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WR10R003

GROUNDWATER RECHARGE CHARACTERISTICS AND SUBSURFACE NUTRIENT DYNAMICS UNDER ALTERNATE BIOFUEL CROPPING SYSTEMS IN WISCONSIN

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WRI Project Number WR10R003

Final Report

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PROJECT SUMMARY

Title: Groundwater Recharge Characteristics and Subsurface Nutrient Dynamics Under Alternate Biofuel Cropping Systems in Wisconsin

Project I.D.: WR10R003

Investigators: Anita Thompson, K.G. Karthikeyan, Randall Jackson

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Background/Need: High yielding cropping systems such as perennial switchgrass and hybrid poplar trees have been proposed to supply feedstock to the latent cellulosic ethanol industry. Maintaining or expanding acreage in perennial crops and some pastures (or even idle Conservation Reserve Program (CRP) lands) will reduce acreage devoted to corn. While these systems are well known for producing large quantities of aboveground biomass, an important consideration is their relative sustainability in a variety of agroecological settings. The potential for widespread introduction of non-traditional agronomic cropping systems and management for cellulosic biofuel production has generated concerns about associated unintended environmental consequences. Knowledge gaps exist with regard to water and nutrient dynamics when alternative cropping systems are used in the context of meeting the needs for biofuel production. Few studies have investigated subsurface drainage from cellulosic biofuel crops under continued biofuel cropping management within the same environmental conditions.

Objectives: The major goal of this project was to further understanding of water and nutrient dynamics associated with biofuel cropping systems. The specific objective was to measure subsurface (below the root zone) drainage and nutrient (N, P, C) fluxes for continuous corn (CC), monoculture switchgrass (SG) and hybrid poplar (HP) cropping systems.

Methods: The study was conducted at the University of Wisconsin (UW) Arlington Agricultural Research Station (AARS) Arlington, Wisconsin. Experimental plots were established in a randomized complete block design near the southwest corner of the research station in the spring of 2008 by the DOE Great Lakes Bioenergy Research Center (GLBRC). Automated Equilibrium Tension Lysimeters, soil moisture and temperature sensors, and tensiometers were installed within eight plots (representing five different cropping treatments): two CC, two rotational corn (RC), two monoculture SG, one monoculture Miscanthus (MIS), and one HP cropping treatments. Sub-surface (below the root zone) drainage samples were collected weekly during wet periods (e.g. spring, early summer) and bi-weekly during dry periods (e.g. late summer, fall, winter). Samples were analyzed in our laboratory for dissolved reactive phosphorus (DRP), nitrite (NO_2), nitrate plus nitrite (NO_3 + NO_2), ammonium (NH_4^+), total nitrogen (TN), total phosphorus (TP), dissolved organic carbon (DOC), pH, and EC. The focus of this report is on the SC, CC, and HP cropping systems. Results for MIS and RC are not included because: (i) the MIS crop over the AETL was not well established during the study period, (ii) the crop rotation for one of the RC plots was changed after AETL installation, and (iii) only one replicate was available for each cropping system.

Results and Discussion:

Freeze/thaw dates for SG, CC, and HP varied by only a few days and only slight differences in temperature (<2^{o}C) were observed throughout the soil profiles during most of the study period. The largest differences occurred mainly during the early growing season when temperatures were warm and canopy among cropping systems was most different. Soil water depletion during the growing season was greater for CC than SG in 2011, but the opposite trend was observed in 2012; changes were more pronounced at shallow depths. We observed the perennial crops (SG and HP) to have higher soil water holding capacity throughout most of the study period. Differences in soil water are attributable to physiological differences between the crops including canopy cover and root structure.

Total drainage throughout the study period followed the order SG > CC >> HP and most drainage occurred in the spring and early growing season. More drainage occurred from SG than CC in spring and winter seasons and this trend was reversed during summer and fall. Seasonal drainage from HP was always lower than SG and CC.

Total nitrate (NO_3-N) loading during the study period followed the order CC >> SG > HP and the greatest loads occurred in the spring and early growing season. Average seasonal NO_3-N concentrations were higher for CC than SG throughout the year and exceeded 90 mg/L in most seasons. No samples from HP during the study had detectable NO_3-N concentrations. Greater NO_3-N loads were calculated for CC than SG throughout the study period; NO_3-N load from HP could not be determined. Almost all of the N losses occurred in the NO_3-N form. Differences between cropping systems could be due in part to excessive fertilizer applied to the CC plots.

Similar to the drainage trends, DRP loadings were greater for SG than for CC during spring and winter with the opposite trend occurring during summer and fall. All seasonal loads were below 0.30 kg/ha; the highest and lowest export was observed for SG and HP, respectively. Similar to our observations for N, most of the P losses occurred in the dissolved form.

No significant differences in DOC concentration were observed among cropping treatments within seasons. The overall average DOC concentration of all samples was 5.0 ± 0.3 mg/L. Seasonal differences in DOC loading followed drainage trends. DOC loading in CC was significantly higher than SG in summer and fall; conversely, in winter and spring, DOC loading from SG was significantly higher than both CC and HP. The ability of SG to store more carbon in the soil profile may have contributed to the greater DOC loadings in winter and spring.

Conclusions/Implications/Recommendations: As cellulosic biofuel production expands, cropping systems will need to be matched to climate, soils, and environmental concerns in a region, due to differential impacts of each cropping system on water and nutrient dynamics. Results from this study suggest that high yielding perennial cropping systems, such as switchgrass and hybrid poplar, could reduce NO_3-N losses compared to systems involving corn (as the latter also requires additional N inputs). However, switchgrass systems could be vulnerable to leak more nutrients during seasons when ET demand is low (spring, winter) leading to high drainage volumes. Limited data (only for 1 season) indicate that both drainage rates and nutrient losses could be lower under hybrid poplar throughout the year. Selection of appropriate cropping systems for a region should consider potential differences in leachate dynamics and nutrient concentrations to minimize environmental impacts of biofuel production systems.

Research on subsurface drainage quantity and quality should be extended to additional cropping systems with continued biomass removal on different soil types and physiographic conditions. These cropping systems could include native species, such as, prairie plantings or other biodiverse combinations (e.g., annual + perennial crops). Future studies should also encompass long-term monitoring (over several growing seasons), which will facilitate the development and rigorous validation of models that can be applied at various spatial scales. With the cellulosic biofuel demand expected to grow rapidly in the next decade, research needs to keep up with implementation and relay information to producers to ensure that reducing fossil fuel imports does not come at the cost of degraded environmental resources.

Related Publications: Stenjem, R.S. 2013. Subsurface water and nutrient dynamics of cellulosic biofuel cropping systems. M.S. Thesis, University of Wisconsin – Madison.

Key Words: Nitrogen, Phosphorus, Carbon, Leachate, Corn, Switchgrass, Hybrid Poplar

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I. INTRODUCTION

Corn grain is currently the primary feedstock for biofuel ethanol production in the United States (U.S.), which spurred farmers to plant the most U.S. corn acres since WWII (93.5 million ac.) in 2007, and the last three years had the 4th, 3rd and 2nd most U.S. acres of corn planted, respectively, since WWII (NASS, 2010). Biofuel production from grain-based crop production systems, by promoting increases in corn acreage, can have significant water quality implications. Use of corn grain for ethanol potentially diverts food grain; in 2011, an estimated 5 billion bushels of corn grain (40% of total production) was dedicated to ethanol production (USDA, 2012). Additionally, corn is a high input crop requiring fertilizers, herbicides, and pesticides to maximize yields (Sims et al., 2010). Cellulosic ethanol production, where the vegetative part of plants is converted to fuel, promises to relieve our reliance on fossil fuels to a greater degree than grain-based ethanol (Sims et al., 2006; Escobar et al., 2009). To maximize fuel yields, fast growing, high biomass-yielding crops are the most favorable alternatives (Solomon et al., 2007). However, the infrastructure to generate ethanol from potential sources such as perennial grasses and fast growing woody species is not well developed as those existing for grain-based sources.

High yielding cropping systems (e.g., perennial switchgrass, hybrid poplar trees) have been proposed to supply feedstock to the latent cellulosic ethanol industry. Maintaining or expanding acreage in perennial crops and some pastures (or even idle Conservation Reserve Program (CRP) lands) will reduce acreage devoted to corn. While these systems are well known for producing large quantities of aboveground biomass, an important consideration is their relative sustainability in a variety of agroecological settings (Jordan et al., 2007). While alternative cropping systems are better suited to provide and sustain beneficial ecosystem services, their effects on water and nutrient dynamics when used in the context of meeting the needs for biofuel production are unknown. Current estimates for cellulosic fuel yields range widely because of variations in climate, soils, topography, and conversion technologies. Based on fuel yield estimates for corn stover and switchgrass in climates similar to the Midwestern U.S. (Schmer et al., 2012; Sindelar et al., 2012), roughly 16-35 million ha of suitable land would be needed to achieve the U.S. goal (Energy Independence and Security Act of 2007) of 60.6 billion L yr^{-1} of cellulosic biofuels by 2022.

The potential widespread introduction of non-traditional agronomic cropping systems and management for cellulosic biofuel production has generated environmental concerns. If cellulosic biofuels gain acceptance, modern agriculture is expected to produce enough crops to meet the food, fiber, and energy demands of an ever growing population (Uhlenbrook, 2007; Escobar et al., 2009). From an environmental sustainability standpoint, competition for and contamination of irrigation or drinking water supplies needs to be considered, as well as all potential impacts on the hydrologic balance (Uhlenbrook, 2007). Feedstock crops will need to be selected based on land types due to spatial variations in water availability, soils, topography, etc. (Carroll and Somerville, 2009) and to minimize environmental impacts.

Field plots comprising cropping systems that are well known for their biomass production potential and favored in the Great Lakes Region for cellulosic ethanol production were established in 2008 through the DOE Great Lakes Bioenergy Research Center (GLBRC) at the Arlington Agricultural Research Station (AARS), Arlington WI. Two of these systems represent Type I feedstock crops (U.S. DOE, 2006), continuous corn and corn-soybean rotation, i.e., being historically used for food production they have undergone extensive selection for grain production traits. Switchgrass is a C4 perennial grass that is native to North America (Sanderson et al., 2006) and has been identified for its biofuel feedstock potential because it: (i) is perennial, tolerates repeated defoliation, (ii) is adapted to a wide range of environmental conditions (Sanderson and Wolf, 1995; Casler et al., 2004), (iii) has high tolerance to drought, nutrient deficiencies, and high temperatures (Sage and Zhu, 2011), (iv) sequesters large amounts of C in soils, and (v) provides good wildlife habitat. In addition, switchgrass has been sown on millions of acres of CRP land throughout the Midwest. Hybrid poplar has been identified as a key feedstock for biofuel production throughout much of the U.S., including the Great Lakes Region (U.S. DOE, 2006). The trees produce large quantities of aboveground biomass in 5-yr cycles. Poplar provides several advantages relative to traditional row crops: it requires less fertilizer, can be grown on marginally productive soils, and provides structural and biological diversity within a landscape.

Understanding water and nutrient dynamics associated with biofuel crop production will be critical to protecting water resources. Few studies have investigated subsurface drainage from cellulosic biofuel crops under continued biofuel cropping management within the same environmental conditions. This report summarizes findings from a study investigating subsurface (below the root zone) drainage and nutrient loads from continuous corn, monoculture switchgrass, and hybrid poplar.

II. PROCEDURES AND METHODS

Study Site: The study was conducted at the University of Wisconsin (UW) AARS, Arlington, WI (43° 17' N, 89° 22' W; Fig. B1, Appendix B). Experimental plots were established in a randomized complete block design (60 plots divided into five, 12-plot blocks; Fig. B2, Appendix B) near the southwest corner of the research station in the spring of 2008 by GLBRC. Eight plots (representing five different cropping treatments) were selected to investigate subsurface drainage and nutrient dynamics: two continuous corn (CC), two rotational corn (RC), two monoculture switchgrass (SG), one monoculture Miscanthus (MIS), and one hybrid poplar (HP) cropping treatments. Each plot measured 27.4 m W by 42.7 m L and was subdivided into a main plot section and two edge effect sections. All drainage and soil monitoring equipment was installed within or immediately adjacent to the main plot area and disturbance associated with installation was limited to the edge areas. Crops were managed (by GLBRC personnel) according to UW-Extension recommendations for planting, harvesting, and rates of pesticide, herbicide, and fertilizer application. Planting and harvest dates, 2011 yields, fertilizer rates and application dates are provided in Tables B1-B3 of Appendix B (data provided by Dr. Sanford, Assistant Scientist, GLBRC).

Soils and Climate: The primarily prairie soils and continental humid climate of Arlington, WI, are typical for the upper Midwestern U.S. The soils within the study plots are primarily well drained Plano Silt Loam soils with 0-6% slopes. Average profiles for these soils are: silt loam 0-0.3m, clay loam 0.3-1.1m, and sandy loam 1.1-1.5m (NRCS Web Soil Survey). Average annual precipitation at Arlington is 83.7 cm, with nearly half (40.1 cm) falling from Jun. through Sep. Average monthly maximum temperatures range from -5°C (Jan.) to 27.2°C (Jul.) and minimum temperatures from -13.3°C (Jan.) to 15.6°C (Jul.).

Equipment: Automated Equilibrium Tension Lysimeters (AETLs) were installed to measure subsurface (below the root zone) drainage from each cropping system. The AETLs utilized suction to sample water draining through the soil profile directly above the lysimeter. The suction was automatically adjusted based on measured soil-water tension in the surrounding soil, thereby minimizing convergent/divergent flows to/around the lysimeter. Each AETL included a lysimeter, soil monitoring instrumentation, control box, and control program.

Lysimeters measured 25cm W x 75cm L x 15 cm H (constructed by Dick's Superior Metal Sales, Madison, WI.) and were constructed of 1.6 mm thick stainless steel, with a 1 mm thick porous stainless steel top with 0.2 µm diameter pores (Mott Metallurgical Corporation, Farmington, CT) that allowed water to flow from the soil into the lysimeter. Two sheets of filter paper (1.0 µm over 0.5 µm; Pargreen Process Technologies, Addison, IL) were placed on the top of the porous plate and wetted with DI water. The filter paper maintained moisture near the porous plate during dry periods. Two stainless steel tubes (6.4 mm O.D.) at the base of the lysimeter functioned as vacuum and sample tubes. Electric tensiometers (heat dissipation sensors; model 229, Campbell Scientific, Logan, UT) were used to measure soil-water tension and set appropriate lysimeter suction. Each tensiometer was calibrated using a pressure plate extractor system (Product Number 1600; Soil Moisture Equipment Corporation, Goleta, CA). Water content reflectometers (CS616; Campbell Scientific, Logan, UT) were used to monitor changes in soil water storage and a site specific calibration was conducted. Type-T (copper-Constantine) thermocouples were used to monitor temperature throughout the soil profile. Each AETL was operated by a control box that consisted of a datalogger (10X, 23X, CR1000; Campbell Scientific, Logan, UT) to run the control program and measure soil sensors, an excitation module to heat the tensiometers, pneumatic valves (operated by a 12V relay driver) for controlling pumping and bleeding, and a pump to pull air from the lysimeter. Dataloggers were programmed to: (i) measure matric potential, moisture content and temperature, (ii) monitor and set appropriate suction in the lysimeter, and (iii) store hourly averages of all data. Instrumentation depths are provided in Table B4 of Appendix B.

Installation: Eleven lysimeters were installed within the eight plots: for CC and SG (3; within and between plot replication); RC[1] (2; between plot replication); HP (2; within plot replication) and MIS (1; no replication). Lysimeters were installed beneath undisturbed soil profiles by excavating into the wall of large soil pits as close to the main plot as possible. Lysimeters within SG and MIS plots were installed just inside the main plot. Lysimeters within RC and CC plots were installed one corn row just east of the main plot and spanned two corn rows. Lysimeters within the HP plot were installed within the edge section. Lysimeters were positioned such that the top was just above the interface of the clay-loam B and sandy C horizons. Any water leaving the B horizon was considered representative of potential ground water recharge. Due to spatial variation in soil horizons, the lysimeter depths varied among plots (0.6 – 1.45m). Two or four water content reflectometers and two or four thermocouples were installed in the soil pit wall near the lysimeter. Tensiometers were installed above the porous plate of the lysimeter and in the bulk soil (in the B-Horizon 10-15 cm from the back edge and at the depth of the top of the lysimeter); differences measured indicated convergent/divergent flow or tensiometer failure.

Lysimeters were positioned in contact with the ceiling of the soil cavity and supported by a spring plate and wood blocks (Fig. B3, Appendix B). Stainless steel tubing was connected to the sample and vacuum tubes and extended outside the cavity where rubber tubing was attached and extended to the soil surface. Wooden support frames supported the soil above the cavity and plywood covered the soil cavity and protected the lysimeter during backfilling (Fig. B4, Appendix B). All wires/tubes were bundled inside PVC pipe and connected to a control box outside of the plot. Additional details on the equipment, calibration procedures, instrumentation levels and depths of sensors are provided in Stenjem (2013).

Sampling: Subsurface (below the root zone) drainage samples were collected weekly during wet periods (e.g. spring, early summer) and bi-weekly during dry periods (e.g. late summer, fall, winter), to ensure sufficient volumes for nutrient analyses. Due to differences in installation dates and troubleshooting periods, data collection start times for each lysimeter varied (Table B5, Appendix B).

Leachate was collected via the lysimeter sampling tube using a ½ HP vacuum pump and 0.75 L vacuum trap, powered by a portable generator. Approximately 750 mL of water from each lysimeter was collected to flush the vacuum trap and sample hoses. Another 750 mL was then collected, split and sub-sampled for nutrient analyses. A 125 mL sub-sample was acid preserved for NO_3, NH_4, TN, TP and DOC analysis. An additional 120 mL was divided into two 60 mL bottles: one was field-filtered (0.45 µm) for NO_3 and DRP analyses and the other unfiltered for pH and EC. Additional water was pumped from the lysimeter and the total volume was recorded. During dry periods, when < 750 mL of water was present in the lysimeter, no nutrient analyses were conducted, due to contamination issues with insufficient flush volume.

Samples were analyzed in our laboratory for dissolved reactive phosphorus (DRP), nitrite (NO_2), nitrate plus nitrite (NO_3 + NO_2), ammonium (NH_4^+), total nitrogen (TN), total phosphorus (TP), dissolved organic carbon (DOC), pH, and EC. All nutrients (except DOC) were analyzed using an AQ2 Discrete Analyzer (Seal Analytical, Hampshire, U.K.) according to USEPA methods. DOC was analyzed using a DR5000 UV-vis spectrophotometer (Hach Company, Loveland, CO) and pre-assembled test kit (Product # 2815945; Hach Company, Ames IA) following digestion using a Hach DRB200 Digital Reactor Block. Additional details on the analytical methods are provided in Stenjem (2013).

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[1] In 2011 plot 406 (Fig. B2, Appendix B) was planted in corn as part of a corn-canola-soybean rotation. Plot 408 utilized the same rotation and was installed in Oct 2011, with corn production expected in 2012.In spring 2012 the cropping rotations were modified by the GLBRC. Plot 406 was then designated as part of a continuous corn with winter cover crop rotation and plot 408 was planted in a corn-soybean rotation, starting with soybeans in 2012.

Data Analysis: Two cumulative time periods (Period I: 14 Apr 2011 to 31 Aug 2012; Period II: 13 Jul 2011 to 31 Aug 2012) were selected for analysis. The start dates correspond to the first sampling date for the SG/CC and HP cropping systems. Additionally, the study period was sub-divided into six seasons (Table 1) for comparison of drainage depth, average nutrient concentrations and loadings among SG, CC, and HP. Results for MIS and RC are not included as: (i) the MIS crop over the AETL was not well established, (ii) the crop rotation for one of the RC plots was changed after AETL installation, and (iii) only one replicate is available for each cropping system; however results are provided in Stenjem (2013).

Table 1 – Seasonal time periods used to compare the cropping systems.

Season	**Time Period**
Spring 2011	1 Apr 2011 to 15 June 2011
Summer 2011	15 June 2011 to 21 Sept 2011
Fall 2011	21 Sept 2011 to 20 Dec 2011
Winter 2012	20 Dec 2011 to 20 Mar 2012
Spring 2012	20 Mar 2012 to 12 June 2012
Summer 2012	12 June 2012 to 31 Aug 2012

Average drainage depth, nutrient (NO_3-N, NH_4-N, DRP, DOC) concentration and load were calculated for each sampling date and cropping system and summed for each time period. Cumulative standard errors were calculated for seasonal values of drainage depth, nutrient concentration and load. A water balance was calculated for summer 2011 and 2012. Evapotranspiration (ET) was estimated as the residual of measured precipitation (P), runoff (RO), soil water storage (ΔS), and drainage (D). Runoff was directly measured using 1 m^2 drainage area collectors installed in CC and SG cropping systems. Samples with concentrations below the detectable limit were excluded from the average. If an AETL was not functioning during a sampling interval that replicate was excluded from the treatment average and variance calculations for that interval. Cumulative nutrient loads and standard errors for each time period and cropping system were calculated. Pairwise Welch's t-tests were performed for statistical comparisons among cropping treatments ($\alpha = 0.1$). Welch's t-test has less power than the standard t-test; however, it was selected due to the low level of replication and large variability within/among cropping systems.

III. RESULTS AND DISCUSSION

Climatic Conditions: During the study period (1 Apr 2011 to 31 Aug 2012) there was 114.0 cm of precipitation (rainfall and snow liquid water equivalent). Precipitation from Apr to Dec 2011 and from Jan to Aug 2012 was below the 30-year annual average (1981-2010) for Arlington, WI, by 5.0 and 12.2 cm, respectively. Air temperatures for 10 of the 17 study months were warmer than the 30-year monthly average temperatures (1981-2010) for Arlington, WI. Monthly precipitation and average air temperatures are given in Appendix B (Tables B6 and B7).

Soil Temperature: Differences in soil profile temperatures between SG, CC, and HP were not large; freeze/thaw dates varied by only a few days and only slight differences (1-2^{o}C) were observed throughout the soil profiles during most of the study period. The largest differences occurred mainly during the early growing season when temperatures were warm and canopy among cropping systems was most different.

In 2012, the soil profile in all treatments was thawed (temperature at 20 cm > 0^{o}C) between 5 - 9 Mar, approximately 3 wks earlier than in 2011. The thaw date for HP was later than SG and CC, possibly because leaf litter was not removed from HP. Residue remaining on the soil surface acts as an insulator, resulting in later thaw dates in the spring (Dormaar and Carefoot, 1996).

Slight differences in soil temperature were measured early in the growing season (May-Jun). From 1 Jun 2011 to 1 Jul 2011 the soil temperature at 20 cm in CC was 0.5 to 2 ^{o}C warmer than that in SG. The fast growing thick canopy of the SG likely shaded the ground while the CC had much more exposed soil. Later in the growing season, after canopy development in CC, these differences were not observed. The same trend with larger differences was observed in 2012. Soil temperatures for the cropping systems were generally within 0.5 °C during Mar and Apr. By 25 May 2012, temperature at 20 cm was in the following order: CC (21.5 °C) > SG (19.7 °C) > HP (18.6 °C). The difference between CC and SG fluctuated in June; however, CC was approximately 2 °C higher than SG until after 4 Jul 2012. After 25 May, temperatures for SG and HP were similar (within 1 °C).

Soil Moisture: Average daily volumetric water content (VWC) data for CC, SG, and HP (at 20 and 65 cm) are included in Appendix B (Fig. B5). VWC measurements were used to estimate average daily soil profile water storage (cm water/cm soil) from the soil surface to a depth of 65 cm (Fig. 1). Periods when soil was frozen below 20 cm depth were excluded. The decrease in VWC during the growing season was greater for CC than SG in 2011 but greater for SG than CC in 2012; changes were more pronounced at 20 cm depth. In 2011, both SG and CC maximum and minimum VWC measurements occurred on the same dates (except min. VWC at 20 cm) (Fig. B5, Appendix B). Warm and dry conditions in 2012 resulted in larger differences in soil-water distribution among the cropping systems. Maximum VWC was attained earlier in SG and HP (7-8 May) than in CC plots (25 May); warmer conditions in spring 2012 caused HP and SG to begin transpiring earlier than in 2011 and well before CC was planted. The field capacity, wilting point, and saturation for Plano Silt Loam soil are approximately 30.3, 15.2 and 40% over 0-60cm depth (NRCS Web Soil Survey).

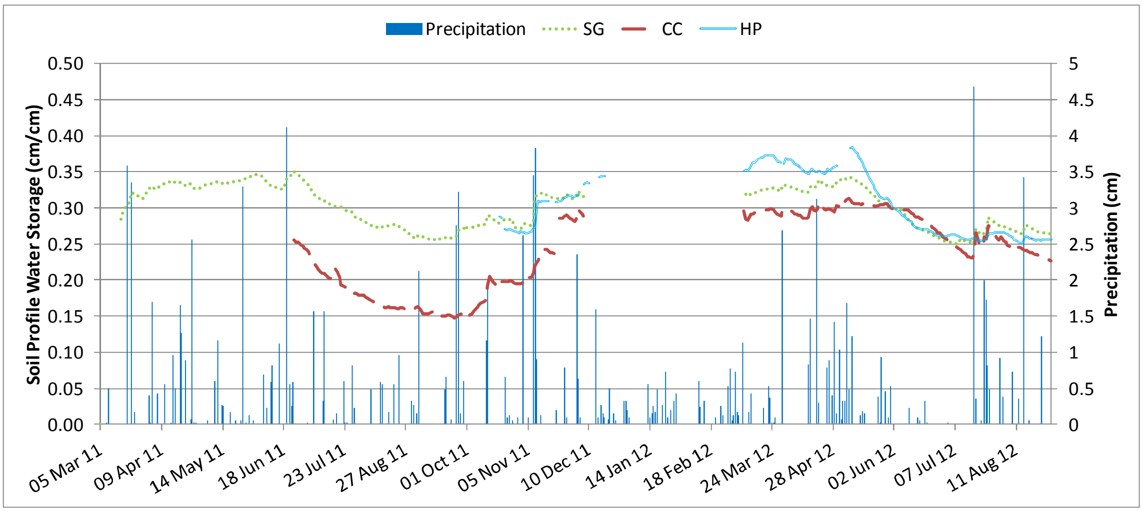

Figure 1. Daily average soil profile water storage for SG, CC, and HP (cm of water per cm of soil). Water content measurements taken at 20 and 65 cm.

We observed the perennial crops to have higher soil water holding capacity through most of the study period. The water stored in the soil profile in SG was higher than CC from the beginning of data collection until 1 Jun 2012 (Fig. 1); in early-Oct 2011 this difference was as large as 0.13 cm/cm. Soil water storage was higher under HP than both CC and SG during spring 2012; however, as the cropping systems began transpiring differences in soil water content became negligible.

The soil-water differences between SG and CC are likely due to physiological differences between the crops. According to McIassac et al. (2010), the dense canopy of switchgrass provides more shade than corn, which reduces evaporation throughout the growing season resulting in higher soil-water content. Furthermore, the root structure of switchgrass is dense and deep and the constant decay of dead roots provides organic matter enrichment (Percival et al., 2000; Blanco-Canqui, 2010) which improves water holding capacity of the soil, preventing the draw down observed in the corn crop (Fageria, 2012).

Drainage Depth: For Period I, cumulative drainage at SG and CC represented 44% and 36% of the total 115.2 cm of precipitation received (30-year average = 127.4 cm); drainage for CC and SG was not significantly different (p=0.27; Table 2). For Period II, drainage for SG, CC, and HP represented 45%, 30%, and 5%, respectively, of the total 88.6 cm of precipitation (30-year average = 99.9 cm); drainage in SG and CC were significantly greater than that in HP ($p < 0.05$) and SG was significantly different from CC ($p < 0.05$). All drainage during this time period occurred after 10 Nov 2011. Brye et al. (2000) reported similar drainage-to-precipitation ratios for no-till corn fields at AARS (35% in 1996; 43% in 1997). Most of the drainage from SG and CC occurred during spring and early summer (Fig. 2 and 3), prior to significant aboveground vegetation development (indicated by inverse relationship between Leaf Area Index (LAI) and drainage depth as shown in Appendix B, Figures B6 and B7). No drainage was measured during the mid-growing season, attributable to increased ET, and late fall. Similar season-dependent trends were reported by Brye et al. (2000).

Table 2. Cumulative drainage and standard errors for SG, CC, and HP during the study period. Means within a time period with different letters are statistically different ($p<0.10$).

	Precipitation (cm)	Drainage (cm)		
		SG	CC	HP
14-Apr-11 to 31-Aug-12	115.2	50.9^{a} ± 4.8	41.4^{a} ± 1.8	-
13-Jul-11to 31-Aug-12	89.1	39.8^{a} ± 4.0	26.3^{b} ± 1.3	4.8^{c} ± 1.4

Switchgrass has been reported to lower soil bulk density compared to corn rotations (Bharati et al., 2002; Rachman et al., 2004), partly explained by more continuous macropores created by root channels and biological activity (Blanco-Canqui, 2010). Additionally, dense switchgrass canopy cover intercepts raindrops, preventing soil surface sealing, reducing runoff and increasing infiltration (Blanco-Canqui, 2010). These properties may explain the drainage differences between CC and SG.

Interestingly, a single sampling period, from 20 Feb 2012 to 5 Mar 2012, yielded 9.1 cm of drainage from SG, which is 18% of the total drainage from SG for the entire study period. This sampling period coincided with the earlier and faster than normal thaw in 2012 and suggests that increased infiltration facilitated by SG may allow for more drainage during large rainfall or thaw events. Drainage from SG was the greatest overall, with most occurring early in the growing seasons of 2011 and 2012.

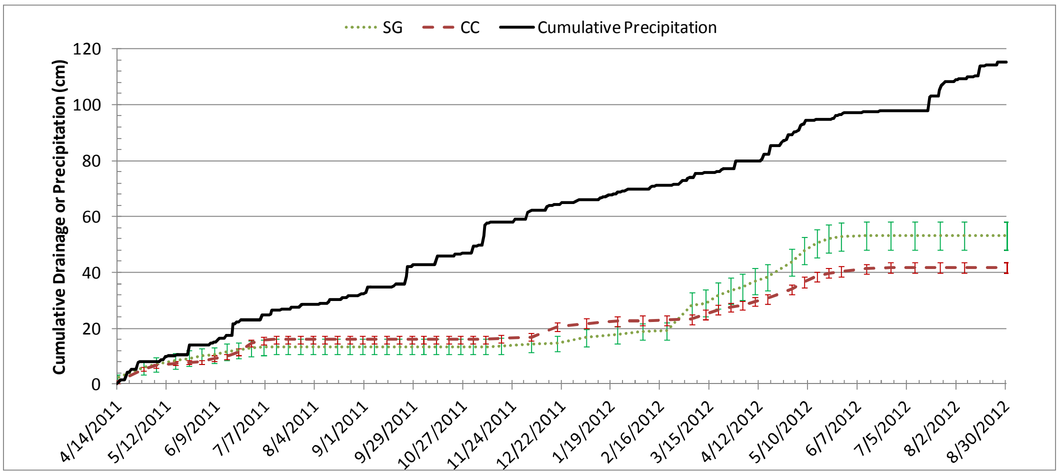

Figure 2. Cumulative drainage for Period I in SG and CC. Error bars indicate cumulative standard error.

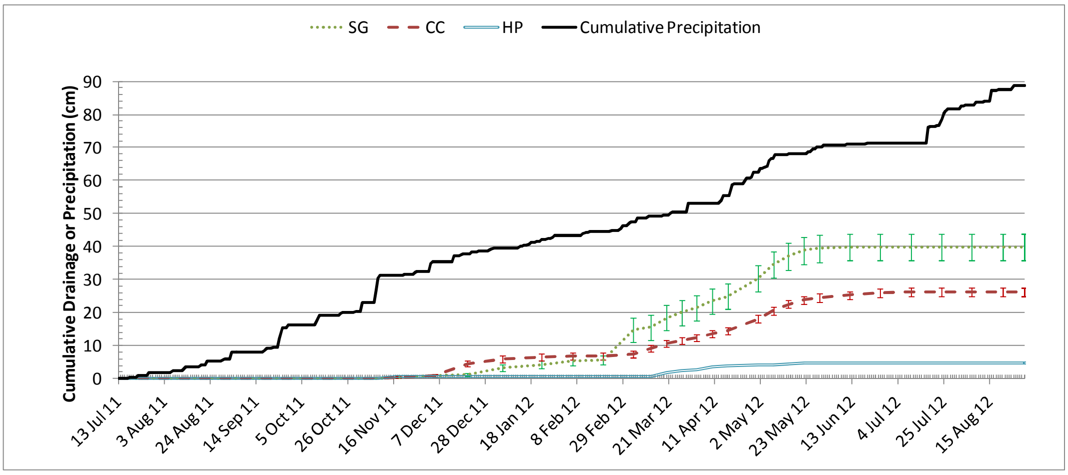

Figure 3. Cumulative drainage for Period II from SG, CC, and HP. Error bars indicate cumulative standard error.

Seasonal differences in drainage were observed among these cropping systems (Table 3). More drainage occurred from SG than CC in spring 2011 (4.6 cm; $p=0.37$), winter 2012 (10.6 cm; $p<0.10$), and spring 2012 (6.5 cm; $p<0.05$). Conversely, more drainage occurred from CC than SG in summer 2011 (4.1 cm; $p<0.05$), fall 2011 (2.5 cm; $p=0.29$), and summer 2012 (0.9 cm; $p<0.05$). Drainage from HP was always lower than in SG and CC. The differences in drainage among cropping systems could be partially attributed to differences in soil surface cover. After harvest and before planting (winter and spring), CC had lower surface residue cover, which results in reduced infiltration (Blanco-Conqui and Lal, 2009). Additionally, macropore development in SG likely enhanced infiltration and drainage during winter and spring. During summer and fall, ET differences between the cropping systems, particularly in the early summer when SG canopy developed earlier than CC, likely impacted drainage.

Table 3. Average seasonal drainage depths, NO_3-N loads, DRP loads, and DOC loads for SG, CC, and HP. Values in parentheses are standard errors. Means within seasons with different letters are significantly different ($p<0.10$).

Season	Drainage Depth (cm)			NO_3-N load (kg/ha)			DRP load (kg/ha)			DOC load (kg/ha)		
	SG	CC	HP	SG	CC	HP[1]	SG	CC	HP	SG	CC	HP
Spring 11	14.1^{a} (2.8)	9.5^{a} (0.8)	-	12.6^{a} (0.5)	85.2^{b} (1.5)	-	0.06^{a} (0.01)	0.02^{a} (0.002)	-	-	-	-
Summer 11	1.7^{a} (0.6)	5.8^{b} (1.1)	-	2.0^{a} (0.3)	55.3^{b} (3.0)	-	0.02^{a} (0.004)	0.09^{b} (0.011)	-	0.48^{a} (0.25)	1.87^{b} (0.35)	-
Fall 11	3.1^{a} (1.0)	5.6^{a} (1.2)	0.7^{a} (0.8)	0.3^{a} (0.4)	26.2^{a} (7.0)	0.0 (0.0)	0.00^{a} (0.002)	0.04^{a} (0.009)	0.00^{a} (0.0)	0.14^{a} (0.13)	2.1^{b} (0.03)	0.00^{a} (0.0)
Winter 12	16.4^{a} (3.6)	5.8^{b} (0.5)	1.0^{c} (1.1)	6.1^{a} (1.3)	56.5^{a} (15.1)	0.0 (0.0)	0.29^{a} (0.023)	0.03^{b} (0.011)	0.00^{b} (0.0)	8.59^{a} (0.41)	2.36^{b} (0.11)	1.11^{c} (0.13)
Spring 12	20.5^{a} (1.4)	14.0^{b} (0.6)	3.1^{c} (1.0)	9.4^{a} (2.5)	137.5^{b} (11.0)	0.0 (0.0)	0.17^{a} (0.008)	0.06^{b} (0.008)	0.00^{c} (0.001)	7.05^{a} (0.36)	4.30^{b} (0.31)	0.54^{c} (0.04)
Summer 12	0.0^{a} (0.0)	0.9^{b} (0.2)	0.0^{a} (0.0)	0.0^{a} (0.0)	4.7^{a} (3.0)	0.0 (0.0)	0.00^{a} (0.00)	0.00^{a} (0.001)	0.00^{a} (0.0)	0.00^{a} (0.0)	0.26^{a} (0.12)	0.00^{a} (0.0)

Water Balance: A water balance was calculated for summer 2011 and summer 2012. In both summers, more drainage occurred from CC than SG and soil water storage in CC decreased more than SG. Lower water requirements for CC than SG in the early summer (result of different growth stages), likely explain the greater drainage from CC. Evapotranspiration, the residual of the measured water balance components, was the largest component of the water balance for CC and SG in both summers (Table 4). Despite very dry conditions in Jun 2012, more rainfall occurred in summer 2012 than summer 2011. However, the heaviest rainfall occurred after crops were established and virtually no runoff was produced during summer 2012.

Table 4. Summer 2011 and 2012 water balances for CC and SG

Summer 2011				Summer 2012		
	CC	SG			CC	SG
Precip(cm)	13.4	13.4		Precip (cm)	17.7	17.7
ΔS (cm)	-14.0	-12.9		ΔS (cm)	-1.5	-0.1
Runoff (cm)	1.7	0.1		Runoff (cm)	0.0	0.0
Drainage(cm)	5.8	1.7		Drainage (cm)	0.9	0.1
ET (cm)	19.9	24.5		ET (cm)	18.3	17.7

Nitrate: Nitrate loading during Period I was greater in CC than SG (Fig. 4). The total NO_3-N load to the lysimeters during this time was 329.5 ± 15.7 kg/ha in CC, and 28.0 ± 3.4 kg/ha in SG. Both cropping treatments exhibited similar patterns in loading; the highest rates of loading occurred in Mar-Jun, no loading occurred during Jul-Aug, followed by minimal loading between Sep-Feb. Nitrate loading for Period II was greater in CC than SG and no loading was measured in HP. Total NO_3-N loading during this time was 189.3 ± 15.1 kg/ha in CC and 15.3 ± 3.3 kg/ha in SG.

Nitrogen fertilization likely contributed to the different NO_3-N loadings. Both CC and SG received similar levels of N fertilizer in 2011 (65 kg/ha in CC; 55 kg/ha in SG), despite high soil test NO_3-N in the CC plot (#411, Fig. B2) (149 kg NO_3-N/ha). At this soil N level, UW-Extension does not recommend N fertilizer application to corn grown in silt loam soils (Laboski et al., 2006). Trends in water-extractable NO_3-N (Table B8, Appendix B) also point to the presence of higher soil NO_3-N in the CC plots.

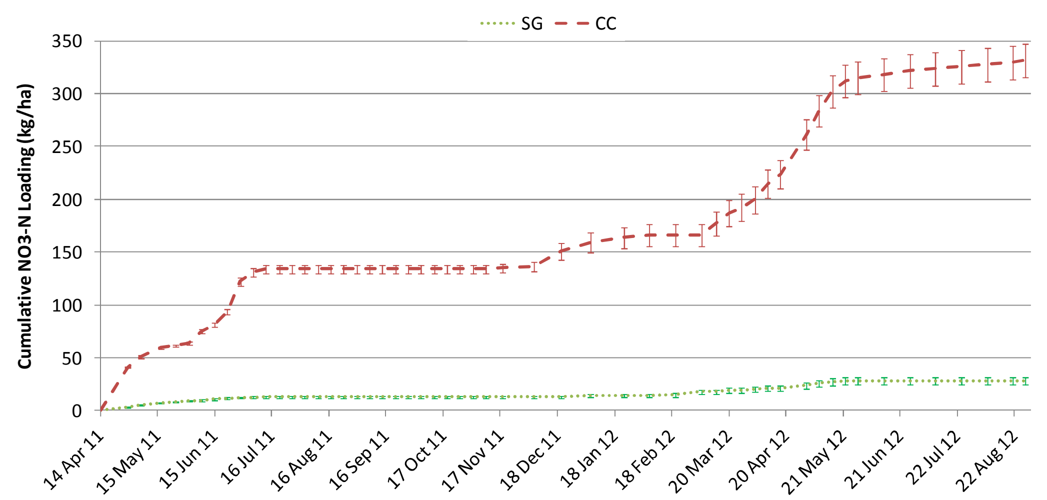

Figure 4. Cumulative NO_3-N loading in SG and CC for Period I. Error bars indicate cumulative standard error.

Average seasonal NO_3-N leachate concentration was higher for CC than SG at all times of the year (Table 5). During spring 2011, summer 2011, winter 2012, and spring 2012, NO_3-N concentrations from CC exceeded 90 mg/L (range of 93.7 to 98.8 mg/L). During all seasons, NO_3-N concentrations from CC were significantly greater than those in drainage from SG plots ($p<0.10$). It is important to note that average NO_3-N concentrations from SG plots exceeded the EPA drinking water standard of 10 mg/L during the spring (10.7 mg/L) and summer (12.3 mg/L) of 2011. No samples collected during the study from the HP cropping system had detectable concentrations of NO_3-N (0.25 mg /L).

Nitrate concentrations for CC were greater than the range of 15-40 mg/L reported for corn in similar studies in the Midwestern U.S. (Owens, 1990; Andraski et al., 2000; Brye et al., 2003; Rekha et al., 2011). The higher NO_3-N concentrations could be due to excessive fertilizer applied to the CC plots; other studies aimed to apply optimum levels of N fertilizer. The higher NO_3-N concentrations in CC resulted in greater loads than SG throughout the study period which were significantly different ($p<0.1$) in spring and summer 2011, and spring 2012 (Table 3). The differences were not significant during fall 2011 ($p=0.17$), winter 2012 ($p=0.19$), and summer 2012 ($p=0.26$).

During our 17-month study period, ~330 kg NO_3-N/ha leached from the CC cropping system while <190 kg N/ha was added in the form of N fertilizers. The soil-test NO_3-N level in one of the CC plots was 149 kg NO_3-N/ha. Brye et al. (2003) attempted to quantify the N balance for corn cropping systems with varying tillage and reported net N leaving the soil profile (as high as 150 kg NO_3-N/ha) in corn cropping systems. However, the authors pointed to the difficulty in quantifying the N cycle in-situ at small (plot) scale levels. Over their 3.5-year study duration, the average annual N balance residual in no-till optimally-fertilized corn ranged between -64 and +115 kg/ha (negative number indicates N outputs > N inputs). Brye et al. (2003) suggested longer periods of time (>5 years) are required to evaluate the N balance of corn as mineralization rates of soil organic matter are driven by climatic conditions and can vary greatly from year to year and spatially depending on soil conditions.

Table 5. Average seasonal NO_3-N, DRP and DOC concentrations for SG, CC, and HP. Values in parentheses are standard errors. Means within seasons with different letters are significantly different ($p<0.10$).

Season	NO_3-N concentration (mg/L)			DRP concentration (mg/L)			DOC concentration (mg/L)		
	SG	CC	HP	SG	CC	HP	SG	CC	HP
Spring 11	10.8^{a} (0.76)	98.4^{b} (1.95)	-	0.06^{a} (0.01)	0.02^{b} (0.002)	-	-	-	-
Summer 11	12.3^{a} (0.92)	97.6^{b} (5.7)	-	0.09^{a} (0.02)	0.12^{a} (0.02)	-	3.4^{a} (1.6)	2.6^{a} (0.8)	-
Fall 11	5.9^{a} (2.7)	53.3^{b} (18.2)	0.43 (0.0)	0.04^{a} (0.02)	0.10^{a} (0.03)	0.06^{a} (0.02)	1.7^{a} (1.0)	3.6^{a} (1.6)	1.7^{a} (0.8)
Winter 12	4.6^{a} (1.6)	98.8^{b} (18.3)	0.0 (0.0)	0.11^{a} (0.02)	0.05^{b} (0.01)	0.02^{c} (0.004)	5.9^{a} (1.0)	4.2^{a} (1.4)	7.5^{a} (1.3)
Spring 12	5.7^{a} (1.5)	93.66^{b} (8.2)	0.0 (0.0)	0.08^{a} (0.00)	0.04^{b} (0.01)	0.02^{c} (0.01)	3.1^{a} (0.4)	3.2^{a} (0.4)	3.8^{a} (1.0)
Summer 12	0.0^{a} (0.0)	70.99^{b} (11.2)	0.0 (0.0)	0.00 (0.00)	0.03 (0.00)	0.00 (0.0)	0.00 (0.0)	3.9 (0.3)	0.00 (0.0)

Ammonium: NH_4-N concentrations/loadings were low for all treatments with the majority (81%) of samples containing < 0.02 mg/L. NH_4-N average concentrations (< 0.11mg/L) were not statistically different among cropping systems during any season. Loadings for all treatments were <0.06 kg NH_4-N/ha, except in winter 2012 (<0.12 kg NH_4-N/ha).

Total N: Almost all of the N losses occurred in the NO_3-N form, with the ratio of NO_3-N/TN > 0.95 for almost 90% of the leachate samples.

Dissolved Reactive Phosphorus (DRP): Average DRP concentrations were below 0.12 mg/L throughout the study period (Table 5). There were no significant differences among cropping systems in summer 2011 (SG-CC: $p=0.38$) and fall 2011 (SG-CC: $p=0.16$, SG-HP: $p=0.61$, CC-HP: $p=0.37$); however, concentrations from CC were greater than those measured for the other cropping systems. In winter 2012, average DRP concentration in SG leachate was significantly greater than both CC ($p<0.05$) and HP ($p<0.01$), and DRP concentration in CC was significantly greater than HP ($p<0.05$). Similarly, in spring 2012 average DRP concentration in SG was greater than CC ($p<0.01$), and both were significantly greater than HP ($p<0.01$). Our DRP concentrations (Table 5) are similar to those reported by Brye et al. (2002).

Cumulative DRP loadings measured in all cropping systems during the study were below 0.30 kg/ha, with season-dependent differences among the cropping systems (Table 3). DRP loadings for SG were greater than for CC during spring and winter; conversely, DRP loadings for CC were greater than for SG during summer and fall. The lowest DRP loading was obtained for the HP treatment.

Total phosphorus (TP): Similar to our observations for N, most of the P losses occurred in the dissolved form. All measured TP concentrations were < 0.05 mg P/L. Water entered the lysimeters through 1.0 and 0.5 µm filter paper, which could have removed all particulate P forms.

Carbon: No significant differences in DOC concentration were observed among cropping treatments within seasons (p-values ranged from 0.11 to 1.0); leachate collected after 22 June 2011 was analyzed for DOC. The highest DOC concentrations occurred during winter 2012 in all cropping systems. Agren et al. (2012) attributed higher DOC concentrations in soil-water to a "freeze-out" effect as frost develops in the soil profile, which could potentially lead to higher concentrations in leachate during winter months. The average seasonal DOC concentrations for all treatments are summarized in Table 5. In general the ranges of concentrations within a season were similar among cropping systems, although in summer 2011 and winter 2012, SG concentrations varied more than either CC or HP (Table 5). The overall average DOC concentration of all samples analyzed was 5.0 ± 0.3 mg/L. DOC concentrations fall within ranges reported by other studies. McCarthy and Bremner (1992) reported average DOC concentrations in tile drain effluent of $\leq$ 3.0 mg/L from agricultural catchments in Indiana. Brye et al. (2000) reported DOC concentrations of 5-20 mg/L for leachate measured with AETLs in prairie and corn at AARS.

Differences in DOC loading among cropping systems varied seasonally (Table 3). During summer and fall 2011, DOC loading in CC was significantly greater ($p<0.05$ and $p<0.1$, respectively) than SG. Conversely, in winter of 2012, DOC loading from SG was significantly higher than both CC ($p<0.01$) and HP ($p<0.01$). Likewise, in spring 2012, DOC loading in SG was significantly greater than CC ($p<0.05$) and HP ($p<0.01$). Higher DOC loading in SG in winter and spring 2012 may be due to the ability of SG to store more C in the soil profile. Organic matter inputs to soil are generally greater in warm season grasses than row crops (Brown et al, 2004; Frank et al., 2004); the additional C in the soil increases the likelihood of higher DOC leachate concentrations. DOC loadings measured in the present study are at the lower end of reported values. Annual exports of soluble C from most agricultural catchments in North America was estimated to be 10-100 kg/ha (Hope et al., 1994). Dalzell (2007) reported DOC losses via tile drains of 15-20 kg/ha for a modeled agricultural and forested watershed. Brye et al. (2000) reported DOC losses of 17-48 kg/ha from prairie and 90-180 kg/ha from no-till corn.

IV. CONCLUSIONS AND RECOMMENDATIONS

Cellulosic biofuels provide renewable alternatives to fossil fuels; however, the potential water resource impacts of wide scale production of cellulosic biofuel crops have not yet been extensively studied. Rapid expansion in the production of biofuels is expected in the next decade across the U.S., with many different cropping systems being investigated to meet the growing demands. Field studies are necessary to assess the environmental impacts of these cropping systems, including changes in the quantity and quality of subsurface drainage.

Seasonal differences in drainage were observed among the three cropping treatments evaluated in this project. Drainage during spring and winter was greater in SG than in CC and HP attributable, in part, to differences in surface residue coverage. In winter and spring, the CC plots had minimal residue coverage allowing the potential for surface crusting to develop, which is known to reduce infiltration by increasing runoff. Additionally, the deep fibrous root structures of SG and HP could have promoted greater infiltration compared to the CC plots. The trend in drainage amount was reversed during summer with CC plots yielding more leachate than the SG and HP plots. In both SG and HP plots, due to ET demands the soil moisture was depleted earlier in the growing season than in the CC plots.

Due to small differences in nutrient concentrations, seasonal nutrient loading among cropping systems followed the trends in drainage depth, except for NO_3-N. Throughout the study period, NO_3-N loading from CC exceeded that of the other cropping systems. Seasonal NO_3-N loading for CC varied between 4.7 and 137.5 kg NO_3-N/ha while NO_3-N loads for SG were between 0 and 12.3 kg NO_3-N/ha. Leachate samples from HP plots had very low NO_3-N concentrations. Despite comparable N fertilizer application rates in CC and SG, substantially more NO_3-N leaked out of CC cropping system throughout the year.

As cellulosic biofuel production expands, cropping systems will need to be matched to climate, soils, and environmental concerns in a region, due to differential impacts of each cropping system on water and nutrient dynamics. Results from this study suggest that high yielding perennial cropping systems (e.g. switchgrass, hybrid poplar) could reduce NO_3-N losses compared to systems involving corn (as the latter also requires additional N inputs). However, switchgrass systems could be vulnerable to leak more nutrients during seasons when ET demand is low (spring, winter) and that produce high drainage volumes. Limited data (only for 1 season) indicate that both drainage rates and nutrient losses could be lower under hybrid poplar throughout the year. Selection of appropriate cropping systems for a region should consider potential differences in leachate dynamics and nutrient concentrations to minimize environmental impacts of biofuel production systems.

Research on subsurface drainage quantity and quality should be extended to additional cropping systems with continued biomass removal on different soil types and physiographic conditions. These cropping systems could include native species, such as, prairie plantings or other biodiverse combinations (e.g., annual + perennial crops). Future studies should also encompass long-term monitoring (over several growing seasons), which will facilitate the development and rigorous validation of models that can be applied at various spatial scales. With the cellulosic biofuel demand expected to grow rapidly in the next decade, research needs to keep up with implementation and relay information to producers to ensure that reducing fossil fuel imports does not come at the cost of degraded environmental resources.

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APPENDIX A Awards/Pulications/Reports/Patents/Presentations

Publications:

Stenjem, R.S. 2013. Subsurface water and nutrient dynamics of cellulosic biofuel cropping systems. M.S. Thesis, University of Wisconsin – Madison.

Presentations:

Stenjem, R.S., A.M. Thompson and B.J. Lepore. 2012. Water and nutrient fluxes under biofuel cropping systems. Annual Meeting of the American Water Resources Associate Wisconsin Section. Wisconsin Dells, WI, March 1-2, 2012.

Stenjem, R.S., A.M. Thompson, K.G. Karthikeyan, M. Polich and B.J. Lepore. 2012. Surface and subsurface water and nutrient dynamics for biofuel feedstock cropping systems. Annual International Meeting of the American Society of Agricultural and Biological Engineers. Dallas, TX, July 29 – Aug 1, 2012.

APPENDIX B

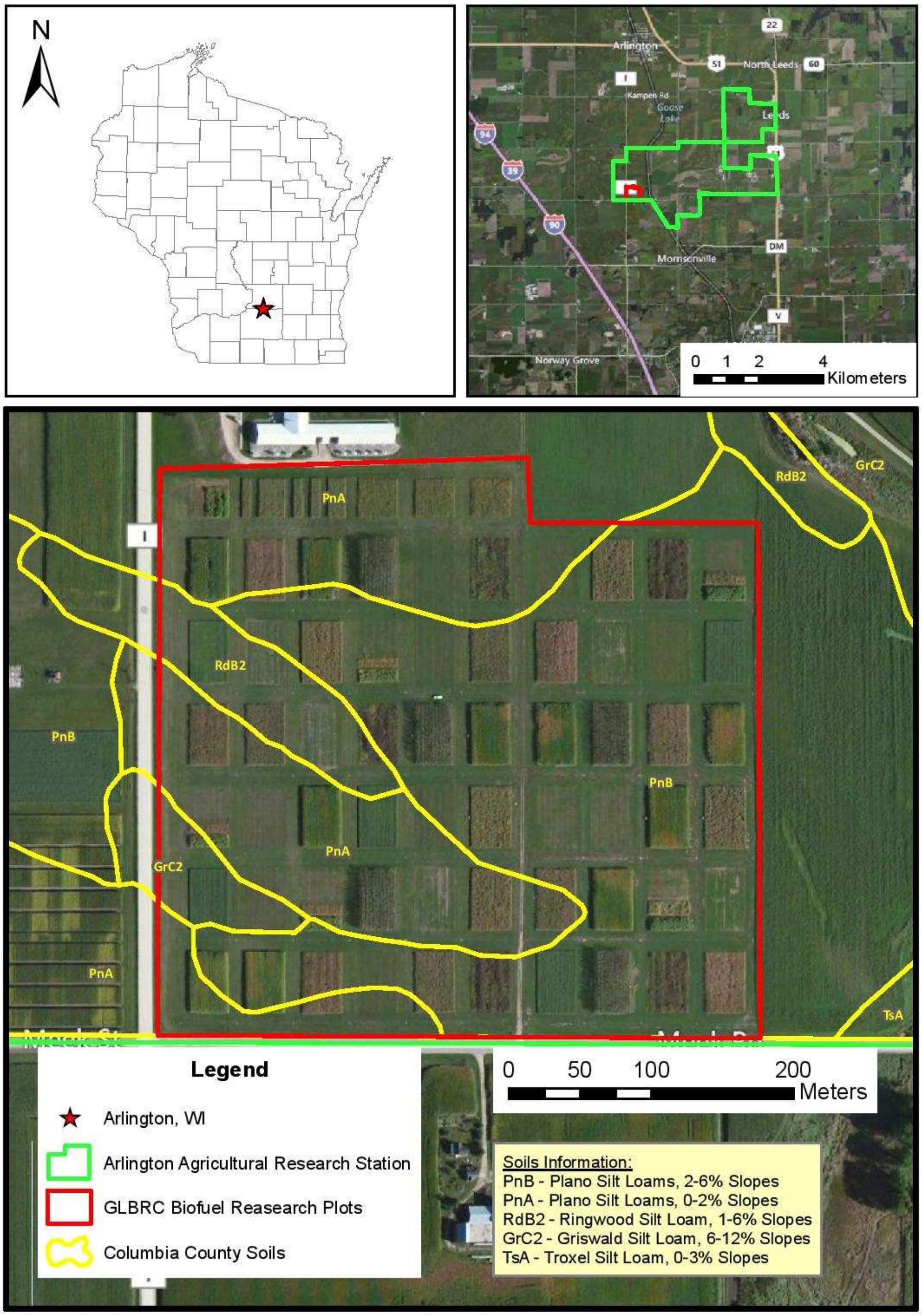

Figure B1. Locations of Arlington, WI; AARS; and the Biofuel Research Plots at AARS (Stenjem, 2013).

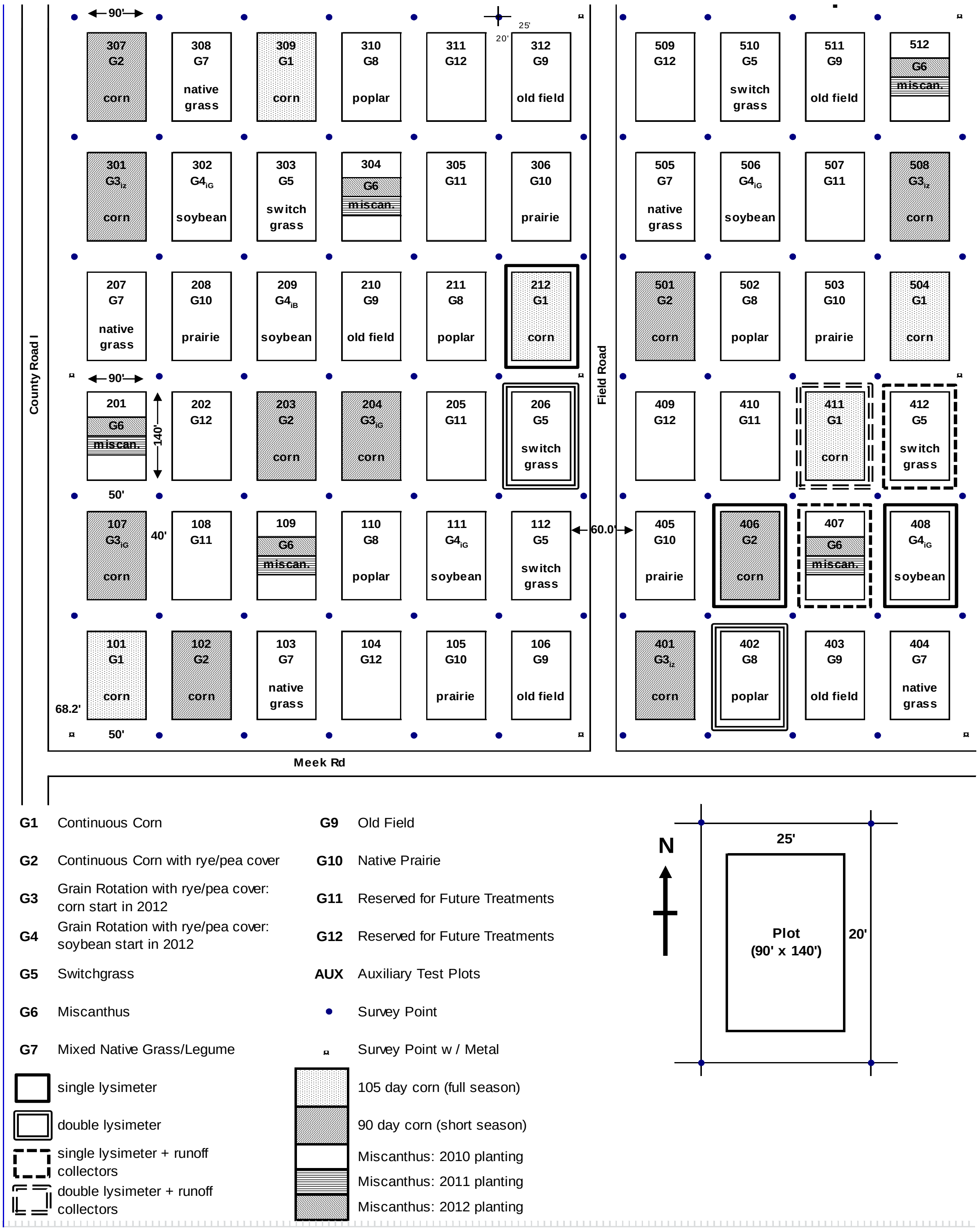

Figure B2. Map of Great Lakes Bioenergy Research Center Biofuel Plots located at AARS (Courtesy of Gregg Sanford, GLBRC).

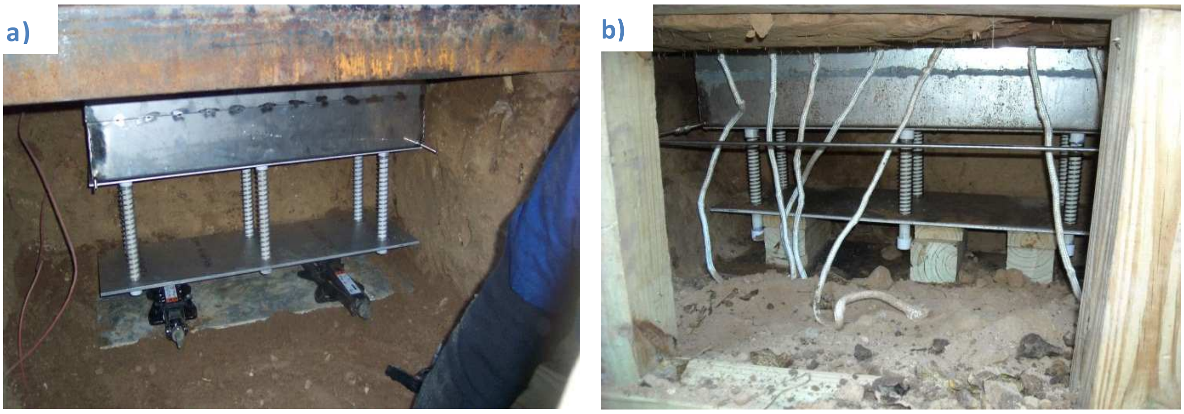

Figure B3. (a) Lysimeter and spring plate inside soil cavity with screw jacks for installation beneath. Tensiometer wires shown to the left of lysimeter. (b) Lysimeter and spring plate installed. Wooden blocks under spring plate to maintain spring force and lysimeter contact with cavity ceiling.

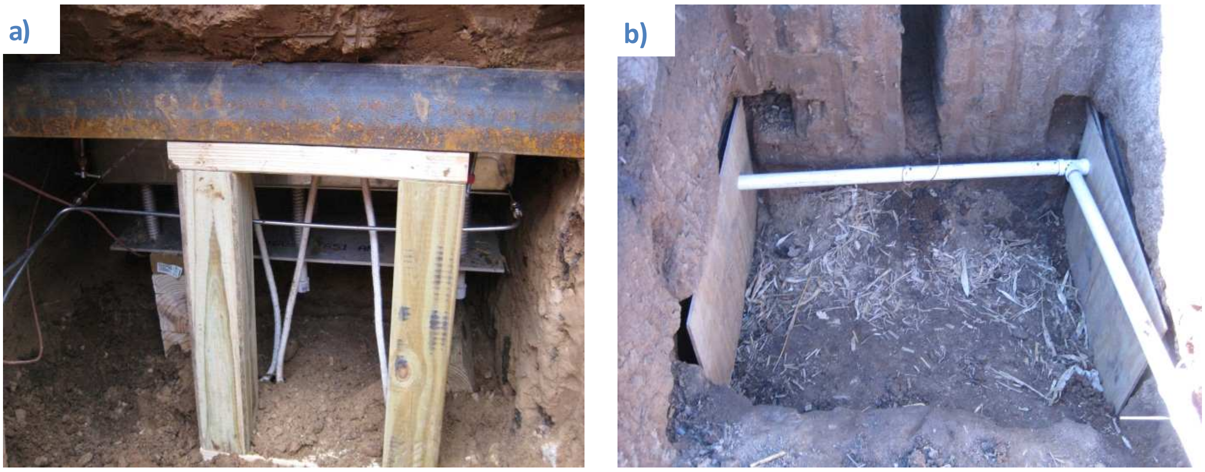

Figure B4. (a) Wooden weather treated support frames installed beneath angle irons to provide support to soil profile above cavity. (b) Weather treated plywood covering to prevent cavity from damage during backfilling. PVC tudes contain sensor wires and lysimeter tubing extends to the control box on soil surface.

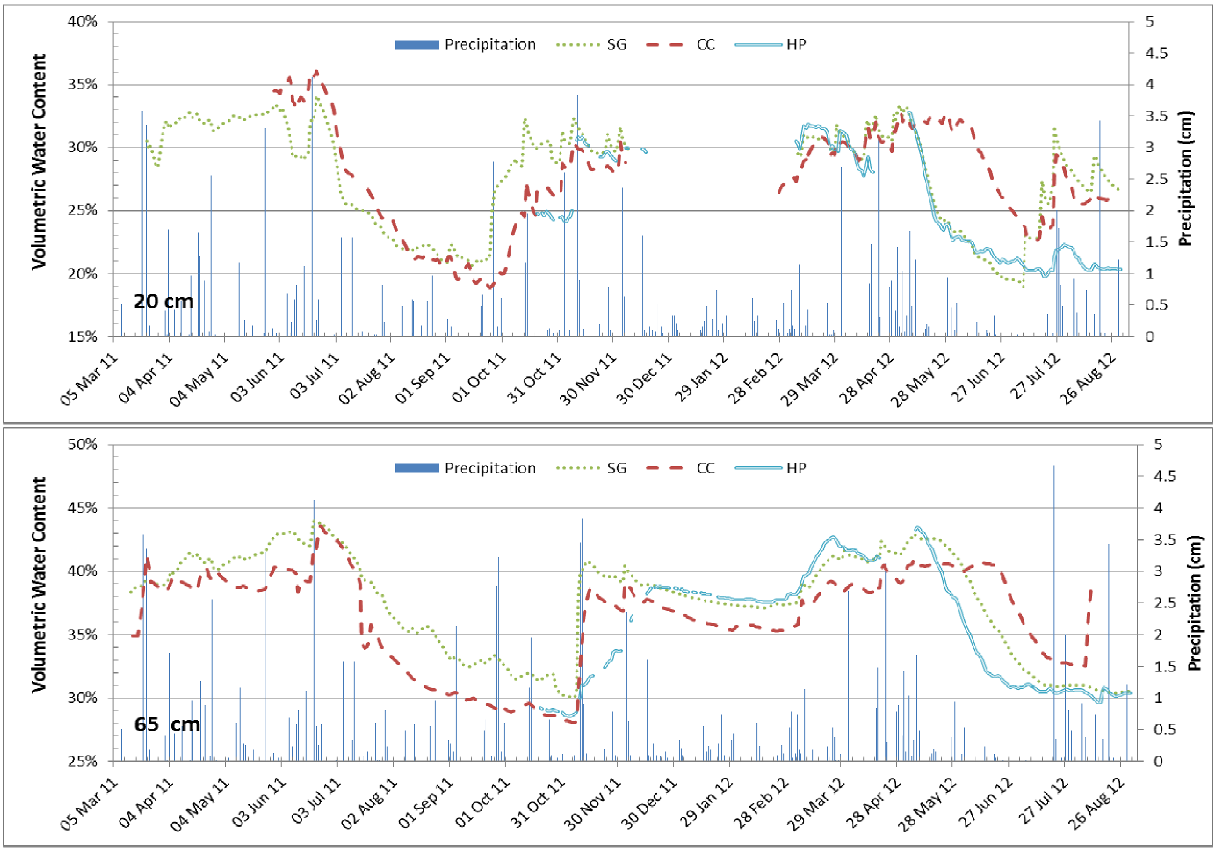

Figure B5. Volumetric water content at 20 cm (top) and 65 cm (bottom) in SG, CC, and HP from 5 Mar 2011 to 31 Aug 2012. At 20 cm time periods where soil was frozen have been excluded.

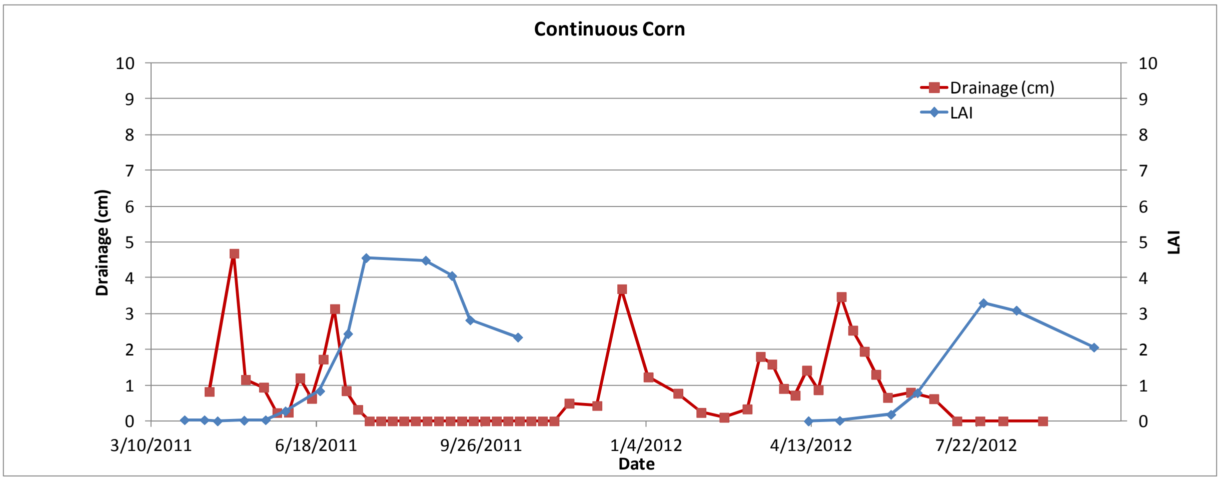

Figure B6. Time series of drainage depths and Leaf Area Index (LAI) for continuous corn during study. LAI data provided by Dr. Oates, Assistant Scientist, GLBRC.

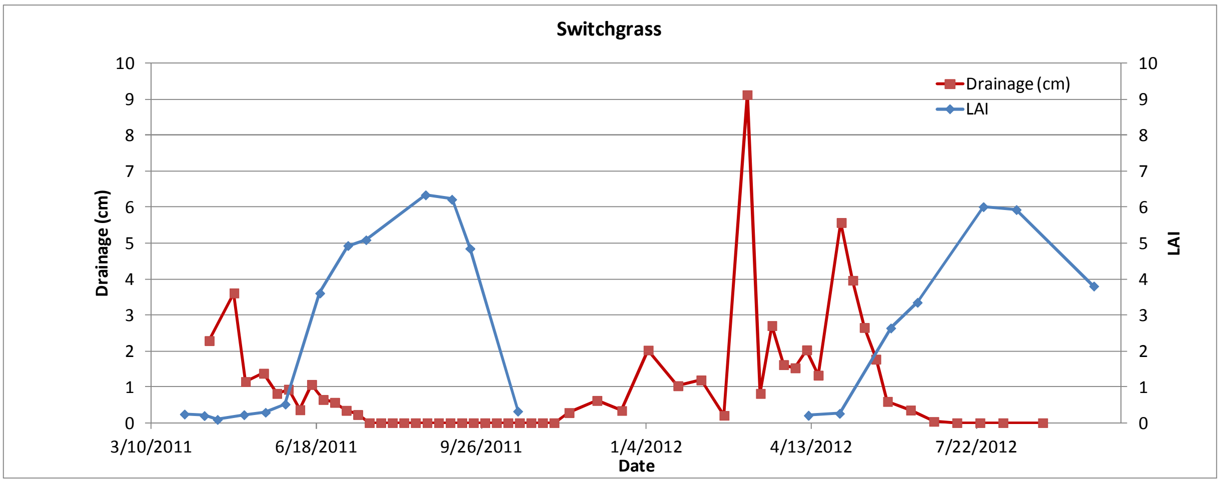

Figure B7. Time series of drainage depths and Leaf Area Index (LAI) for switchgrass during study. LAI data provided by Dr. Oates, Assistant Scientist, GLBRC.

Table B1. Planting and harvest dates, for the cellulosic biofuel cropping systems.

Cropping Treatment	Planting Date		Harvest Date	
	2011	2012	2011	2012*
RC	6 May	10 May	25 Oct	9 Oct
CC	6 May	10 May	25 Oct	9 Oct
SG	May 2008	--	10 Oct	9 Nov
MIS	19 May	--	10 Oct	9 Nov
HP	May 2008	--	--	--

*Data collection ended 31 Aug 2012

Table B2. 2011 cellulosic biofuel cropping system Yields at AARS.

	Grain		Stover/Biomass	
Treatment (Plot #)	m^3/ha	bu/ac	Mg/ha	ton/ac
RC (406)	18.9	219	5.6	2.5
RC (408)*	-	-	-	-
CC (212)	18.6	215.2	6.3	2.9
CC (411)	17.5	202.3	6.3	2.9
SG (206)	-	-	6.9	3.1
SG (412)	-	-	6.5	3.0
MIS (407)	-	-	18.3	7.5
HP (402)**	-	-	-	-

* Planted in Canola during 2011

**Not harvested in 2011

Table B3. 2011 growing season GLBRC fertilizer application dates, rates, and cumulative nutrient application rates for cellulosic biofuel cropping systems at AARS. Fertilizer guaranteed analysis (%N-%$P_2O_5$0-%K_2O) provided.

	Fertilizer Application Date			Fertilizer Application Guaranteed Analysis (N-P_2O_5-K_2O): Rate (kg/ha)			Total Added (kg/ha)		
	N	P	K	N	P	K	N	P	K
RC	14 May 25 June	14 May	4 May 14 May	5-14-42: 112 28-0-0: 97	5-14-42: 112	0-0-60: 50.4 5-14-42: 112	64.6	6.8	63.9
CC	14 May 35 June	14 May	4 May 14 May	5-14-42: 112 28-0-0: 210.6	5-14-42: 112	0-0-60: 50.4 5-14-42: 112	64.6	6.8	63.9
SG	27 May	-	-	34-0-0: 164.6	-	-	56.0	-	-
MIS	27 May	-	-	34-0-0: 164.6	-	-	56.0	-	-
HP	-	-	-	-	-	-	-	-	-

Table B4. Instrumentation installation depths in experimental field plots at AARS including GLBRC installed instrumentation

Plot	Treatment	Lysimeter* depths (cm)		TDR depths (cm)		Thermocouple depths (cm)	
		This Study	GLBRC	This Study	GLBRC	This Study	GLBRC
206	G5– SG	N-90 S-110	120	20, 65	2, 20, 35, 50, 65, 95, 125	20	2, 10, 20, 35, 50, 65, 95, 125 (two at each depth)
212	G1– CC	90	120	20, 65	2, 20, 35, 50, 65, 95, 125	20	2, 10, 20, 35, 50, 65, 95, 125 (two at each depth)
402	G8– Poplar	N – 80 S – 90	120	20, 65	2, 20, 35, 50, 65, 95, 125		2, 10, 20, 35, 50, 65, 95, 125 (two at each depth)
406	G2- Rotation (Corn in 2011)	120	120	4, 20, 35, 65	-	10, 20, 35, 50, 65	-
407	G6– MIS	185	120	4, 20, 35, 65	-	10, 20, 35, 50, 65	-
408	G4– Rotation (Corn in 2012)	190	120	4, 20, 35, 65	-	10, 20, 35, 50, 65	-
411	G1– CC	N-105 S-100	120	20, 65	2, 20, 35, 50, 65, 95, 125	20	2, 10, 20, 35, 50, 65, 95, 125 (two at each depth)
412	G5- SG	195	120	20(2), 65	2, 20, 35, 50, 65, 95, 125	20	2, 10, 20, 35, 50, 65, 95, 125 (two at each depth)

*GLBRC lysimeters are suction cup type lysimeters, not equilibrium tension lysimeters

Table B5. AETL installation periods, data collection, water sampling, and nutrient analysis starting dates

Plot Number	Installation	Soil Sensor Data Collection	Water Sample Collection	Nutrient Analyses
206	Nov 2010	17 Mar 2011	14 Feb 2011	29 May 2011
212	Oct 2010	21 Nov 2010	6 Apr 2011	29 May 2011
402	July 2011	19 Oct 2011	18 Nov 2011	18 Nov 2011
406	Oct 2010	24 Jan 2011	28 Feb 2011	29 May 2011
407	Oct 2010	13 Apr 2011	17 May 2011	29 May 2011
408	Oct 2011	23 Nov 2011	5 Mar 2012	5 Mar 2012
411	Oct 2010	5 Mar 2011	15 Mar 2011	29 May 2011
412	Nov 2010	2 Mar 2011	6 Mar 2011	29 May 2011

Table B6. Precipitation (cm liquid water equivalent) depths for Arlington, WI during 2011 and 2012 (NOAA)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2011	1.75*	2.79*	8.08*	11.12	6.15	8.94	5.44	3.84	10.16	4.06	11.48	6.48	80.28
2012	3.20	1.73	6.35	9.40	7.69	0.74	10.14	7.08	-	-	-	-	-
30 yr Avg	2.69	2.90	5.11	8.20	8.71	10.31	9.80	10.80	9.19	6.20	6.10	3.40	83.41

*Outside of the study period but offer insight into the climate conditions preceding the study.

Table B7. Monthly and 30 year average air temperatures (°C) during 2011 and 2012 at Arlington, WI (NOAA)

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
2011	-9.8*	-6.8*	-0.8*	6.2	12.9	19.2	23.3	19.8	13.6	9.5	2.9	-2.1
2012	-5.2	-2.6	8.5	7.4	16.3	21.5	24.6	19.6	-	-	-	-
30-year Average	-9.0	-6.0	0.5	7.5	14.0	19.0	21.5	20.5	16.0	9.5	1.0	-5.5

*Outside of the study period but offer insight into the climate conditions preceding the study.

Table B8. Soil NO_3-N analysis for CC and SG plots performed in August 2012.

Plot[1] (Crop)	**NO_3-N (water extractable – soils from top 95 cm)**
206 (SG)	0.8 mg/kg of soil
412 (SG)	0.7 mg/kg of soil
411 (CC)	19.0 mg/kg of soil
212 (CC)	3.2 mg/kg of soil

[1] Plot numbers shown in Fig. B2