a yield decline with decreasing DTC (Table 4.3). Switchgrass yield was unaffected by DTC for 2010 and 2011, demonstrating its capacity to be productive under a wide range of soil conditions. The exception was the K2cut treatment in 2011 (Fig. 4.6, 4.7; Table 4.4). As DTC increased, the K2cut yield also increased. The first harvest of the K2cut occurred in early June after which 34 kg N ha^{-1} was applied for a total of 101 kg N ha^{-1}. After the first cutting, the crop received very little rainfall over a period of about six weeks (Fig. 4.4). As a result the treatments with deep DTC had more plant-available water stored that allowed for more re-growth. Those K2cut treatments with shallow DTC had little re-growth during this same period and visually showed greater water stress.

Switchgrass treatments were also compared to the reference treatment K67 to assess yield differences for 2010 and 2011 (Fig. 4.6 and 4.7 respectively; Table 4.4). In 2010, K0 and CR showed significantly less yield than K67. Kanlow 0 was a treatment included to represent acreage in USDA's Conservation Reserve Program (CRP). Switchgrass growth on such land is greatly inhibited without N fertilization. For CR, 67 kg N ha^{-1} demonstrated insufficient N or a cultivar limitation when compared to the same

N rate of Kanlow (K67). For 2010 the other switchgrass managements (K34 and K101) gave similar yield as K67.

Because of stand maturity, the 2011 growing season for switchgrass gave the opportunity to see better the differences in yield among the treatments. When compared to the reference K67, all treatments were significantly different (Table 4.4). Since there were no effects of DTC, the differences are expressed as intercept differences in the regression models. These differences are visible as presented in Figure 4.7. Switchgrass management differences showed K101 to out-yield the reference K67 by 2626 kg ha^{-1} with all other treatments yielding less than K67. Further economic analysis needs to be done to see if the added biomass yield in response to the added N is cost effective.

Energy grown as a function of DTC

Analysis to find the amount of energy grown (EG-N) was done for corn, soybean, and switchgrass cropping systems. The EG-N was found by taking yield and converting that value to energy. The corresponding energy associated with N production was subtracted from the grown feedstock energy for the respective treatments.

Corn grown in 2009 was the only situation that showed there to be a DTC relationship to energy grown (Fig. 4.8; Table 4.5). Corn grain yield (Fig.4.4) would suggest all three years would show similar results when observing energy grown, however, when the energy portion is calculated it includes energy from stover too and that changes the relationship for EG-N. In this analysis I included all of the stover grown, but other studies have shown that by taking off 50% of stover will decrease soil organic carbon (Blanco-Canqui and Lal, 2009). If stover were not included in this analysis, the EG-N figure would look similar to the grain yield figure, with the outcome of increasing energy with increasing DTC. Soybean energy produced was not affected by DTC in 2009 and 2010 (Fig. 4.9; Table 4.5); however, the energy grown in 2011 was suppressed by the droughty conditions and the deep DTC proved to provide more water than shallow DTC. When observing the EG-N in soybean, the highest energy values (Fig. 4.9) were less than the average values observed in corn (Fig. 4.8), showing the ability of corn to produce overall larger amounts of energy.

Switchgrass EG-N was calculated for the K67, K0, K101, and CR treatments. In 2010, legume establishment issues for KNL and KWC and K2cut only receiving one cutting prevent a complete two years' worth of data for these treatments. For both years, EG-N in for switchgrass did not show a DTC relationship (Fig. 4.10, 4.11; Table 4.5). The treatments K67 and K101 showed only a difference of 0.74 GJ ha^{-1} indicating that for the year after establishment, 67 kg N ha^{-1} was sufficient N. In 2011 there were more distinct differences in the amount of EG-N among the treatments and this is likely due to a more mature stand (Fig. 4.11; Table 4.5). Over both years, K0 and CR had the lowest EG-N (Fig. 4.10 and 4.11; Table 4.5). Future analysis needs to be done to calculate optimal N rate in switchgrass grown on claypan soils.

Averaged annual energy grown as affected by management and DTC

Corn and soybean were combined and averaged for the three years of production to represent the grain cropping system. Individual management treatments for switchgrass were averaged for 2010 and 2011. Grain and switchgrass management EG-N were then compared as a function of DTC (Fig. 4.12). There were no DTC relationships for any treatments (Table 4.6). The K0 treatment showed the most similarities to the grain system for EG-N. However, it is possible that the longer no N is applied, the energy grown with this system will diminish. The CR treatment appears to have cultivar limitations with yield that cause it to produce significantly less energy than Kanlow at the same level of N fertilization. Kanlow 67 and K101 produced more than double the EG-N when compared to the grain system (Fig. 4.12; Table 4.6). Further analysis needs to be done to see whether the additional 34 kg N ha^{-1} in the K101 treatment is an economically justifiable option over K67. The capacity of switchgrass to produce more energy on less productive soils with less N over contrasting climate years supports the premise that switchgrass is a viable alternative to grain cropping for some areas in the claypan soil landscape.

CONCLUSION

Corn, soybean, and switchgrass yield and EG-N were analyzed as a function of DTC. In corn there was a repeated trend of yield decreasing with diminishing DTC. For EG-N, corn was not affected by DTC; however, removal of stover on claypan soils is not a good conservation practice (Blanco-Canqui and Lal, 2009), and will over time decrease the productivity of already less productive soils. Removal of stover from the energy equation would cause EG-N to have a significant DTC relationship. Future analysis could be done to see how the suggested amounts of stover removal affect EG-N. With the exception of 2011, soybean yield and EG-N were less affected by DTC. Switchgrass yield and EG-N were not affected by DTC and illustrated the ability of switchgrass to produce well on less productive soils regardless of growing season weather.

With an increasing demand for bioenergy, the need for bioenergy feedstocks other than corn and soybean is needed. The use of conservation friendly cropping systems like switchgrass would potentially preserve and/or restore productivity and other ecosystem functions which have been affected by long-term row cropping practices. This research demonstrates the potential of switchgrass as an energy crop when grown on non-productive land. The EG-N for switchgrass is greater than grain production on the same land because of resiliency to weather extremes and better N use efficiency. Switchgrass's greater water use efficiency than grain crops is in part because of its ability to grow rapidly in the spring when grain crops are being planted. This research supports the ideas that non-productive land in grain crops be put into a perennial grass system that offers economic benefits to farmers and conservation benefits to the environment. Such a step would avoid the conflict of food vs fuel and help decrease the demand on foreign oil.

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TABLES

Table 4.1 Management treatment descriptions for both Experiments 1 and 2.

Treatment Identification	Annual vs. Perennial	Cropping System	Species	N Fertilizer
				(kg/ha^{-1})
Experiment 1				
G1	Annual	Corn - Soybean	Corn odd yrs / Soy even yrs	168
G2	Annual	Soybean - Corn	Soy odd yrs / Corn even yrs	0
K0	Perennial	Switchgrass	Kanlow	0
K67	Perennial	Switchgrass	Kanlow	67
Experiment 2				
CR	Perennial	Switchgrass	Cave-n-Rock	67
K67	Perennial	Switchgrass	Kanlow	67
K101	Perennial	Switchgrass	Kanlow	101
K2cut	Perennial	Switchgrass	Kanlow	67 + 34
K+WC†	Perennial	Switchgrass	Kanlow + White Clover	0
K+NL†	Perennial	Switchgrass	Kanlow + Native Legumes	0

† Legumes were frost seeded in the spring of 2011. Therefore in 2010, 34 kg N ha^{-1} was applied to these two treatments and for that year only is represented by K34.

Table 4.2 Planting, fertilizing, and harvest dates for corn and soybeans hybrids and their respective populations.

Crop/Year	Planting date	Fertilized date	Harvest date	Hybrid used	Population
Corn					Plants ha^{-1}
2009	June 1	June 1	Oct. 28	MC-590VT3 RR	69,000
2010	April 19	May 3	Sept. 13	MC-550GT RR	69,000
2011	May 5	March 23	Sept. 8	MCT-583 QUAD RR, LL	69,000
Soybeans					
2009	June 3	N/A	Nov. 11	NK S39-A3 RR	370,000
2010	June 5	N/A	Oct. 15	NK S37-F7 RR	370,000
2011	May 25	N/A	Oct. 7	NK S38-H8 RR	370,000

Table 4.3 Corn and soybean yield in 2009, 2010, and 2011as affected by management and DTC. In the regression equations Y=yield (kg ha^{-1}) and X=DTC(cm).

Year	Treatment	Regression Equation	Statistical Effect		r^2/R2
			Intercept	Linear	
			-----------probability---------		
Corn					
2009	G1	$Y= 6922 + 124.5X$	<0.0001	<0.001	0.58
2010	G2	$Y= 7565 + 29.8X$	<0.0001	0.06	0.23
2011	G1	$Y= 2955 + 79.2X$	<0.0001	0.02	0.32
Soybean					
2009	G2	$Y= 3759 + 3.45X$	<0.0001	0.35	0.06
2010	G1	$Y= 2928 + 14.34X$	<0.0001	0.20	0.11
2011	G2	$Y= 1990 + 17.73X - 0.487X^{2\dagger}$	<0.0001	0.01	0.56

† For 2011 soybean yield a quadratic relationship was significant (P=0.04).

Table 4.4 Switchgrass yields in 2010 and 2011 as affected by management and depth to claypan (DTC) In the regression equations Y=yield (kg ha^{-1}) and X=DTC(cm).

Response Variable	Treatment	Regression Equation	Statistical Effect			r^2
			DTC†	Management Comparison††		
			Linear	Intercept	Linear	
			------------------probability----------------			
2010						
	K67 (Ref)	Y= 6789 - 6.0*X*	0.29	<0.0001	0.34	0.02
	K0	Y= 4520 - 8.9*X*	0.72	<0.0001	0.86	0.01
	K34	Y= 6307 - 8.9*X*	0.16	0.11	0.75	0.06
	K101	Y= 7028 - 10.6*X*	0.21	0.51	0.64	0.11
	CR	Y= 5097 + 5.3*X*	0.50	<0.0001	0.30	0.03
2011						
	K67 (Ref)	Y= 12761 + 19.8*X*	0.42	<0.0001	0.38	0.02
	K0	Y= 6536 + 27.7*X*	0.66	<0.0001	0.88	0.02
	K101	Y= 15386 - 5.7*X*	0.77	<0.01	0.53	0.01
	CR	Y= 7827 + 35.1*X*	0.15	<0.0001	0.69	0.17
	K2cut	Y= 9819 + 76.9*X*	0.05	<0.01	0.13	0.28
	KNL	Y= 8434 – 0.4*X*	0.99	<0.0001	0.58	<0.001
	KWC	Y= 7819 + 25.2*X*	0.39	<0.0001	0.90	0.06

† Treatments analyzed with a two-tailed T test where $H_o : B_L = 0$. B_L is the linear (i.e. slope) term of the regression equation.

†† The reference (K67) was analyzed with a two-tailed T test where $H_o : B_i = 0$. B_i represents both the intercept and linear term of the regression equation. For the other management treatments, intercept and linear terms are analyzed with a two-tailed test where $H_o : B_{i(treatment)} = B_{i(reference)}$.

Table 4.5 Corn, soybean, and switchgrass energy grown less energy from N fertilization (EG-N) (GJ ha^{-1}) as affected by management and DTC. In the regression equations Y=EG - N (GJ ha^{-1}) and X=DTC(cm).

Response Variable	Treatment	Regression Equation	Statistical Effect Intercept	Linear	r^2/R^2
			-----------probability----------		
Corn					
2009	G1	Y= 155 + 1.3*X*	<0.0001	0.03	0.29
2010	G2	Y= 164 + 0.1*X*	<0.0001	0.82	0.004
2011	G1	Y= 90 + 0.68*X*	<0.0001	0.27	0.09
Soybean					
2009	G2	Y= 70 + 0.1*X*	<0.0001	0.35	0.06
2010	G1	Y= 56 + 0.2*X*	<0.0001	0.37	0.06
2011	G2	Y= 43 + 0.1*X* - 0.001$X^{2\dagger}$	<0.0001	0.01	0.03
Switchgrass					
2010					
	K67	Y= 135 - 0.2*X*	<0.0001	0.14	0.07
	K0	Y= 91 - 0.2*X*	<0.0001	0.72	0.01
	K101	Y= 135 - 0.2*X*	<0.0001	0.21	0.11
	CR	Y= 99 + 0.1*X*	<0.0001	0.50	0.03
2011					
	K67	Y= 272 - 0.3*X*	<0.0001	0.38	0.03
	K0	Y= 132 + 0.6*X*	<0.0001	0.66	0.02
	K101	Y= 304 - 0.1*X*	<0.0001	0.77	0.01
	CR	Y= 136 + 0.7*X*	<0.0001	0.15	0.17

† For 2011 soybean yield a quadratic relationship was significant (P=0.04).

Table 4.6 Corn, soybean and switchgrass averaged annual energy grown - N (GJ ha^{-1}) as affected by management and DTC. In the regression equations Y=EG - N (GJ ha^{-1}) and X=DTC(cm).

Response Variable	Treatment	Regression Equation	Statistical Effect: Intercept	Statistical Effect: Linear	r^2
			-----------probability----------		
Corn/Soybean	G1&G2	Y= 97 + 0.3*X*	<0.0001	0.34	0.08
Switchgrass	K67	Y= 196 + 0.3*X*	<0.0001	0.62	0.02
	K0	Y= 123 - 0.6*X*	<0.0001	0.69	0.02
	K101	Y= 223 - 0.3*X*	<0.0001	0.37	0.07
	CR	Y= 131 + 0.3*X*	<0.0001	0.37	0.07

FIGURES

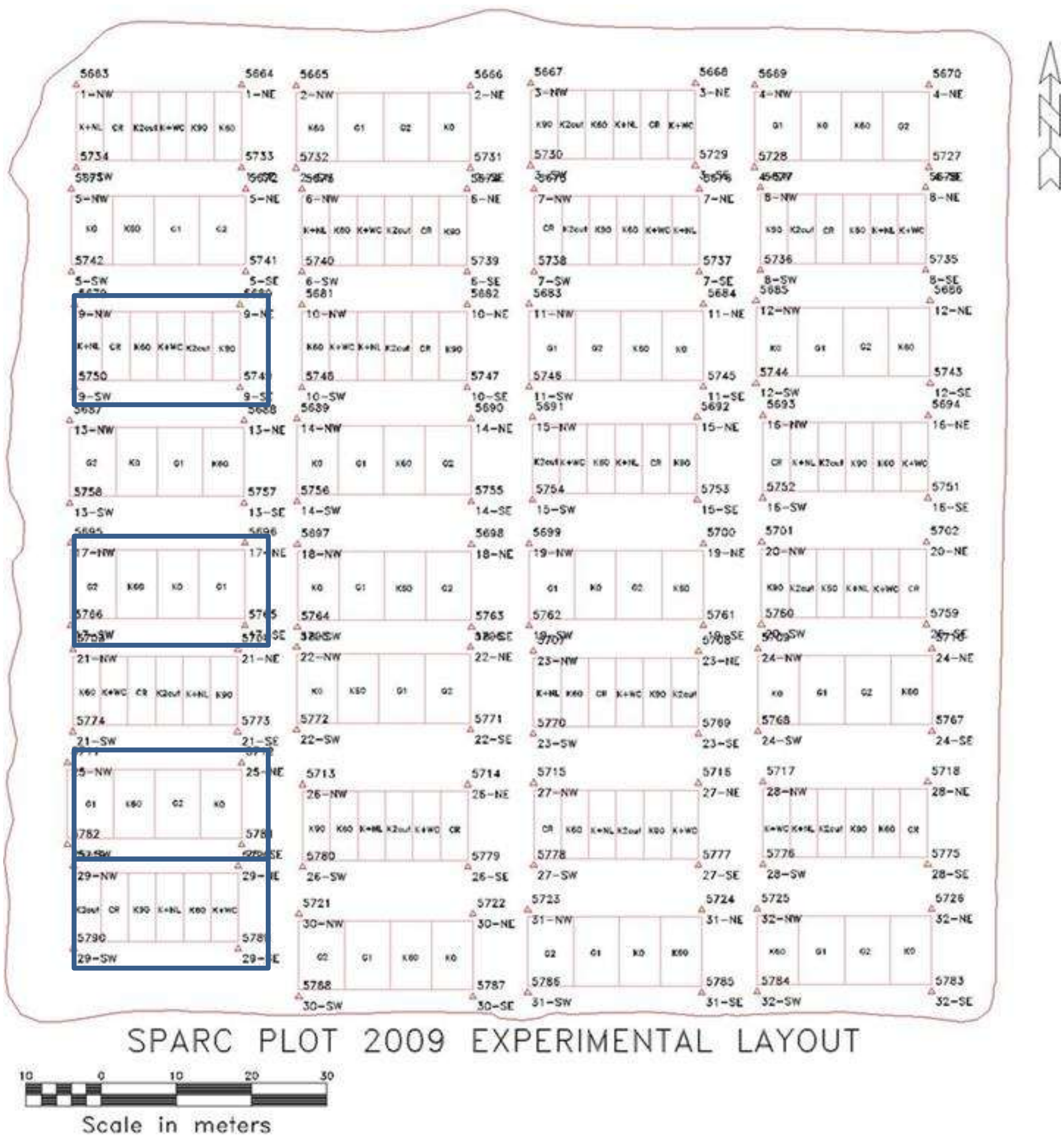

Figure 4.1 SPARC plot layout with treatments. Those plots highlighted with a box were not used in the 2011 analysis due to weed and fertilizer error issues. (see text for more details)

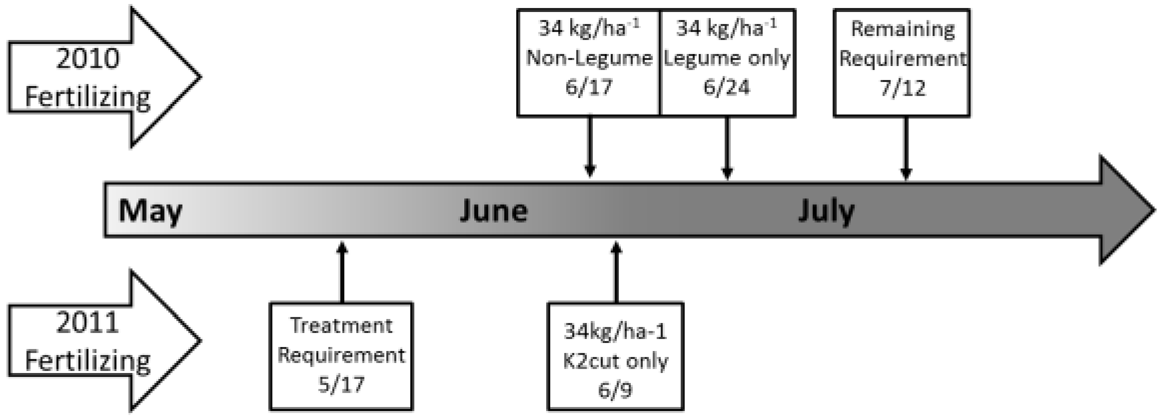

Figure 4.2 Timeline of nitrogen fertilizer dates and amounts for switchgrass in 2010 and 2011.

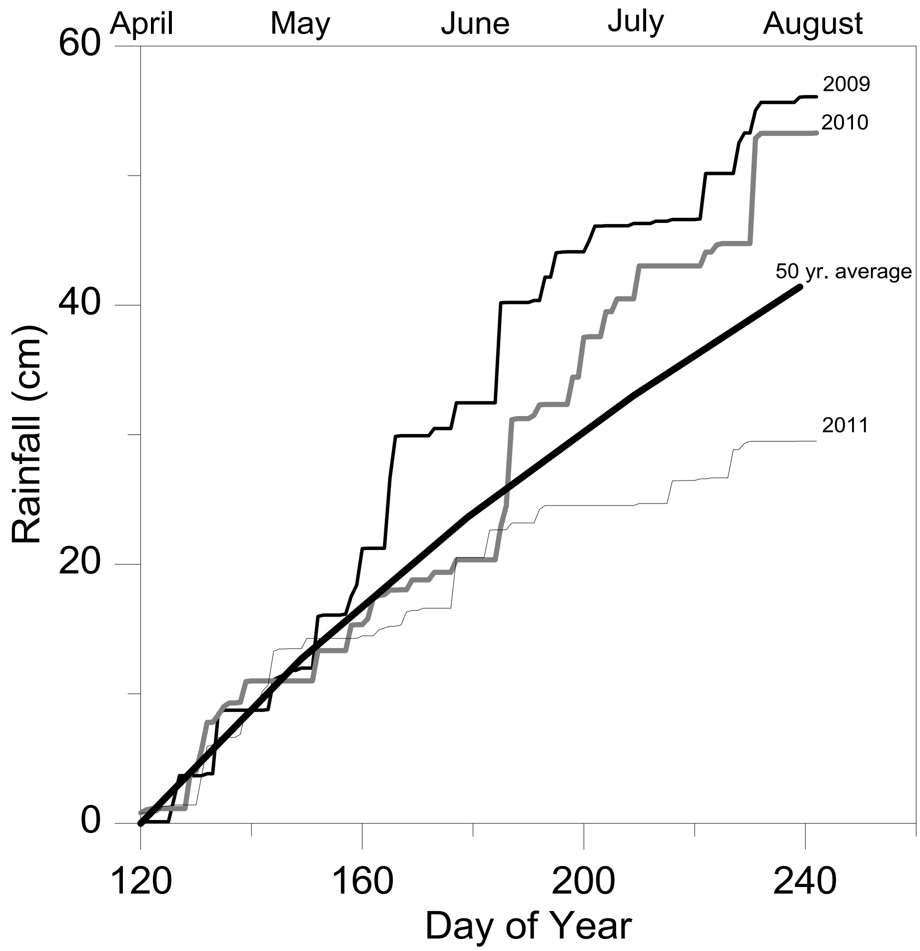

Figure 4.3 Precipitation data from April to August for 2009, 2010, 2011, and the 50 year average.

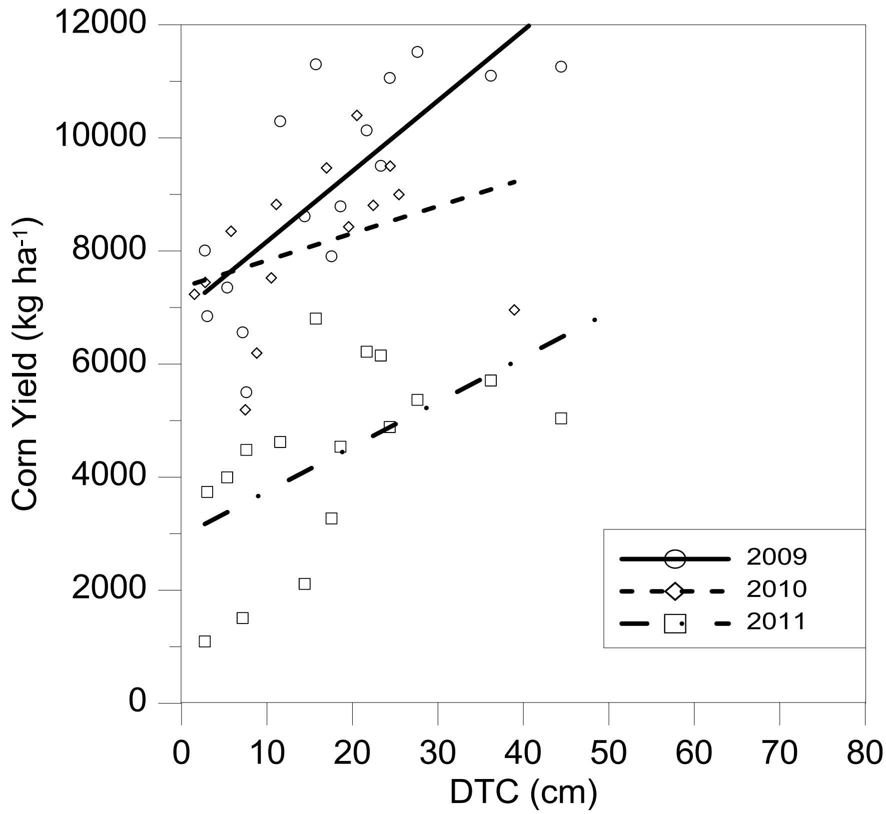

Figure 4.4 Corn yield for 2009, 2010, and 2011 as a function of DTC. (see Table 4.3 for regression equations)

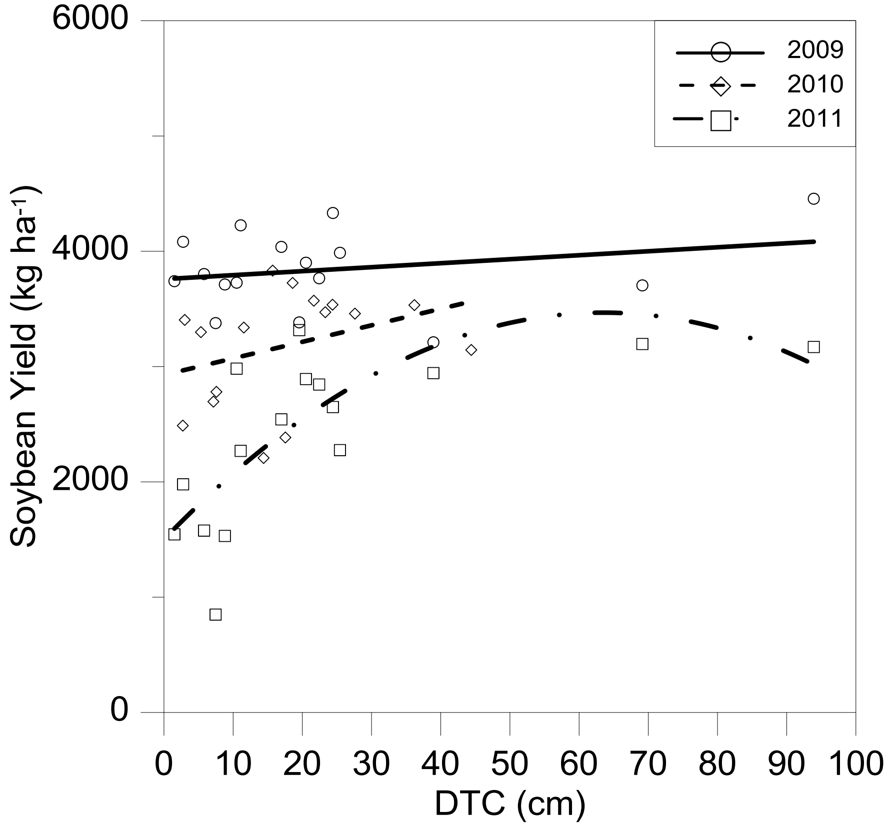

Figure 4.5 Soybean yield for 2009, 2010, and 2011 as a function of DTC. (see Table 4.3 for regression equations)

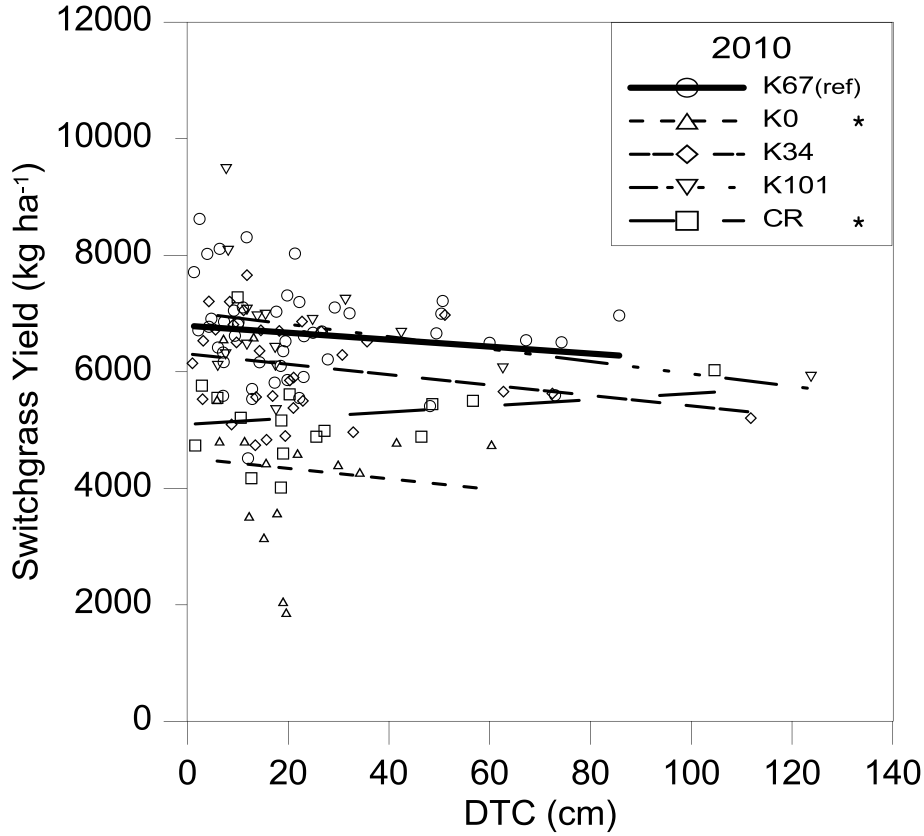

Figure 4.6 Switchgrass yield for 2010 as a function of DTC. (see Table 4.4 for regression equations)

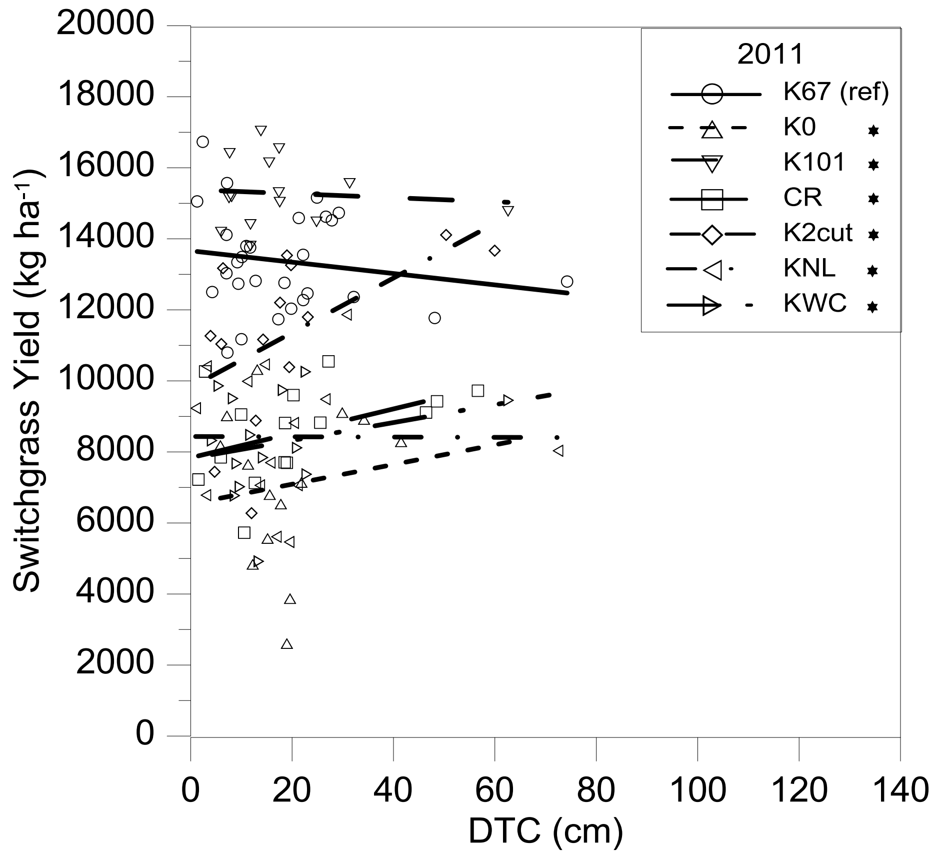

Figure 4.7 Switchgrass yield for 2011 as a function of DTC. Stars in legend indicate significant differences at the 0.05 level from the reference K67. (see Table 4.4 for regression equations)

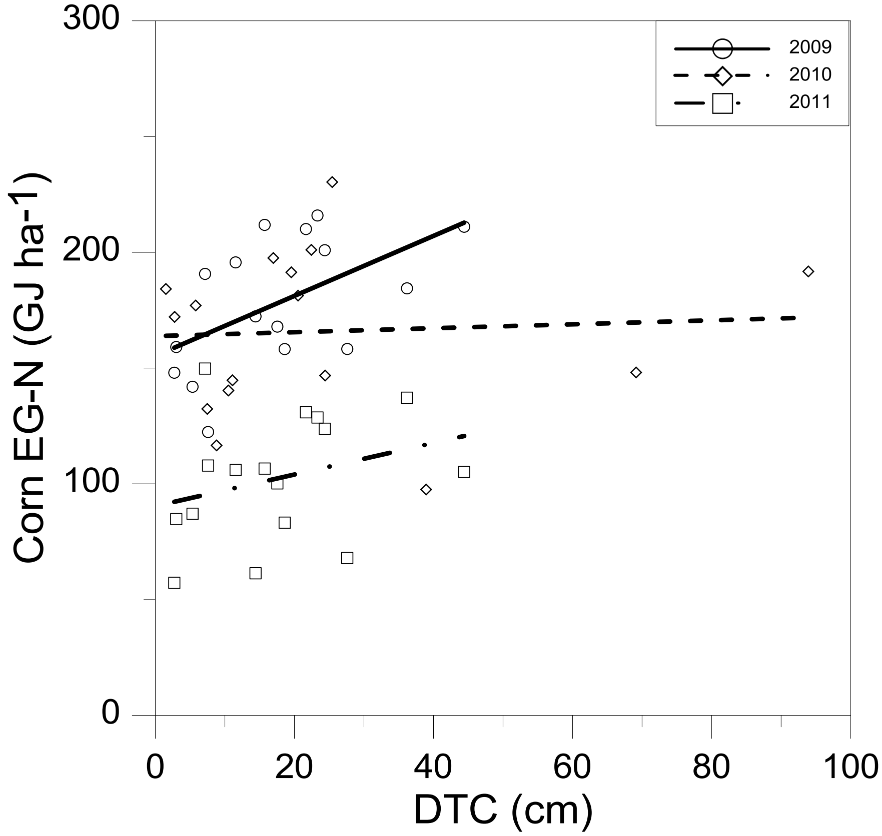

Figure 4.8 Corn energy grown for 2009, 2010, and 2011 as a function of DTC. (see Table 4.5 for regression equations)

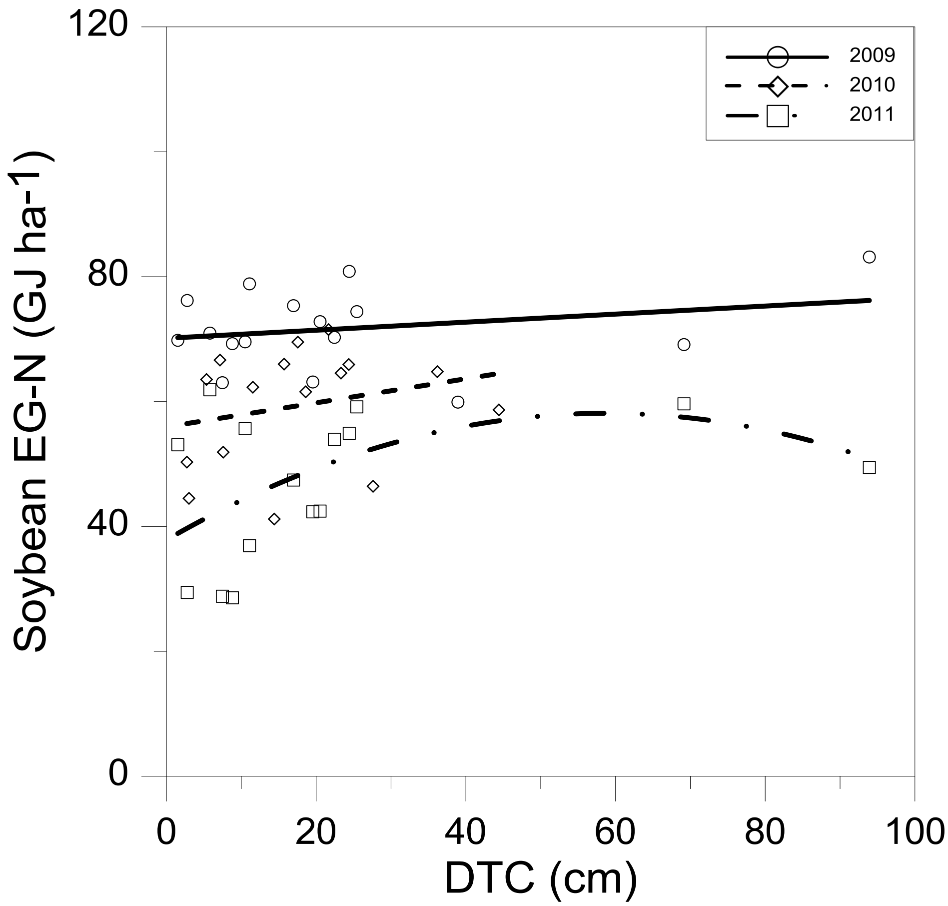

Figure 4.9 Soybean EG-N for 2009, 2010, and 2011 as a function of DTC. (see Table 4.5 for regression equations)

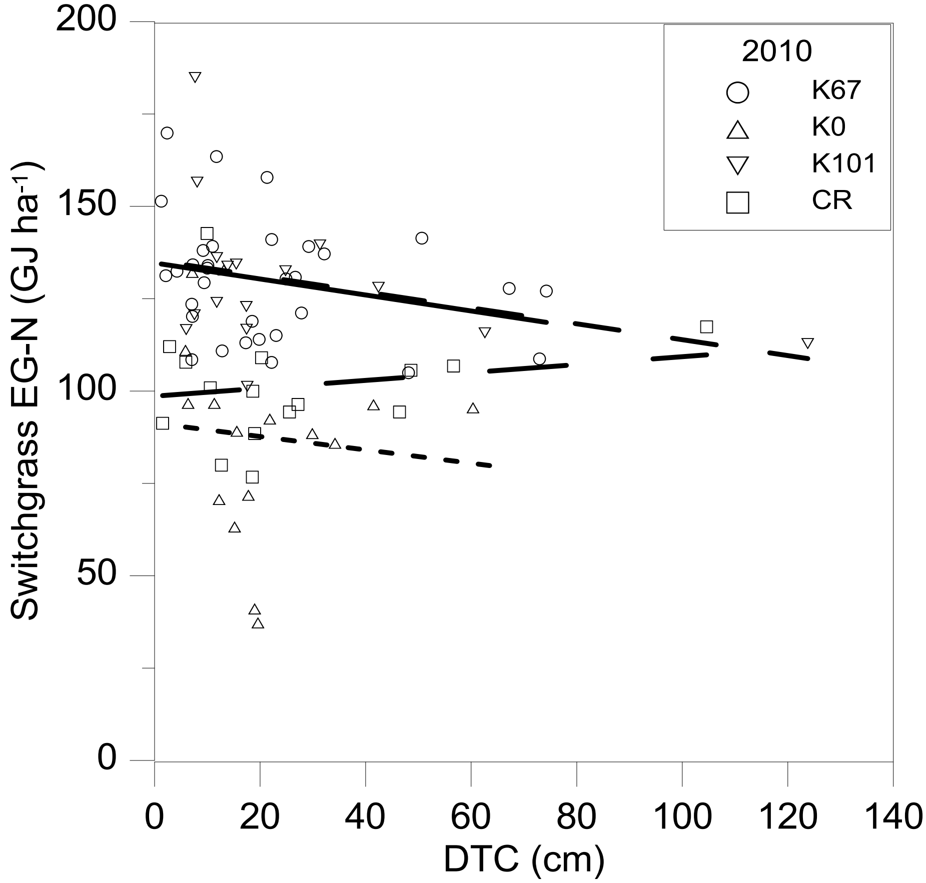

Figure 4.10 Switchgrass EG-N for 2010 as a function of DTC. (see Table 4.5 for regression equations)

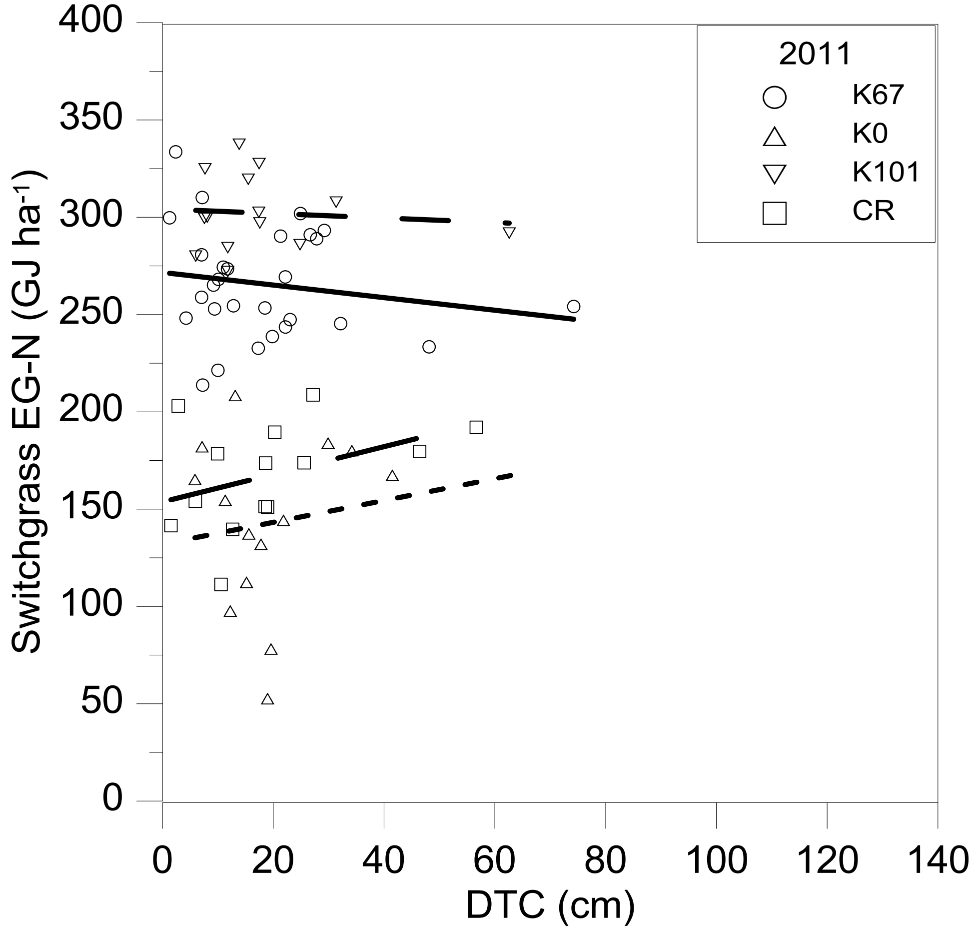

Figure 4.11 Switchgrass EG-N for 2011 as a function of DTC. (see Table 4.5 for regression equations)

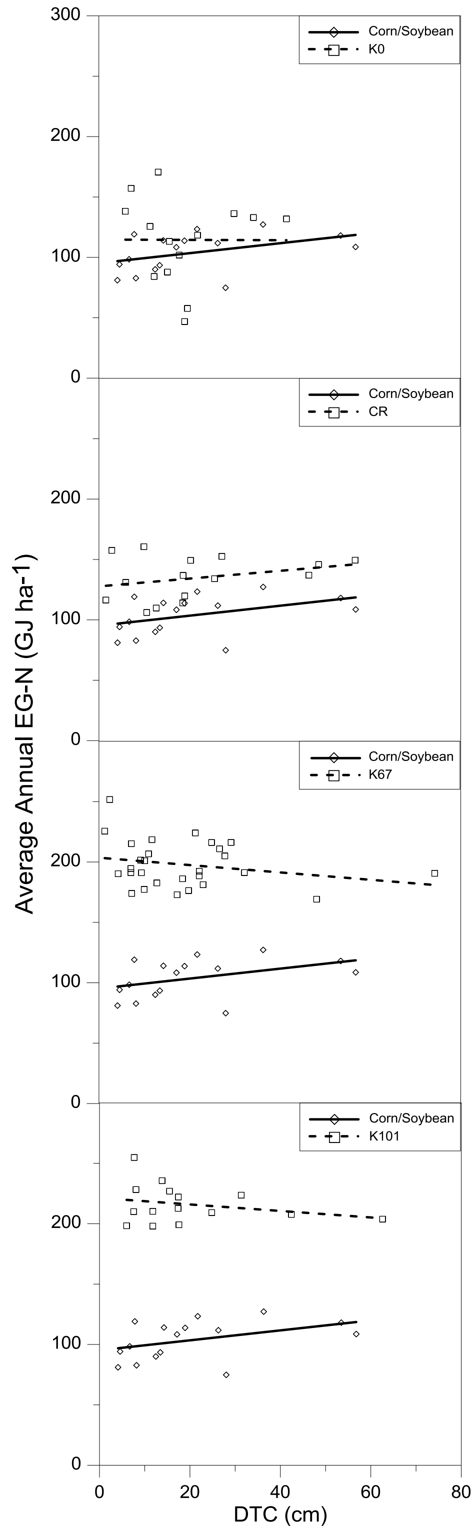

Figure 4.12 Corn, soybean and switchgrass averaged annual EG-N (GJ ha^{-1}) as affected by management and DTC. (see Table 4.6 for regression equations)

CHAPTER 5: SUMMARY

For the non-productive soils found in the Midwest claypan region, the need for an alternative bioenergy feedstock cropping system to traditional corn and soybean rotation is needed. Switchgrass is an alternative cropping system that offers solutions to the many problems associated with growing corn and soybean on these soils. If switchgrass is to be grown within the claypan landscape for bioenergy, information concerning the economical and environmental benefits is needed. This research was conducted to evaluate canopy-based sensing for determining the growth, N health, and yield of switchgrass as impacted by DTC; to assess the N loss potential for corn and switchgrass production as affected by the DTC; and to compare the impact of DTC on corn, soybean, and switchgrass yield and bioenergy production.

The results from this study were:

- Canopy sensors in switchgrass were able to detect differences in N management during late June and early July. The stand density and height of switchgrass were found to cause these differences.
- Early season canopy sensor readings were able to predict future yields in newly established stands of switchgrass when N was sub-optimal. The sensors were, however, excellent at predicting end-of-season yields in mature stands.
- The amount of N that was unaccounted for in corn production was greater than in switchgrass. Nitrogen unaccounted for in corn production decreased as DTC increased, but in switchgrass there was no effect.

- On Midwest claypan soils, corn yield is much more sensitive to N stress influenced by moisture than switchgrass. Corn and soybean were sensitive to drought and as DTC increased their yields also increased.
- Switchgrass yields were unaffected by DTC on mature stands. If switchgrass is harvested in the early summer, DTC will affect the overall yield performance on a drought year.
- Corn and Soybean energy grown was less than half the amount of energy grown in switchgrass fertilized with 67 kg N ha^{-1} or more.