ENVIRONMENTAL AND ECONOMIC RESEARCH AND DEVELOPMENT PROGRAM

Maximizing Ecological Services and Economic Returns by Targeted Establishment of Biomass Grasslands for Electricity and Heat Generation in Wisconsin

Final Report
April 2012

PREPARED BY:

M.E. DORNBUSH (PI)[1];
P.D. BAUMGART[1];
K.J. FERMANICH[1];
A.M. RIETH[3];
J.R. STOLL[2];
A.C. VON HADEN[3];
[1]DEPARTMENT NATURAL AND APPLIED SCIENCES,
[2]DEPARTMENT OF PUBLIC AND ENVIRONMENTAL AFFAIRS,
[3]ENVIRONMENTAL SCIENCE & POLICY GRADUATE PROGRAM,
UNIVERSITY OF WISCONSIN-GREEN BAY

focus on energy℠
Partnering with Wisconsin utilities

This report was funded through the Environmental and Economic Research and Development Program of Wisconsin's Focus on Energy.

Table of Contents:

Executive Summary:

Our objective was to evaluate the economic and environmental outcomes of converting poorly drained, marginal agricultural areas into perennial, biomass yielding grasslands for electricity and heat Generation in NE Wisconsin. We targeted poorly drained, marginal cropland for three main reasons. First, planting these areas into annual row crops is often delayed, prevented, or unprofitable in wet years. However, seasonal (spring) soil saturation is expected to maximize warm season grass production by providing ideal moisture availability during the more commonly water-limited summer. Second, the wetter conditions and finer textured soils (more clay) characterizing low-lying areas in NE Wisconsin should maximize carbon-sequestration rates. Establishing grasslands in these areas will also maximize carbon (C) sequestration per unit lost agricultural productivity for food or fiber. Third, establishing perennial grasslands in the low-lying areas juxtapositioned between agricultural uplands and aquatic systems will reduce nutrient and sediment loading into aquatic systems, thereby providing an additional ecological service for the same land conversion costs in NE Wisconsin. In combination, we predicted that the establishment of biomass production systems should be targeted at low-lying locations to maximize farm profitability, C-sequestration, and water quality benefits. We also reasoned that this targeted approach could benefit additionally from shared interest and cost-sharing with existing US Department of Agriculture (USDA)/Natural Resource Conservation Service (NRCS) conservation programs, as well as potential phosphorus (P) trading opportunities between point sources and agricultural sources within the Fox-Wolf basin through the on-going Lower Fox River (LFR) Total Maximum Daily Load (TMDL) being conducted by the Wisconsin Department of Natural Resources, the US Environmental Protection Agency, and local partners in NE Wisconsin.

We addressed our above points using three interdisciplinary objectives integrating environmental, economic, and political perspectives. Objective 1 was to quantify and compare harvestable aboveground grass biomass and crop-grain yield, associated harvestable P contents, and C and P sequestration in soil and perennial roots in established upland and lowland native-species grasslands and crop fields. Objective 2 was to model changes in erosion and stream water quality resulting from conversion of upland and lowland crop fields to native-species grasslands in NE Wisconsin watersheds. Objective 3 was to create an economic analysis of the combined value of harvestable aboveground production (biomass or grain yield) and ecological services (e.g., C- and P-sequestration and water quality changes) associated with converting upland and lowland crop fields into native-species grasslands for the LFR watershed. This study provides information critical for an informed discussion of the economic benefits and challenges associated with the implementation of biomass based energy production within NE Wisconsin.

Key findings of Objective 1: to quantify and compare harvestable aboveground grass biomass and crop yield, associated harvestable P contents, and C and P sequestration in soil and perennial belowground biomass in established upland and lowland native-species, biofuel grasslands and crop fields.

Grass biomass production potential in NE Wisconsin was competitive with values reported from the Midwest in general, while row crop production was notably lower. Grass biomass production was equal in both upland and lowland topographic positions, but production was notably reduced for row crops in low lying areas. Targeting marginal fields, defined as those containing a significant proportion of lowland, seasonally wet soils, appears a viable strategy from a pure production standpoint. Our results support the use of graminoid-dominated, diverse plantings, and we suggest greater research into the potential of specific legume selection and inclusion to meet nitrogen demands. We found no significant effect of grassland establishment on soil carbon pools, likely due to naturally slow accumulation rates, the variable nature of soil C stocks, or the lack of baseline, pre-establishment data from our grassland and row crop study plots. Soil phosphorus pools appear to have been redistributed to greater depths within grassland systems than observed in row crop fields, potentially reducing the likelihood of erosional losses of phosphorus into water bodies once row crop fields are converted to perennial biofuel grasslands. The significantly larger, and perennial, live belowground biomass present in grassland systems represents a large, and highly predictable, sequestration pool for both carbon and phosphorus, benefiting both atmospheric carbon content and phosphorus-based water quality concerns.

Key findings of Objective 2: to model changes in erosion and stream water quality resulting from conversion of upland and lowland crop fields to biofuel grasslands in N.E. Wisconsin watersheds.

We used Soil and Water Assessment Tool (SWAT) and Geographic Information System (GIS) models to simulate several agriculture-to-energy crop scenarios in NE Wisconsin. The first two scenarios targeted converting crop fields with either the highest proportions of somewhat poorly to very poorly drained soils, or the highest proportions of poorly to very poorly drained soils, respectively. However, both scenarios included incidental areas with soils classified as somewhat poorly drained, poorly drained, and very poorly drained. Somewhat poorly drained soils are generally defined as those soils that are wet at shallow depths for significant portions of the growing season, to the point that mesophytic crop growth is often limited in the absence of artificial drainage. Poorly drained soils are wetter, and are defined as those soils that are wet at shallow depths for long periods of the growing season, generally preventing the growth of mesophytic crops in the absence of artificial drainage. Very poorly drained soils are those soils that retain free water at the soil surface for much of the growing season, largely excluding the growth of mesophytic crops in the absence of artificial drainage. The third scenario targeted the somewhat poorly drained crop fields that were previously characterized to have high P yields (65 percentile of simulated phosphorus yields from the Lower Fox River watershed). We estimated that converting a modest 7% of the current agricultural cropland to energy crops would result in phosphorus reductions ranging from 4.9% to 6.5% relative to baseline loads from agricultural sources. Somewhat greater reductions were estimated for total suspended solids, with reductions ranging from 6.4% to 8.3%. Targeting crop fields that were most likely to have high P yields resulted in the greatest estimated reduction in P and total suspended solids. While the overall declines in P and total suspended solid loadings are small in comparison to the Total Maximum Daily Load (TMDL) targets for the Lower Fox River (LFR), the reductions were effective on an area-weighted management change basis.

Key findings of Objective 3: to create an economic analysis of the combined value of harvestable aboveground production (biomass or grain yield) and ecological services (e.g., C- and P-sequestration and water quality changes) associated with converting upland and lowland crop fields into native-species grasslands for Brown Co, Wisconsin.

Farm-scale returns for marginal low lying fields in the LFR sub-basin that were managed following our modeled corn silage, corn grain, soybean rotation ranged from -\$51.04 to \$29.13 per acre, while non-subsidized biofuel grasses in the same locations had returns of \$25.52 per acre. Under all modeled scenarios, biofuel grasslands offered a viable alternative crop for the Lower Fox River sub-basin, independent of subsidies. When potential subsidies were also considered, returns from planting biofuel grasslands increased by up to $100 per acre, making biofuel grasses very attractive. Regional economic impacts based upon local expenditures and revenues supported the benefits of seeking a Biomass Crop Assistance Program (BCAP) designation and the associated establishment of a pelletizing plant for the Lower Fox River (LFR) sub-basin. Impact analysis for Planning (IMPLAN) modeling suggested that implementation of these changes in concert with increased biofuel grassland production would create 46 direct jobs and generate close to $7.7 million in direct economic impact. Total economic output in the region, according to the regional impact analysis, is expected to increase by $10.1 million. However, overall employment is expected to decline, with 32 jobs lost in the region following a reduction in row crop acreage, as row crop agriculture is a more labor intensive activity than production via biofuel grasslands and pelletizing activities.

List of Abbreviations:

BCAP	**Biomass Crop Assistance Program**
C	**carbon**
CEC	**conventional energy crop scenario**
CLU	**Wisconsin DNR common land unit field boundary**
CPI	**consumer price index**
GBMSD	**Green Bay Metropolitan Sewerage District**
GIS	**Geographic Information System**
IMPLAN	**Impact Analysis for Planning Model**
LFR	**Lower Fox River**
P	**phosphorous**
PVP	**poorly to very poorly drained soils**
SVP	**somewhat to very poorly drained soils**
SVP-WQ	**somewhat to very poorly drained soils with high P yields**
SWAT	**Soil and Water Assessment Tool**
TMDL	**total maximum daily load**
TSS	**total suspended solids**

Introduction:

Our future energy needs will be met by implementing a diverse energy portfolio that includes traditional fossil fuels (coal and natural gas), nuclear, and renewables (wind, solar, geothermal, and biomass) (Turner 1999, Lehmann 2007). While many uncertainties remain, four points are clear: 1) there will be no single source solution to our future energy needs, 2) our combined energy portfolio must reduce the release of fossil C into the atmosphere, 3) the energy portfolio that we choose should maximize both economic and environmental returns per unit investment, and 4) conversion of current agricultural lands into energy-biomass production systems should be done in a way that minimizes the loss of food and fiber production. Solid biomass based fuels provide one of the more cost effective and environmentally beneficial sources of renewable energy (www.grassbioenergy.org, Olsen 2001, Snippen 2011, US DOE 2011). As coal prices increase, or as political will to reduce greenhouse gas emissions increase, biomass based energy becomes increasingly attractive and competitive, and if produced using low-input systems, biofuel production can simultaneously reduce current atmospheric CO_2 levels through C sequestration associated with plant growth and soil development (Tilman et al. 2006a).

Biomass production systems vary greatly in their environmental impacts. For example, intensive agricultural production systems rely heavily on fossil fuels to subsidize crop production through the practice of annual plantings, and pesticide, herbicide, and fertilizer applications (Odum 2007). In contrast, perennial native grasslands are low-input, high-productivity systems requiring minimal to no external inputs following establishment (Tilman et al. 2006a). Specifically, diverse grassland plantings have lower pest infestations, include N-fixing legumes that reduce grassland N demand, have higher maximum aboveground production and lower inter-annual production variability (Tilman et al. 2006b), higher soil-C sequestration rates (Fornara and Tilman 2008), and enhanced landscape biodiversity than comparable monoculture grasslands. In contrast, while single species plantings of native switchgrass also yield high aboveground biomass production (Lemus et al. 2008), these plantings are ecologically less stable, often requiring subsequent weed and pest control, or fertilization to maintain vigorous stands (Teel 1998, Parrish and Fike 2005). All additional external inputs required to maintain biomass production systems reduce the net carbon balance of biomass based energy, thereby reducing its associated environmental benefit (Tilman et al. 2006a). For this reason, we focused our analysis on multispecies, diverse native grassland plantings.

Perennial biomass production systems also provide significant water quality improvements when located strategically within the landscape (Dale et al. 2010, Robertson et al. 2011). For example, multispecies riparian buffers have been widely implemented in Central Iowa to improve stream water quality, habitat, and biodiversity (http://www. buffer.forestry.iastate.edu/). A similar program is now actively being implemented along Baird Creek in Brown Co, WI by the Brown Co. Department of Land & Water Conservation for similar justifications (http://www.co.brown.wi.us/land_conservation/LCindex_notheme.htm). These initiatives are almost universally associated with significant cost-sharing opportunities from government organizations (e.g. http://www.nrcs.usda.gov/). In most instances, annual haying of these grasslands is also permitted (Lovell and Sullivan 2006), as is the case for Brown, County within the Lower Fox River (LFR) basin. While many of these programs specifically target low lying areas for the soil and water conservation benefits reaped from their conversion into perennial systems, their frequent flooding during the spring planting period also makes them unreliable for traditional row-crop production, yet the fine textured, wet soils characterizing low-lying areas also gives them a notably high C-sequestration potential once converted into perennial grasslands (Jobbágy and Jackson 2000).

Thus, we argue that targeted plantings of diverse, perennial grasslands in low-lying, marginal agricultural areas maximizes both economic and environmental returns through cost-sharing during establishment, by converting areas supporting the least reliable agricultural production, by reducing fossil fuel inputs, by enhancing water quality benefits, and by maximizing soil C-sequestration potentials.

The objective of our project was to evaluate the economic and environmental outcomes of converting poorly drained, marginal agricultural areas into perennial, biomass yielding native grasslands in NE Wisconsin. We focused on poorly drained, marginal cropland areas for three main reasons. First, planting these areas into annual row crops is often delayed, prevented, or unprofitable in wet years. However, seasonal (spring) soil saturation is expected to maximize warm season grass production by providing ideal moisture availability during the summer growing season (Abrams et al. 1986). Second, the wetter conditions and finer textured soils (more clay) characterizing low-lying areas (Schimel et al. 1985) should maximize C-sequestration rates (Jobbágy and Jackson 2000). Establishing grasslands in these areas should also maximize C sequestration per unit lost agricultural productivity for food and fiber. Third, establishing perennial grasslands in the low-lying areas juxtapositioned between agricultural uplands and aquatic systems will also reduce nutrient and sediment loading into aquatic systems (Schultz et al. 2000), thereby providing an additional ecological service for the same conversion costs. In combination, we predicted that the establishment of biomass production systems should be targeted at low-lying locations to maximize farm profitability, C-sequestration, and water quality benefits. Due to the economic challenges often facing emerging industries (McGinnis 2008), we emphasize economic incentives for implementation that benefit from shared interests and cost-sharing with existing USDA/NRCS conservation programs, as well as potential phosphorus trading opportunities within the Fox-Wolf basin through the on-going Lower Fox River (LFR) Total Maximum Daily Load (TMDL). The three principle objectives of our project were:

1) to quantify and compare harvestable aboveground grass biomass and crop yield, associated harvestable P contents, and C and P sequestration in soil and perennial belowground biomass in established upland and lowland native-species grasslands and row crop fields;

2) to model changes in erosion and stream water quality resulting from conversion of upland and lowland row crop fields to perennial native biofuel grasslands; and

3) to create an economic analysis of the combined value of harvestable aboveground production (biomass or grain yield) and ecological services (e.g., C- and P-sequestration and water quality changes) associated with converting upland and lowland row crop fields into native-species biofuel grasslands in N.E. Wisconsin watersheds.

The report below provides an estimate of the social desirability (environmental and economic) of converting 7% of current agricultural acreage in the Lower Fox River sub-basin into perennial biofuel grasslands that can be used for heat or electrical generation.

<u>Addressing Objective 1</u>: quantify and compare harvestable aboveground grass biomass and crop yield, associated harvestable P contents, and C and P sequestration in soil and perennial belowground biomass in established upland and lowland native-species, biofuel grasslands and crop fields.

Objective 1 Results Summary:

Grass biomass production potential in NE Wisconsin was competitive with values reported from the Midwest in general, while row crop production was notably lower. Grass biomass production was equal in both upland and lowland topographic positions, but was notably reduced for low lying row crops. Targeting marginal fields, defined as those containing a significant proportion of lowland soils, appears a viable strategy from a pure production standpoint. Our results support the use of graminoid-dominated, diverse plantings, and we suggest greater research into the potential of specific legume selection and inclusion to meet nitrogen demands. We found no significant effect of grassland establishment on soil carbon pools, likely due to naturally slow accumulation rates, the variable nature of soil C stocks, or the lack of baseline, pre-establishment data from our grassland and row crop study plots. Soil phosphorus pools appear to have been redistributed to greater depths within grassland systems, than observed in row crop fields, potentially reducing the likelihood of erosional losses of phosphorus into water bodies. The significantly larger, and perennial live belowground biomass present in grassland systems represents a large, and highly predictable, sequestration pool for carbon and phosphorus, benefiting both atmospheric carbon content and phosphorus-based water quality concerns.

Brief Overview of Field Methods:

Field plots were established in the summer of 2009 within the LFR basin onto currently cropped fields (n = 6 plots) and established (25+ years old) perennial, native-species grasslands (n = 6 plots) located at higher (n = 6 plots) and lower landscape (n = 6 plots) positions. Plots established in grasslands were 15 x 5 m, while plots established in active row crop fields were 15 x 10-m. Specifically we established 3 paired upland and lowland grassland plots, and 3 paired upland and low-lying row crop plots (total of 12 plots), allowing for the examination of significant vegetation or soil properties by landscape position interactions. Paired plots were blocked according to current and past management histories to help control for undocumented differences in soils, land use histories, and other field related concerns. Study plots were located on the Kewaunee/Manawa silt loam soil association common in Northeast Wisconsin. Kewaunee soils are classified as fine, mixed, active, mesic Typic Hapludalfs and are associated with well drained upland or sloped landscape positions (Table A1). Manawa soils are classified as fine, mixed, active, mesic Aquollic Hapludalfs and are associated with somewhat poorly drained lowland and level landscape positions (Table A1). A more complete description of our study sites is provided in Appendix A.

Aboveground production in grassland plots was determined approximately one week following the first killing frost (Parrish and Fike 2005) in late October/November of 2009, 2010, and 2011 by clipping all biomass 10 cm above the soil surface (to represent mower cutting height) in 0.5 m by 1.0 m quadrats. An additional sample collection occurred at peak standing biomass in early August 2011 to evaluate temporal changes in aboveground biomass throughout the second half of the growing season. Aboveground biomass for corn silage was clipped 20.32 cm above the soil surface (representing combine head height) in September of 2009 just prior to commercial harvest using 0.76 m by 0.80 m quadrats to account for row size. Aboveground biomass in winter wheat was clipped 10 cm above the soil surface (to represent mower cutting height for straw) in July 2010 in 0.76 m by 0.80 m quadrats. Irrespective of topographic position or vegetation type, six aboveground biomass samples were collected per plot and collection time. Samples were returned to the laboratory, where moisture corrected yield was calculated from 65°C dry biomass weights that were estimated to contain 2% residual moisture. A constant of 60 pounds per bushel was used to convert wheat grain yields from a mass to volume basis (Conley et al. 2010). Plant species richness in grassland plots was determined in three 1 m by 1 m quadrats per plot in June and October of 2011.

For both grasslands and row crops, soil C, P, bulk density, and soil texture were determined from 40-cm deep soil cores collected in 2009 and 2010 (n = 12 total per plot) with a 6.2 cm inner diameter steel soil corer. Soil cores were divided into four 10-cm depths, returned to the lab, then sieved through a 2 mm mesh screen to remove gravel and large organic debris. Soils were then subdivided for root and soil property analyses. Bulk density calculations were corrected for gravel content and soil pH was determined in a 1:1 soil-to-water ratio. Soil C was analyzed by combustion and corrected for inorganic C content at 900°C using a Shimadzu SSM-5000A/TOC-V CSH (Shimadzu Corporation, Kyoto, Japan), and Bray 1 P (soil P-available P) was determined on a Lachat Quikchem 8500 (Hach Company, Loveland, CO, USA).

Root biomass was determined following the protocol of Dornbush et al. (2002), with C content determined in a manner identical to organic soil samples. Root P content was determined following the method of Schulte et al. (1987). Root production in grassland plots was determined using a modified root ingrowth procedure of Jordan and Escalente (1980), with six ingrowth cores per plot for the winter (November 2009 to April 2010), early summer (April 2010 to July 2010), and late summer (July 2010 to November 2010) seasons. Due to the annual nature of the row crops studied (corn silage and winter wheat), we assumed that root biomass present just prior to crop harvests represented annual root production (Russell et al. 2009). All root production cores were processed following the procedures of Dornbush et al. (2002). All root biomass data is presented on a 65°C dry mass basis.

Annual Aboveground Production in Annual Row Crop Systems and Perennial Native Grasslands:

Annual Row Crops:

General Patterns of Row Crop Yield:

Our study sites were planted to corn silage in 2009 and winter wheat in 2010. Averaged across all plots, corn silage in 2009 yielded an average of 10.8 ± 2.9 short tons per acre (861.9 ± 236 g m^{-2}), but was highly variable ranging from a low of 0.6 short tons per acre to a maximum of 19.0 short tons per acre (Table 1). Reported silage yield for Brown County, WI in 2009 was 14.0 short tons per acre, slightly lower than the expected average yield of 16.2 short tons per acre for the county based solely on historic trends (average yield = 0.1793(calendar year) - 343.99; $R^2 = 0.48$; http://www.nass.usda.gov/Data_and_Statistics/Quick_Stats/ for 1970-2009). Thus, 2009 represented a slightly lower than average production year for corn silage in Brown County, WI, and our study sites yielded less than reported county wide averages (Appendix B). The latter point confirms that our plots were successfully established in marginal fields, a point further emphasized below. In general, Brown, Co. WI lies along the northern most range of corn grain production in the US, with yields notably lower than in central Corn Belt areas of southern Wisconsin, Iowa, and Illinois (http://www.nass.usda.gov/

Charts_and_Maps/Crops_County/index.asp). Corn silage harvest removed approximately 22.3 ± 1.6 kg P ha^{-1}.

Wheat grain yield in 2010 averaged 63.3 ± 15.5 bushels per acre (377.9 ± 92.6 g m^{-2}) across all plots, but as with corn silage, yield was highly variable. Our lowest yielding plots produced approximately 6.9 bushels per acre, while high yielding plots reached 102.2 bushels per acre. Wheat straw followed similar patterns, averaging 1.3 ± 0.3 short tons per acre (256.2 ± 61.4 g m^{-2}), ranging from a low of 0.2 short tons per acre to a high of 2.0 short tons per acre (Table 1). Brown Co., WI averaged 74.5 bushels per acre for the 2010 harvest, above expectations of 66.3 bushels per acre based solely on historic trends (average yield = 0.869(calendar year) - 1679.5; $R^2 = 0.61$; http://www.nass.usda.gov/Data_and_Statistics/Quick_Stats/for 1970-2009 planting date). Patterns observed for corn were again reflected in the 2010 winter wheat harvest, with slightly lower than average yields in our plots relative to county wide averages, with strong inter-plot variation in total production. As with corn data, our wheat yields are also modest, relative to those reported for other wheat producing counties in the US, where winter wheat yields often exceed 80 bushels per acre (http://www.nass.usda.gov/Charts_and_Maps/Crops_County/index.asp). A combined harvest of winter wheat straw and grain would remove 21.7 ± 1.1 kg P ha^{-1} from row crop systems, which is surprisingly similar to P removal via corn silage harvest (22.3 ± 1.6 kg P ha^{-1}). Approximately half of this P is removed via straw (10.5 ± 1.4 kg P ha^{-1}) and half via grain (11.7 ± 0.6 kg P ha^{-1}).

Table 1. *Moisture corrected harvestable aboveground production (mean ± standard error) from well drained (upland) and somewhat to very poorly drained (lowland) areas in Brown, Co., WI. Each vegetation type had three independent, paired upland and lowland study plots.*

Year	**Vegetation Type**	**Topography**	**Mean Yield**	**Yield Units**	**Moisture Content (%)**
2009	Corn Silage	Upland	16.67 ± 1.29	short tons/acre	65
2009	Corn Silage	Lowland	4.86 ± 2.62	short tons/acre	65
2010	Wheat grain	Upland	92.93 ± 6.02	bushels/acre	13
2010	Wheat grain	Lowland	33.66 ± 16.97	bushels/acre	13
2010	Wheat straw	Upland	1.97 ± 0.03	short tons/acre	16
2010	Wheat straw	Lowland	0.70 ± 0.33	short tons/acre	16
2009 to 2011	Grassland	Upland	1.90 ± 0.24	short tons/acre	16
2009 to 2011	Grassland	Lowland	2.25 ± 0.28	short tons/acre	16

Note: All moisture contents were standardized on a wet weight basis ((wet-dry)/wet), as is common in agricultural practices.

Topographic Position Effects on Row Crop Yield:

Variation in row crop production for both corn silage (ANOVA; $F = 11.75$, $P = 0.076$) and winter wheat grain (ANOVA; $F = 15.45$, $P = 0.059$) and straw (ANOVA; $F = 15.87$, $P = 0.058$) were marginally significantly different between topographic position, with yields notably higher in upland plots in both years and with both crops. Corn silage production in lowlands averaged 29.1% of upland plots, while wheat grain and straw production averaged 36.2% and 35.6%, respectively, in lowland relative to upland plots. Corn silage averaged 16.7 ± 1.3 short tons per acre in uplands, and 4.9 ± 2.6 short tons per acre in lowlands. Wheat grain averaged 33.6 ± 17.0 bushels per acre in lowlands and 92.9 ± 6.0 bushels per acre in uplands. Wheat straw yielded 0.7 ± 0.3 short tons per acre in lowlands and 2.0 ± 0.0 short tons per acre in uplands. Our results are reflected by the few previous studies investigating the effects of small changes in relief and drainage on row crop production. For example, Thelemann et al. (2010) found that corn grain yields in areas prone to water accumulation yielded only 60 to 67% that of better drained areas of the same field. They also reported similar reduction for corn stover and alfalfa. In general the small physical area of each individual lowland swale within fields suggests that farmers are expending full growing expenses for these areas, at a net, underappreciated expense to farmers.

Perennial Native Grassland:

General Patterns of Perennial Native Grassland Yield:

Averaged across two growing seasons, and both lowland and upland landscape positions, grassland production was 371.4 ± 23.9 g m^{-2} yr^{-1} (mean ± SE; 65°C dry mass). This value is in close agreement with the expected 410 g of organic matter production per year based on the widely cited equation of Sala et al. (1988), where grassland annual aboveground production (g/m^2) = -34 + 0.6*(annual precipitation in mm) with an annual average annual precipitation of 741.4 mm for Green Bay, WI (http://www.weather.gov/). Converting our reported 65°C biomass values to a standard moisture content of 16% for biofuels (Anonymous 2007), yielded an average production of 4.33 ± 0.28 t $ha^{-1}yr^{-1}$ (1.9 ± 0.1 short tons per acre year). Based on aboveground P contents (%) from our grassland sites (0.13 ± 0.01% P), commercial harvesting would remove approximately 4.87 ± 0.41 kg P ha^{-1} yr^{-1}, or roughly 4.34 lbs $acre^{-1}$ yr^{-1}. Our reported yield values are very similar to switchgrass (*Panicum virgatum*) yields for mixed-species plantings predicted from annual precipitation by Wang et al. (2010), but are notably lower than the roughly 10 t ha^{-1} yr^{-1} (4.5 short tons per acre year) reported for intensively managed switchgrass monocultures in the Midwest (Renz et al. 2009; Jain et al. 2010; Wang et al. 2010). This point was also stressed in the recent U.S. Billion Ton Update (US DOE 2011), noting that managed switchgrass monocultures can produce 1.5 to 5 times more biomass than unmanaged grasslands. Applying our P content data to production estimates from more intensively managed grassland systems (e.g. 4.5 short tons per acre year; Renz et al. 2009; Jain et al. 2010; Wang et al. 2010), suggests that managed grasslands would remove approximately 11.5 kg P ha^{-1} yr^{-1}, or roughly 10.3 lbs $acre^{-1}$ yr^{-1}, from the watershed. Several important factors that deserve discussion contribute to the lower yield of our high diversity grassland plantings relative to higher input switchgrass monocultures reported elsewhere.

Stand Age Effects on Perennial Native Grassland Yield:

One clear explanation for the lower yields reported from our restored native grasslands relative to those reported from dedicated production systems relates to the age of our grassland. In general, intensively managed switchgrass plantings are re-established every 10 years (US DOE 2011). The restored grassland that we sampled on the University of Wisconsin-Green Bay campus ranged in age from 27 to 36 years old. Baer et al. (2003) found that aboveground production in 3 year old planted native grassland was approximately 125% that of the most productive areas in neighboring natural grasslands in Kansas, USA. Observed differences were further exasperated by nitrogen addition, suggesting that nutrient limitation contributed significantly to these patterns (Baer et al. 2003). Irrespective, old age, and a lack of active management for aboveground growth in our restored grasslands likely reduced the yields that we report from that of the maximum possible yields for our region from either managed monocultures or managed mixed species plantings. It should be noted however, that even at our site, the highest yielding plots that we recorded (3.71 short tons acre^{-1}) fell within the range of values reported for managed systems elsewhere (e.g. Renz et al. 2009), suggesting strong potential for yield production within the marginal lands we targeted in this study.

Plant Composition and Richness Effects on Perennial Native Grassland Yield:

Plant species richness in our study plots ranged from 10 to 20 species m^{-2}, with an average of 14.7 ± 1.4 species m^{-2}. Thus, all of our study plots have high diversity, falling within the species richness level where richness benefits to annual aboveground production are expected to be saturated (Tilman et al. 1997; Tilman et al. 2001). Not surprisingly, we found no relationship between plot richness and fall aboveground biomass ($F = 3.86$, $P = 0.12$, $R^2 = 0.49$), although the relationship was negative (aboveground biomass = 796.28 – 23.44 g m^{-2} (species richness)). It should be noted that the saturating relationship between richness and ecosystem services observed for aboveground production is not expected to hold true as the number of ecosystem services evaluated increases (i.e. as you consider more than just aboveground production), or as the number of years considered increases. In the first case, because different species most significantly affect different ecosystem services, more species are needed to maximize a suite of ecosystem services, than are needed to maximize any single ecosystem service (Zavaleta et al. 2010). Likewise interannual variation in aboveground production has also been shown to decline with increasing plant diversity, due to species specific responses to interannual variations in climate or other environmental factors (Tilman et al. 2006b). While the short duration of our study (3 years) precludes us from testing the relationship between inter-annual variability and plant richness, it is likely that the overall high diversity of all of our plots would contribute to a greater stability of inter-annual aboveground production, relative to lower diversity, monocultures, considering external energy inputs are held relatively similar.

One of the more important compositional effects on aboveground yield was the significant relationship ($F = 8.68$, $P < 0.05$, $R^2 = 0.68$) between fall graminoid dominance and fall aboveground yield. In 2009, 2010, and 2011, aboveground biomass, and percent graminoid and forb biomass, was determined from annual harvests that occurred approximately one week following the first killing frost (the last week of October or the first week of November). In 2011 an additional biomass harvest occurred in August, at the time of maximum standing biomass in our plots. Interestingly, rather than higher graminoid composition simply yielding higher production, it appears that graminoid dominated plots also had a greater fall yield because graminoids more effectively retained their biomass from peak standing crop in summer until our late fall harvest ($F = 17.4$, $P < 0.02$, $R^2 = 0.81$). For example, our most forb dominated plot consisted of roughly 95% forbs by mass at peak standing crop, and in this plot November harvests yielded only 62% of the August yield for the same plot (Figure 1). In contrast, our most graminoid dominated plot was approximately 95% graminoid by mass at peak standing crop, and its November yield was approximately 100% of the biomass recorded in August for that same plot (Figure 1). Averaged across all native grassland plots, post-killing frost harvests averages approximately 74% of peak standing biomass. Similar seasonal relationships have been reported for tallgrass prairie by Knapp et al. (1998), suggesting that yields from forb-rich plots may be more competitive if harvests occur earlier in the season, although this would eliminate the nutrient retention benefits underlying the current practice of harvesting after the first killing frost (Gibson 2007). It should be noted that late fall harvest represent typical best management practices for biomass production systems, owing to the greater nutrient resorption into perennial biomass, and for reducing competition between biomass crops and row crops for harvesting equipment (Heaton et al. 2009). Our results suggest that diverse mixed-graminoid plantings have a high production potential at levels competitive with more intensively managed monocultures. Consideration of best plantings for NE Wisconsin must further consider the unquantified benefits to yield resulting from low intensity nutrients inputs, such as mixed plantings with abundant legumes or manure application.

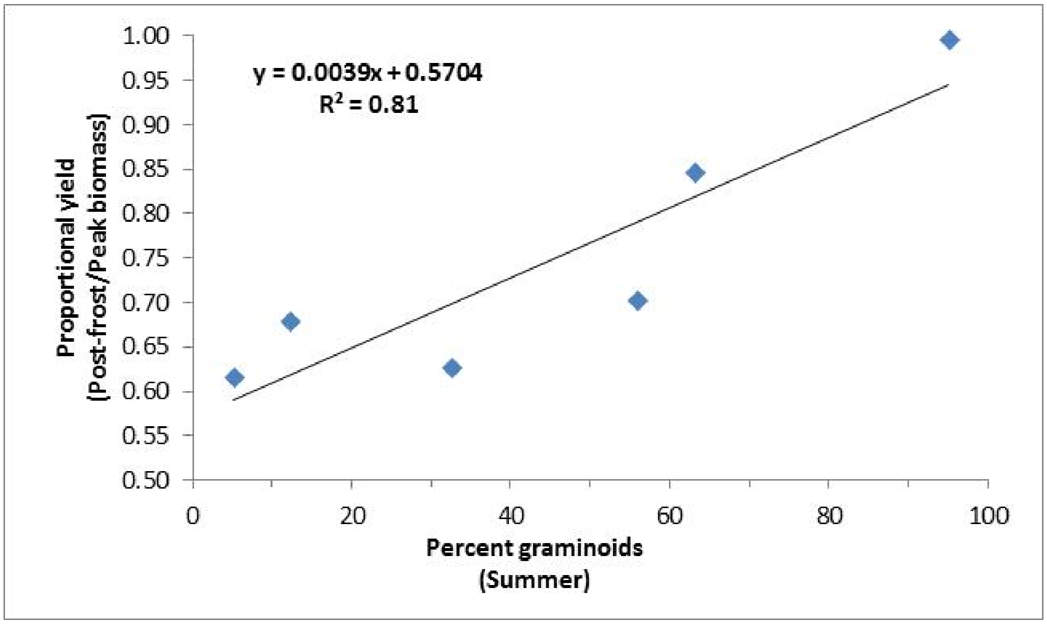

Figure 1. *Relationship between proportional yield of native grassland biomass (harvests one week following the first killing frost relative to harvests at peak standing biomass) and graminoid dominance. All samples were taken in 2011.*

Nutrient Effects on Perennial Native Grassland Yield:

In general fertilizer additions have been shown to increase established tallgrass prairie yields by 46-91% in burned and 2-16% in unburned prairie in Kansas, USA (Knapp et al. 1998). Our grassland sites are burned at irregular intervals, which in general show intermediate (~45% increase) responses to N-fertilization (Seastedt et al. 1991). Annual haying approximates burned conditions, by increasing nitrogen removal and increasing spring soil temperatures, thereby favoring warm season grass production over that of cool season forbs and grasses (Knapp et al. 1998). Irrespective, only two of our plots were burned in the spring prior to the 2009 growing season, with others receiving no biomass removal since spring 2004 or spring 2006 (*G. Fewless unpublished data*). These plots have also not received fertilizer applications for at least as long as the grassland has been established (27-36 years). Irrespective our diverse native grasslands yielded a respectable average yield of 1.9 ± 0.1 short tons per acre year. Published yield estimates for intensively managed switchgrass monocultures for our climate are slightly more than double these yield estimates (4 to 4.5 short tons per acre year; Renz et al. 2009; Jain et al. 2010; Wang et al. 2010), suggesting significant potential for yield improvement through fertilization. Recommended annual N fertilizer application rates for switchgrass monocultures in the Midwest US range from 100 lbs per acre (Gibson 2007) to as little as 54 lbs per acre (US DOE 2011). It should be noted that any realized yield benefits from artificial fertilizers would come at the expense of a greater fossil fuel footprint. Alternatively, Wang et al. (2010) reported that switchgrass dominated mixtures containing legumes produced yields that were roughly 90.8% of the yield of fertilized switchgrass monocultures. Based on our field observations and published estimates of N-fixation rates by prairie legumes (Becker and Crockett 1976, Tlusty et al. 2004) suggests that vertically structured native legumes such as prairie bushclover *(Lespedeza capitata*) or the tickseeds (*Desmodium* spp.), or alternatively vine-like legumes, such as *Vicia* spp., might be viable candidates for inclusion within mixed grass-legume production plantings. Finally, for dairy dominated NE Wisconsin, significant effort should be devoted to understanding the potential benefits and feasibility of manure application to yield in managed biofuel grasslands. Manure application is expected to reduce the need for fossil-fuel based fertilizers, and provide a sustainable and cost-effective option for manure disposal.

Topographic Position Effects on Perennial Native Grassland Yield:

Averaged across two growing seasons, upland grasslands produced an average of 338 ± 27 g/m^2, while lowland plots averaged roughly 405 ± 37 g/m^2 (mean ± SE; 65°C dry mass). Converting 65°C mass to a standard moisture content of 16% for biofuels, yielded an upland production of 3.95 $t\ ha^{-1}yr^{-1}$ (1.8 ± 0.1 short tons per acre year) and a lowland production of 4.73 $t\ ha^{-1}yr^{-1}$ (2.1 ± 0.2 short tons per acre year). Neither year, nor topographic position were statistically significant (Year: $F = 0.34$, $P > 0.5$; Topography: $F = 5.43$, $P > 0.14$), highlighting the potential for significant and consistent grass production across strong soil moisture gradients in NE Wisconsin. In NE Wisconsin, clay rich soils with low topographic relief are both common (USDA Web Soil Survey; http://websoilsurvey.nrcs.usda.gov/) and our most marginal lands for row crop production systems. Low-lying areas in these fields are commonly flooded during spring planting, or flood soon after, resulting in significant loss of row crop production with constant planting costs (see *Topographic Position Effects on Row Crop Yield*). Our data provide strong evidence that perennial graminoids are largely unaffected by these marginal conditions, making them ideal candidates for use in land conversion for biofuel production.

Our study focus on diverse native grassland plantings likely played a primary role in our observation of consistent aboveground yields across strong soil moisture gradients. For example, in 2010 growing season (May to November) surface soil moisture varied considerably among grassland plots, ranging from 32.0% to 48.2% volumetric moisture, and averaging 44.4 ± 2.9% in lowland plots and 33.5 ± 0.9% in upland plots (Table 3). Associated with difference in moisture between upland and lowland plots, we found a marginally significant difference in species richness between upland and lowland plots (ANOVA; $F = 10.57$; $P > 0.08$), with lowland and upland plots averaging 12.9 and 16.4 species, respectively. We also found significant species turnover among our plots, both within and between upland and lowland plots, which were further associated with notable changes in the identity of dominant species (*unpublished data*). In support of this point, Thelemann et al. (2010) found decreased production in switchgrass stands growing in seasonally flooded areas, relative to stands growing in better drained portions of the same fields. For these reasons, we suggest that any targeted production systems for biofuels in the low-topographic relief, high clay soils of NE Wisconsin should consider the potential benefits of planting mixed-graminoid species to accommodate the inherently variable growing conditions within these fields. For example, mixed graminoids consisting of switchgrass (*Panicum virgatum*), indian grass (*Sorgastrum nutans*), and big bluestem (*Andropogon gerardii*) may be ideal for better drained soils, while mixtures of prairie cordgrass (*Spartina pectinata*), common lake sedge (*Carex lacustris*), and river bulrush (*Bolboschoenus* (*Scirpus*) *fluviatilis)* might be needed for lowland settings.

Belowground Biomass and Annual Belowground Production in Annual Row Crops and Perennial Native Grasslands:

General Patterns of and Topographic Position Effects on Belowground Biomass in Annual Row Crops and Perennial Native Grasslands:

Belowground biomass was sampled in late-fall 2009 and 2010 in native grassland, and just prior to agricultural harvest of corn silage in mid-September, 2009, and winter wheat in July, 2010, and thus likely represent maximum belowground biomass for each system (Tufekcioglu et al. 2003). Total belowground biomass (rhizomes plus roots to 40 cm) differed significantly among vegetation types (F = 96.31; $P < 0.001$). Belowground biomass was greatest in grasslands, averaging 1,148.3 ± 115.5 g OM m^{-2}, followed by corn (279.6 ± 41.1 g OM m^{-2}) and winter wheat (178.2 ± 34.9 g OM m^{-2}). These values are nearly identical to the values reported by Tufekcioglu et al. (2003) for switchgrass (*Panicum virgatum*; 1,222.2 g OM m^{-2}) and corn (285.6 g OM m^{-2}) for the top 35 cm of soil in central Iowa, USA. In our study, native grassland biomass was significantly greater than both corn and wheat, but corn and wheat belowground biomass did not differ significantly from each other ($\alpha = 0.05$).

Despite significant differences in total belowground biomass among dominant plant communities, grassland, corn, and wheat all responded in a similar manner to topographic position (Vegetation-by-Topographic interaction term: $F = 0.10$; $P > 0.9$), with total belowground biomass not differing between upland and lowland topographic positions ($F = 0.05$; $P > 0.8$). These patterns agree with observed patterns in above ground biomass for grassland plots in upland and lowland positions, but contrast strongly with observed patterns for aboveground production in both corn and wheat. The similarity in corn and wheat belowground biomass between upland and lowland positions is most likely due to the large abundance of weed biomass present in lowland areas (*unpublished data*). While it was possible to separate out crop and weed biomass for aboveground pools, it was not possible to do so for belowground systems. Irrespective, averaging across upland and lowland plots, perennial native grasslands carried roughly 411% and 644% of the belowground biomass that was recorded in the top 40-cm of soil for corn silage and wheat systems, respectively. Such large differences in belowground biomass and perennial (grassland) verses annual (corn and wheat) root systems have significant implications for the potential storage of C and P in these systems.

General Patterns of and Topographic Position Effects on Annual Belowground Production in Annual Row Crops and Perennial Native Grasslands:

Annual belowground production in the top 40-cm of soil averaged 413.8 ± 59.9 g OM m^{-2} in native grassland, 279.6 ± 41.1 g OM m^{-2} in corn silage, and 178.2 ± 51.3 g OM m^{-2} in winter wheat. Belowground production was marginally significantly different among crop types ($F = 4.34$, $P = 0.099$), but did not differ based on topographic position ($F = 0.37$, $P > 0.5$). As was observed with belowground biomass, topographic patterns in belowground production matched aboveground production for the grassland, but not for corn silage or winter wheat; again likely due to compounding effects of weed growth in the lowland row crop plots. Tukey-Kramer adjusted comparisons found a marginally significant difference between grassland and winter wheat ($P = 0.089$), but no difference between either corn silage and winter wheat or corn silage and grassland ($P > 0.3$). In the case of corn silage and winter wheat, production values represent the maximum biomass accumulated during crop growth, and upon harvest, live biomass pools will quickly return to zero. Thus, row crop systems experience a complete turnover of belowground biomass on an annual basis. In native grassland, belowground production equaled roughly 38% of total standing biomass, suggesting that complete root turnover occurs every 2.65 years. Thus, perennial grassland root systems provide both a large annual input, and a very stable inter-annual pool of belowground biomass for the sequestration on C and P. Considering regional water quality concerns with P loss from soils (Cadmus 2011), root biomass in perennial biomass crops is likely to serve as an effective, inexpensive tool for rapidly reducing, and reliably storing P out of the leachable and erodible soil pool.

Belowground Biomass C and P Pools in Annual Row Crops and Perennial Native Grassland:

Using a weighted average across all rhizome and root diameter classes, live belowground biomass C content (%) differed significantly ($F = 26.72$, $P < 0.005$) among grassland, corn silage, and winter wheat (Table 2). Biomass carbon content decreased from grassland and corn to winter wheat. Carbon content also differed between upland and lowland topographic positions ($F = 8.20$, $P < 0.03$), although this difference may have been driven by the presence of weed roots in crop lowland positions, as grassland root C was indistinguishable in upland and lowland positions (Table 2). Accounting for C content and biomass differences among vegetation types, C storage in belowground biomass differed significantly among vegetation types ($F = 83.26$, $P = 0.0006$), but not topographic positions ($F = 0.03$, $P > 0.87$; Table 2). Grassland belowground systems sequestered approximately 448.6 ± 51.2 g C m^{-2} in the top 40-cm of soil alone. All belowground biomass in winter wheat and corn silage are returned to the soil on an annual basis. In contrast, belowground systems in grassland are perennial, and thus stable. Therefore, belowground C-storage values in native grassland represent stable, net C sequestration, so long as the perennial grasslands remain in place. The top 40 cm of native grassland soils in the Midwest, US generally hold between 70% and 90% of total root biomass (Tufekcioglu et al. 2003; Buyanovsky et al. 1987). As such, if we assume conservatively that we captured 90% of total belowground biomass in our 40-cm soil cores, then extending the belowground biomass pool to its full size suggests that a minimum of an additional 50 g C m^{-2} is likely stored in belowground biomass below 40 cm in our grassland soils. Irrespective, confining a comparison to the top 40 cm that we sampled, suggests that belowground biomass C is a relatively significant pool, representing 7.9 ± 1.5% of the soil C pool in grassland, ranging from a low of 2.3% in our grassland plot with the highest soil C content to a high of 13.4% in the grassland plot with the lowest soil C content. While clearly not as large as the soil C pool, we were able to easily measure large and significant changes in the belowground biomass C pool in our grasslands, relative to crop systems; an important consideration for any C-monitoring programs linked to economic incentives.

Weighted biomass P content (%) was marginally significantly different among vegetation types ($F = 5.78$, $P = 0.066$), but did not differ between upland and lowland topographic positions ($F = 0.53$, $P > 0.49$). Belowground biomass in the grassland had the highest P content, followed by wheat and corn (Table 2). Combining belowground biomass values with P content, produced significant differences in belowground P contents among vegetation types ($F = 144.29$, $P = 0.0002$), but not between upland and lowland positions ($F = 0.04$, $P > 0.83$). Grassland belowground biomass sequestered an average of 2.29 ± 0.36 g P m^{-2} (Table 2), or roughly 23 kg of P ha^{-1} (20.4 lbs $acre^{-1}$). Again the perennial nature of the belowground pool of our mixed-species grassland suggests that conversion of current row crop agricultural land into biofuel grasslands would remove a notable portion of potentially erodible or leachable P from the soil and sequester it into a stable, perennial root system. Considering that P removal via corn silage and winter wheat (straw and grain) crops in our study removed approximately 22.3 ± 1.6 kg P ha^{-1} yr^{-1} and 21.7 ± 1.1 kg P ha^{-1} yr^{-1}, respectively, the rapid removal of P into live belowground biomass pools of perennial native grassland represents approximately one year's worth of P removal via corn silage or winter wheat (grain plus straw) harvesting. Over the long term, aboveground biomass removal for biofuel use is predicted to remove an additional 4.87 ± 0.28 kg P ha^{-1} yr^{-1} from our grassland systems (Section: *General Patterns of Perennial Native Grassland Yield*).

Table 2. *Belowground biomass (roots plus rhizomes) properties for the top 40 cm of the soil profile for upland and lowland study plots in row crop fields and perrennial native grassland in Brown Co., WI. Each vegetation type had three independent, paired upland and lowland study plots.*

Vegetation Type	**Topography**	**Belowground Biomass ($g\ m^{-2}$)**	**Belowground Carbon (%)**	**Belowground Carbon ($g\ m^{-2}$)**	**Belowground Phosphorous (%)**	**Belowground Phosphorous ($g\ m^{-2}$)**
Corn Silage	Upland	284.6 ± 44.7	35.9 ± 0.5	102.6 ± 17.6	0.11 ± 0.01	0.31 ± 0.06
Corn Silage	Lowland	274.6 ± 80.2	38.0 ± 0.7	104.6 ± 31.0	0.15 ± 0.02	0.41 ± 0.15
Winter Wheat	Upland	176.8 ± 20.5	24.1 ± 1.0	43.0 ± 6.5	0.15 ± 0.03	0.27 ± 0.07
Winter Wheat	Lowland	179.5 ± 75.3	32.1 ± 3.8	59.9 ± 30.2	0.14 ± 0.02	0.27 ± 0.15
Grassland	Upland	1080.0 ±147.7	38.8 ± 0.7	419.4 ± 61.2	0.19 ± 0.02	1.94 ± 0.07
Grassland	Lowland	1216.6 ± 200.5	38.9 ± 1.4	477.7 ± 92.2	0.23 ± 0.06	2.64 ± 0.72

Table 3. *General soil properties (mean ± standard error) averaged across the top 40 cm of the soil profile for upland and lowland study plots in row crop fields and perrennial native grassland in Brown Co., WI. Each vegetation type had three independent, paired upland and lowland study plots.*

Vegetation Type	**Topography**	**Volumetric Moisture (%)**	**pH**	**Soil Texture Sand (%)**	**Silt (%)**	**Clay (%)**
Row Crop	Upland	29.5 ± 1.1	6.8 ± 0.3	47.9 ± 5.7	35.1 ± 6.1	17.0 ± 2.1
Row Crop	Lowland	38.2 ± 1.2	7.5 ± 0.1	32.5 ± 12.0	36.6 ± 1.5	30.9 ± 10.5
Grassland	Upland	33.5 ± 0.9	6.1 ± 0.0	55.1 ± 10.0	31.1 ± 3.7	13.9 ± 7.1
Grassland	Lowland	44.4 ± 2.9	7.3 ± 0.2	40.5 ± 0.8	34.3 ± 2.4	25.3 ± 1.8

Soil C, P, and General Soil Properties in Annual Row Crops and Perennial Native Grassland:

In support of our experimental design, we found no significant differences in sand ($F = 0.35$, $P = 0.61$) or clay ($F = 0.25$, $P = 0.67$) content between row crop and grassland plots for the combined 0-40 cm profile (Table 3). Likewise, neither sand ($F = 4.41$, $P = 0.10$) nor clay ($F = 4.10$, $P = 0.11$) differed significantly between upland and lowland plots, suggesting strong support that our site selection successfully mitigated unintentional effects due to soil texture. In further support of sound site selection, we found no significant differences in soil moisture between grassland and row crop sites ($F = 7.92$, $P = 0.11$), with lowlands significantly wetter than upland plots in both vegetation types ($F = 34.81$, $P < 0.005$), as expected (Table 3).

The 30 odd years of vegetative differences between our two study sites does appear to have imparted significant changes to soil properties more directly amenable to modification by biological activity. For example, soil pH differed significantly between grassland and row crop systems ($F = 26.53$, $P < 0.04$), although it also differed between upland and lowland topographic positions ($F = 19.50$, $P < 0.02$). In general, grassland soils had lower pH than row crop soils, and uplands had a lower pH than lowlands (Table 3). More important however, was the significant effect of vegetation type on the total soil mass captured within our 40-cm soil cores (Table 4). Grassland soils held significantly less soil in the top 40 cm, than row crop soils ($F = 18.36$, $P < 0.05$), but soil mass in the top 40-cm of soil did not differ between upland and lowland positions ($F = 1.45$, $P > 0.29$). Averaged across upland and lowland plots, crop soils held approximately 582.79 ± 20.41 kg of soil m^{-2}, while grassland soils held 508.69 ± 25.21 kg of soil m^{-2} (Table 4). Thus, changes in bulk density in response to long-term grassland establishment have reduced surface soil mass (0-40 cm) to only 87% that of existing crop fields. These changes in soil mass must be accounted for in comparisons of soil C and P sequestration or loss between grassland and row crop sites (Paul et al. 2001).

To account for differences in soil mass, we modeled cumulative soil C and soil plant-available P (Bray 1 P) mass as a function of cumulative soil mass using a single factor rise to maximum exponential model (SigmaPlot 11.0, Systat Software, Inc., Chicago, IL, USA) for each of our study plots (n = 12 models). All soil C models were significant (average $P < 0.007$; ranging from $P = 0.0003$ to $P = 0.027$) with very strong fits to our data (average $R^2 = 0.99$; ranging from $R^2 = 0.95$ to $R^2 > 0.99$). With the exception of one plot with a significance of $P = 0.06$, soil P models were also all significant at $\alpha = 0.05$ (average $P = 0.013$; ranging from $P = 0.06$ to $P = 0.0012$) and fit the data well (average $R^2 = 0.97$; ranging from $R^2 = 0.88$ to $R^2 = 1.0$). As the highest soil bulk density was observed in upland row crops, we used those values as our presumed pre-grassland, agricultural bulk density (Paul et al. 2001), then compared modeled cumulative soil C and P values based on typical soil masses for upland row crops at 10-cm, 20-cm, 30-cm, and 40-cm depths (Table 4).

Soil C Pools in Annual Row Crops and Perennial Native Grasslands:

Despite 30 years of grassland development, we found no significant difference in soil C storage between grassland and row crop dominated systems for the top 40-cm (605 kg soil m^{-2}) of the soil profile ($F = 0.04$, $P > 0.8$). Grassland soils averaged 7.1 ± 1.6 kg C m^{-2}, while row crop soils averaged 6.8 ± 0.7 kg C m^{-2} (Table 4). As expected, soil C values were extremely variable, with the highest C content found in a lowland grassland plot with 15.1 kg C m^{-2}, and the lowest C content found in a lowland grassland plot at 4.5 kg C m^{-2}. In contrast to our expectations, we also found no significant effect of topographic position on soil C content ($F = 3.12$, $P > 0.15$). The lack of significance was again likely attributed to the variable nature of soil C among plots, as observed trends generally agreed with our expectations, with uplands averaging 6.2 ± 1.6 kg C m^{-2} and lowland soils averaging 7.7 ± 1.6 kg C m^{-2} (Table 4). Vegetation type did have a marginally significant effect on soil C content within the soil profile ($F = 2.51$, $P = 0.0832$), with higher soil C contents recorded in the surface of grassland soils before diminishing to similar values in crop and grassland soils with depth. A similar significant effect was also found between upland and lowland positions ($F = 3.86$, $P < 0.03$), with higher average C contents in lowland plots, although differences again diminished with increasing depth.

Three key conclusions can be drawn from our soil and belowground biomass C analysis. First, despite significant differences in long-term management, 30 odd years of vegetative differences were insufficient to affect strong changes to soil C pools throughout the top 40-cm of the soil profile. Previous work has found that most changes to soils following conversion of row crop systems to perennial grasslands are restricted to only the very top of the soil profile (Baer et al. 2002; Kucharik 2007; Matamala et al. 2008). Our results agree with these trends, for both upland and lowland plots, suggesting that short-term changes in soil C storage following conversion to perennial grasslands will be small and very difficult to detect, even in our high clay soils. Second, while not significantly different, the absolute largest soil C contents were found in lowland systems, with no significant difference in either belowground biomass, or aboveground production, suggesting that biofuel programs aimed at simultaneously maximizing soil C storage should focus on lowland systems. Finally, despite the fact that soil C represents the largest total C pool in our study, changes in belowground biomass pools far outstripped any potential changes to soil C pools that have occurred over the last 30 years (see *Belowground Biomass C and P Pools in Annual Row Crops and Perennial Native Grassland Section*), suggesting a greater emphasis for managing systems for maximum belowground biomass when C sequestration is a primary goal.

Soil P Pools in Annual Row Crops and Perennial Native Grassland:

We found no significant effect of vegetation type ($F = 0.57$, $P = 0.53$) or topographic position ($F = 1.57$, $P = 0.28$) on soil plant-available P (Bray 1 P) content (Table 4). However, vegetation type ($F = 4.74$, $P < 0.01$), topographic position ($F = 10.20$, $P = 0.0002$), and the interactive effect of vegetation type and topographic position ($F = 2.76$, $P = 0.0643$) all affected the distribution of plant-available P within the soil profile. In general, soil P was more concentrated in the surface soils in lowland plots, while more evenly distributed in upland plots. These trends were further amplified in grassland soils, relative to crop soils. The net effect was that while upland soils trended toward greater soil P content (22.68 ± 6.25 g P m^{-2}) than lowlands (11.00 ± 2.13 g P m^{-2}), any additional P in upland plots was located proportionally deeper in the soil profile. For a similar total available P pool in the top 40 cm of the soil profile, upland grassland soils had proportionally more P with depth, than row crop upland soils. Relative to C, a smaller proportion of total system P was stored in soil, relative to belowground biomass. For example, belowground biomass P represented an average of 21.9 ± 2.7% of the soil P pool in grassland, ranging from a low of 4.3% in the grassland upland plot with the highest soil P content to a high of 47.5% in a grassland lowland plot with relatively average soil P levels. Upland belowground biomass averaged 9.7 ± 2.8% of the upland soil P pool, while lowland belowground biomass averaged 34.1 ± 8.1% of lowland soil P pools. Below ground biomass provides a notable sink for potentially erodible soil P in perennial grasslands, and our data suggests that deep rooted native grasses may be acting to redistribute P to deeper, less erodible soil layers.

Table 4. *Soil mass (kg m^{-2}), soil C content (%), soil C (kg C m^{-2}), soil P content (ppm), and soil P (kg P m^{-2}) (mean ± standard error) averaged across the top 40 cm of the soil profile for upland and lowland study plots in row crop fields and perrennial native grassland in Brown, Co., WI. Each vegetation type had three independent, paired upland and lowland study plots.*

Vegetation Type	**Topography**	**Actual Soil Mass (kg m^{-2})**	**Actual Soil Carbon (kg m^{-2})**	**Modeled Soil Carbon (kg m^{-2})**	**Actual Soil Phosphorous (g m^{-2})**	**Modeled Soil Phosphorous (g m^{-2})**
Row Crop	Upland	605.0 ± 24.0	6.41 ± 1.01	6.53 ± 1.09	17.53 ± 8.25	18.03 ± 8.69
Row Crop	Lowland	560.6 ± 19.0	6.85 ± 0.99	7.07 ± 1.10	13.67 ± 3.34	13.73 ± 3.26
Grassland	Upland	513.3 ± 17.2	5.57 ± 0.43	5.87 ± 0.35	25.11 ± 9.02	27.33 ± 9.94
Grassland	Lowland	504.1 ± 41.6	7.96 ± 2.85	8.33 ± 3.39	8.23 ± 2.03	8.27 ± 2.13

Note: All modeled soil C and P values assumed a pre-grassland soil mass of 605 kg m^{-2} for the top 40 cm of the soil, while actual soil C and P values reflect real differences in bulk density for the top 40 cm of soil.

<u>Addressing Objective 2</u>: model changes in erosion and stream water quality resulting from conversion of upland and lowland crop fields to biofuel grasslands in N.E. Wisconsin watersheds.

Objective 2 Results Summary

This section describes how Geographical Information System (GIS) analyses and simulations with the Soil and Water Assessment Tool (SWAT) model were utilized to identify and quantify lowland marginal farmland where conversion to energy crops might offer the best water quality benefit. The purpose of the analyses provided in this section were to: 1) delineate the areas where marginal agricultural cropland could best be converted to energy crops; and 2) estimate the water quality improvements that could result from this conversion through simulations with the SWAT model that was previously applied by Baumgart (Cadmus 2011) to the Lower Fox River (LFR) sub-basin. The first portion of the section covering Objective 2 describes the GIS analyses that were conducted to find marginal agricultural areas that are most suitable for conversion to energy crops, because they are likely to have lower conventional crop yields due to poorly drained soil characteristics. Several row crop to biofuel grassland land selection scenarios are then developed for later inclusion in the water quality simulations and economic analysis. The last portion of this section describes methods and results from SWAT simulations, which were conducted to simulate the water quality impact from three scenarios that involve converting agricultural cropland to energy crops.

Based primarily on the USDA-NRCS SSURGO soil drainage classification scheme, we developed three energy crop conversion scenarios that targeted poorly drained marginal cropland for conversion to energy crop production: 1) fields with greater than 75.3% of their contained soils classified as somewhat to very poorly drained (SVP); 2) fields with greater than 11.5% of their contained soils classified as poorly or very poorly drained (PVP); and 3) fields with greater than 36% of their contained soils classified as somewhat to very poorly drained, and are located within sub-watersheds of the Lower Fox River (LFR) sub-basin that have simulated phosphorus (P) yields of greater than 1.5 kg ha^{-1} (65 percentile; SVP-WQ). All of these conversion scenarios involved converting an equivalent of 7% of the agricultural cropland in the Lower Fox River (LFR) sub-basin to energy crop production.

At the sub-watershed scale, converting 7% of the agricultural cropland to energy crops produced simulated phosphorus reductions ranging from 4.9% (PVP scenario targeting very poorly drained soils) to 6.5% (SVP-WQ scenario targeting poorly drained soils, with an emphasis on areas with higher phosphorus loads), relative to baseline loads from agricultural sources. Somewhat greater reductions were found for total suspended solids (TSS) at the sub-watershed scale, with reductions ranging from 6.4% for the PVP scenario to 8.3% for the SVP-WQ scenario. Again, both of these results reflect changes to baseline agricultural loads, so contributions from other non-point sources and point sources are not included. Agricultural contributions of phosphorus yield to watershed outlets were reduced by an average of 0.95, 0.89 and 1.2 kg ha^{-1} under the SVP, PVP and WQ-SVP cropland to energy crop conversion scenarios, respectively. Agricultural contributions of TSS yield to watershed outlets were reduced by an average of 384, 326 and 474 kg ha^{-1} under the SVP, PVP and WQ-SVP cropland to energy crop conversion scenarios, respectively. These yield reductions are based on dividing the total reduced mass associated with each scenario, by the amount of land undergoing conversion to energy crops.

To put the estimated reductions in P and total suspended solids associated with energy crop conversion into perspective, the draft LFR Total Maximum Daily Load (TMDL) calls for a 59.2% reduction of phosphorus loads and a 54.9% reduction of TSS loads from the LFR sub-basin to meet water quality targets in impaired streams and the bay of Green Bay (Cadmus 2011). These percent reductions are much greater than those simulated under the SVP-WQ scenario for P (6.5%) and TSS (8.3%). However, our energy crop conversion scenarios directly affect only 7% of agricultural land, so the simulated reductions are effective on an area-weighted management change basis. In addition, it would not be realistic to expect to attain the large reductions specified in the TMDL with a single agricultural management practice change; rather, a suite of best management practices is expected to be necessary to achieve these ends.

GIS Analysis – Identification of Marginal Lowland Scenarios

LFR sub-basin description – modeling units:

As illustrated in Figure 2, the Lower Fox River sub-basin was divided into nine major hydrologic units (watersheds): (1) LF01 - East River; (2) LF02 - Dutchman, Ashwaubenon, and Apple Creeks; (3) LF03 - Plum, Kankapot and Garners Creeks; (4) LF04 - Appleton Watershed, which includes Mud Creek; (5) LF05 - Duck Creek; (6) LF06 - Little Lake Buttes des Morts Watershed, which includes the Neenah Slough Creek; (7) LFM - Lower Fox River Main Channel; (8) LFS7 - East Shore Watershed near Green Bay; and (9) LFS8 - West Shore Watershed. These watersheds were further delineated into a total of 69 sub-watersheds according to surface hydrology, land use and the placement of monitoring stations (Cadmus 2007, 2011). We originally proposed to model the Duck Creek watershed (276 km^2) as a pilot project before proceeding with the remaining LFR watersheds. However, it was more efficient to simply perform most of the GIS analyses and SWAT simulations over the entire LFR sub-basin at the same time. Agricultural land cover is the most prevalent land use/cover in the LFR sub-basin. Wetlands, grasslands and forested areas are relatively small components of the sub-basin compared to urban and agricultural areas. As applied by Baumgart (Cadmus 2011), the primary land cover categories in the LFR sub-basin consist of 50.2% agriculture, 31.3% urban, 9.9% forest, 4.8% wetlands and 2.1% rural roads (excluding open water).

Identification of Marginal Lowland Soils:

For the purpose of this study, marginal soils are considered to be lowland soils with poor water drainage, which under long-term climatic conditions, have reduced crop yields compared to yields from well drained soils. To identify poorly drained, marginal agricultural areas within our Lower Fox River (LFR) sub-basin project area, a soils drainage layer was created using the following steps: 1) the USDA-NRCS SSURGO soil GIS layers and databases for Brown, Outagamie, Calumet and Winnebago counties were obtained from the USDA-NRCS website (http://soildatamart.nrcs.usda.gov) and merged together with the help of the USDA-NRCS Soil Data Viewer 5.2 ArcMap extension software and Microsoft Access; 2) Soil Data Viewer was then applied to the combined soils database and GIS layer to create a soils drainage classification layer; and 3) this soils drainage layer was clipped to exclude non-agricultural/cropland areas and then cross-tabulated with the LFR watershed boundary layer (Cadmus 2011) to produce the watershed soil drainage classes listed in Table 5 and the LFR soil drainage map shown in Figure 2. ESRI ArcGIS software was utilized to create maps and conduct all GIS analysis in this project. We included the following USDA-NRCS soil drainage classes within our classification of

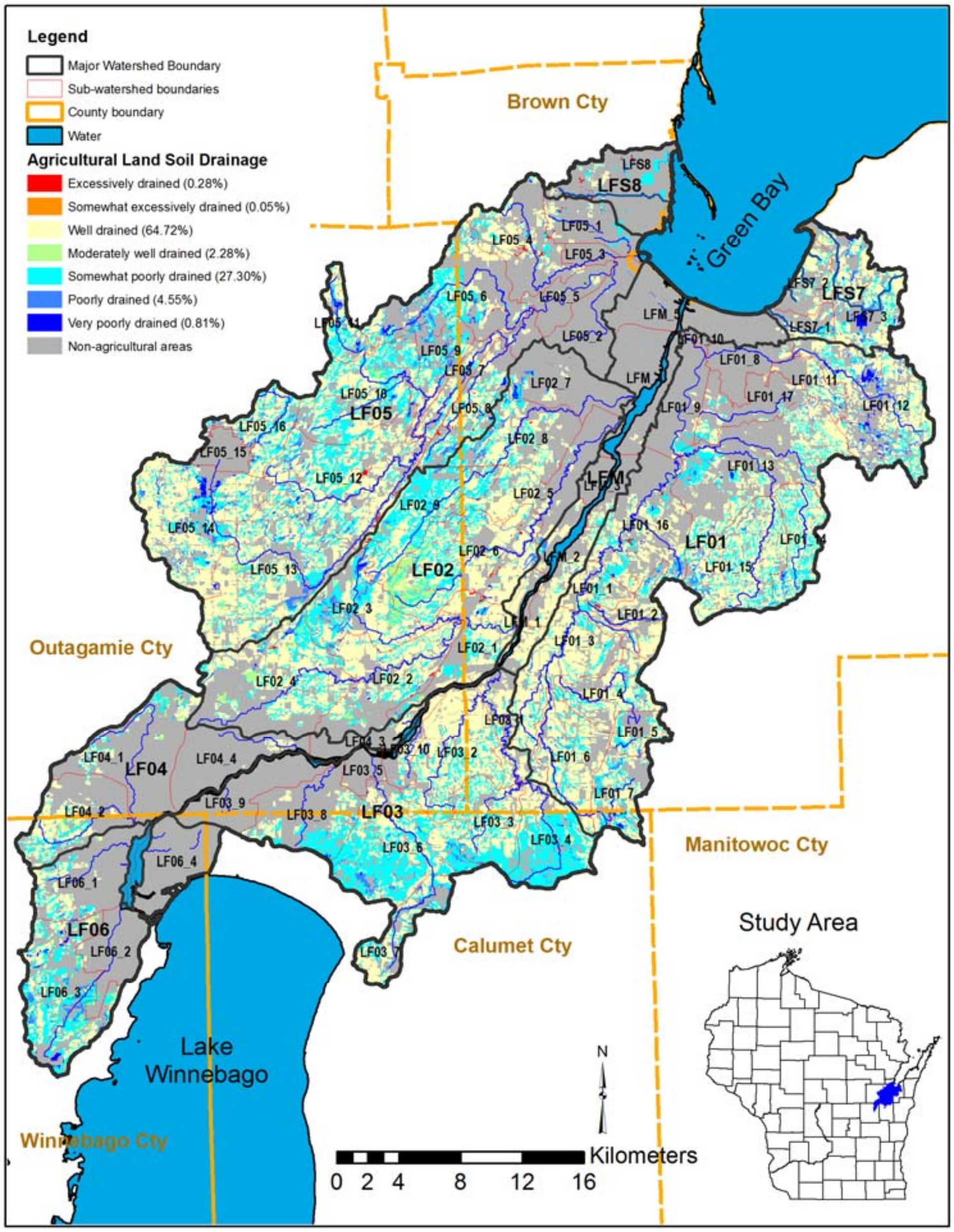

Figure 2. USDA-NRCS SSURGO soil drainage classes on agricultural land in the Lower Fox River sub-basin. Large areas near Green Bay and the Fox Cities are developed and thus unavailable, as are natural areas (background in gray.

poorly drained, marginal soils: somewhat poorly drained, poorly drained, and very poorly drained (Soil Survey Division Staff 1993). Somewhat poorly drained soils are generally defined as those soils that are wet at shallow depths for significant portions of the growing season, to the point that mesophytic crop growth is often limited in the absence of artificial drainage. Poorly drained soils are wetter, and are defined as those soils that are wet at shallow depths for long periods of the growing season, generally preventing the growth of mesophytic crops in the absence of artificial drainage. Very poorly drained soils are those soils that retain free water at the soil surface for much of the growing season, largely excluding the growth of mesophytic crops in the absence of artificial drainage (Soil Survey Division Staff 1993).

Approximately 17% to 53% of the cropland soils within eight of the nine LFR watersheds are classified as somewhat poorly drained, and more than 3% of the soils are classified as poorly to very poorly drained. Over the whole LFR sub-basin, over 32% of the cropland soils are classified as somewhat to very poorly drained, so significant acreage within the LFR sub-basin meets our definition of marginally productive cropland. The following sections describe how these soil drainage classes were combined with farm field boundaries to develop scenarios for converting lowland marginal soil cropland to energy crop production.

GIS Analysis – soil drainage class proportions within delineated farm fields:

Agricultural fields located in the Lower Fox River (LFR) sub-basin were analyzed using GIS and the tabulate area tool to determine the fraction of different USDA-NRCS soil drainage classes within each field boundary (Soil Survey Division Staff 1993). This set of field boundaries was based on the common land unit (CLU) boundaries obtained from the WDNR (clupw924). The CLU boundary dataset was clipped to the LFR sub-basin boundary, and the resulting shapefile was clipped with a modified version of the a 2004 landuse image (as used by Baumgart, Cadmus 2011) that showed only agricultural lands to ensure that most of the polygons were composed of tillable land. Therefore, non-agricultural lands were excluded from the final boundaries, and most of the farm buildings/lots were also excluded. Many small acreage polygons were found, including many that were simply slivers or GIS artifacts. Therefore, the final GIS layer and this analysis were based on polygons that were greater than 2 acres. In the LFR sub-basin, the total acreage was 186,700 acres, with a mean "field" boundary size of 14.5 acres and a median size of 9.4 acres. The Lower Fox River and Green Bay TMDL Project's Agricultural Technical Team estimated that roughly 7% of agricultural land within the Lower Fox River sub-basin could be converted to energy crops without drastically altering existing farming practices (TMDL 2009). This rate translates to about 13,070 acres of the 186,700 acres of agricultural land used in this GIS analysis (field polygons > 2 acres), or 13,900 acres of the 198,300 acres of total agricultural land available within the Lower Fox River sub-basin (all polygons/fields included). The following sections describe how three scenarios which emphasize marginal soils in different manners were developed to attain the 7% energy crop target.

Table 5. *USDA-NRCS SSURGO soil drainage class proportions in Lower Fox River Watersheds (cropland only).*

		--------------- Soil Drainage Class Percentage (not including unclassified) ---------------							
		Marginal Cropland			Fairly Well-drained Cropland				
Watershed	Total Cropland Area (ha)	Very poorly drained	Poorly drained	Somewhat Poorly drained	Moderately well drained	Well drained	Somewhat excessively drained	Excessively drained	Not classified
LF01 - East River	20,569	0.86%	4.40%	20.10%	1.34%	73.05%	0.12%	0.13%	0.09%
LF02 - Apple and Ashwaubenon	16,611	0.43%	3.55%	27.22%	5.47%	62.97%	0.01%	0.35%	0.02%
LF03 - Plum Creek	12,556	0.20%	2.96%	41.05%	1.48%	54.21%	0.09%	0.00%	0.10%
LF04 - Fox River Appleton	1,819	0.14%	3.09%	23.29%	6.27%	66.94%	0.21%	0.07%	0.33%
LF05 - Duck Creek	21,305	1.01%	6.09%	26.38%	0.80%	65.19%	0.02%	0.51%	0.18%
LF06 – LLBDM	3,180	1.97%	6.69%	42.64%	5.42%	43.27%	0.00%	0.00%	1.06%
LFM - Lower Fox - Main Channel	1,411	0.40%	2.84%	6.85%	0.02%	89.84%	0.06%	0.00%	0.18%
LFS7 - East Shore Green Bay	2,475	3.61%	5.97%	17.18%	0.03%	73.08%	0.00%	0.14%	0.26%
LFS8 - West Shore Green Bay	342	0.04%	9.10%	53.53%	0.00%	28.78%	0.00%	8.55%	3.72%
Total	80,268	0.81%	4.55%	27.30%	2.28%	64.72%	0.05%	0.28%	0.17%

Scenario #1, Marginal Soils - Somewhat to very poorly drained classes combined (SVP Scenario):

As shown in Table 6, 52.7%, 43.3%, 34.9%, 27.6%, 14.9% and 9.7% of the 12,899 common land unit (CLU) fields located within the LFR sub-basin were found to have more than 20%, 30%, 40%, 50%, 75% and 90% of the soils within their boundaries classed as somewhat to very poorly drained, respectively (includes somewhat poorly, poorly, and very poorly drained classes). Furthermore, minimum thresholds of greater than 20%, 30%, 40%, 50%, 75% and 90% poorly drained soils translate to 55,970 acres, 50,780 acres, 44,270 acres, 37,260 acres, 21,940 acres and 14,180 acres of poorly drained agricultural soils that could be converted to energy production crops (Table 6). We also assumed for practical purposes that the whole field would be converted to energy crop production, not solely poorly drained areas within the fields, which slightly increases the total acreage available for conversion (last column in Table 6). Selection of only those fields with greater than 92% of the soils classified as somewhat to very poorly drained is sufficient (13,912 acres) to achieve our total agricultural acreage conversion target of 7%. The selected fields are depicted in (Figure 3). Assuming this conversion, about 98.2% of the total converted area is considered lowlands: 78.0% of the soils classified as somewhat poorly drained and 20.2% classified as poorly to very poorly drained soils (13,658 poorly drained/13,912 total field acreage = 98.2% poorly drained). Compared to well-drained fields, these lowland areas are expected to have reduced yields when planted to conventional agricultural crops.

Table 6. *Cumulative percentage of somewhat to very poorly-drained soils within common land unit boundary fields of the Lower Fox River sub-basin. Total number of fields is 12,899.*

Proportion of field poorly drained	Field count	Cumulative fields equal to or better drained (%)	Cumulative fields more poorly drained (%)	Total area poorly drained soils (acres)	Total area entire field (acres)
0	2886	22.4	77.6		
0.05	1131	31.1	68.9		
0.1	755	37.0	63.0		
0.15	698	42.4	57.6		
0.2	627	47.3	52.7	55,970	104,231
0.25	637	52.2	47.8		
0.3	576	56.7	43.3	50,782	83,287
0.35	555	61.0	39.0		
0.4	530	65.1	34.9	44,270	64,619
0.45	496	68.9	31.1		
0.5	454	72.5	27.6	37,255	48,990
0.55	423	75.7	24.3		
0.6	349	78.4	21.6	30,698	37,027
0.65	301	80.8	19.2		
0.7	302	83.1	16.9		
0.75	257	85.1	14.9	21,939	23,943
0.8	209	86.7	13.3		
0.85	223	88.5	11.6		
0.9	**234**	**90.3**	**9.7**	**14,178**	**14,529**
0.95	239	92.1	7.9		
More	1017	100.0	0.0		

These values are for a singular optimal solution which gives the greatest amount of somewhat to very poorly drained soils (SVP) soils possible for converting agricultural cropland to the 7% energy crop target. However, it is improbable that all of these fields will be converted to meet the targeted acreage.

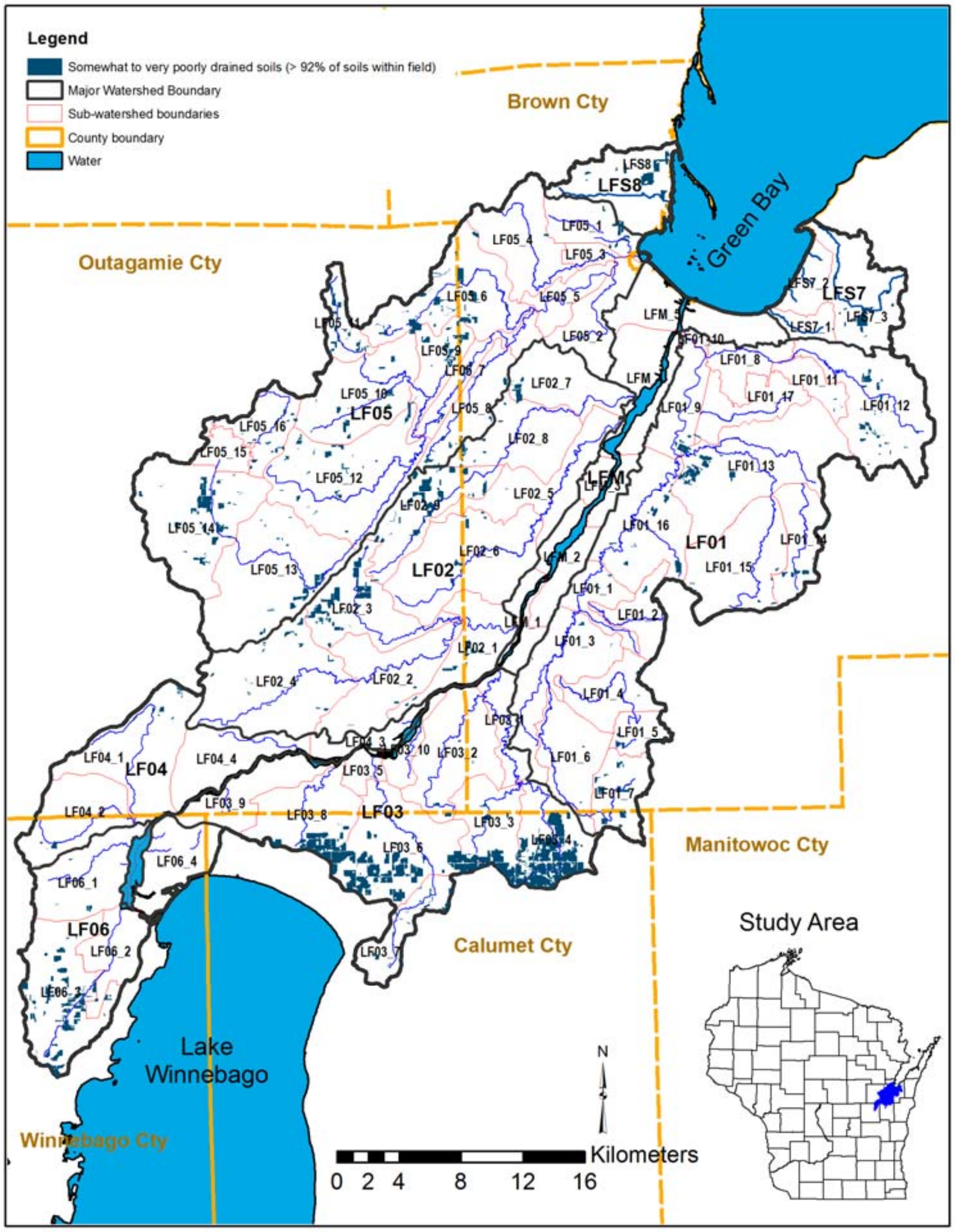

Figure 3. *Agricultural fields in the Lower Fox sub-basin with greater than 92% of the soils classified as somewhat, poorly or very poorly drained.*

Therefore, a more realistic set of values were applied to the economic model under this scenario whereby a larger pool of fields was assumed available for conversion. The selectable acreage was increased to fields containing a minimum of 75.3% of their contained acreage in somewhat to very poorly drained soils. On average, these fields have a lower proportion of acreage in marginal soils and are expected to have a higher standard agricultural crop yield compared to the optimal solution, because there are more well-drained soils in the applied scenario. Based on this relaxed constraint, but larger pool of fields, our modeled applied scenario included 74.07% somewhat poorly drained soils and 17.79% poorly and very poorly drained soils. Within a given field, poorly and very poorly drained soils are often associated with somewhat poorly drained soils, so reduced yields associated with these soils were accounted for even though this category was not specified in the criteria under this scenario. These proportions, along with the reduced agricultural crop yields associated with these lowland soil categories, were applied to the economic model described under Objective 3.

Scenario #2, Very Marginal Soils - Poorly and very poorly drained classes (PVP Scenario):

The same analysis was applied with a more restrictive constraint whereby only poorly and very poorly drained soil classes were considered for conversion to energy crops. As shown in Table 7, 10.5%, 7.6%, 5.4% and 3.9% of the 8,540 CLU fields located within the LFR sub-basin were found to have more than 20%, 30%, 40% and 50% of the soils within their boundaries classified as either poorly or very poorly drained. Minimum thresholds of greater than 20%, 30%, 40% and 50% poorly drained soils translate to 6,750 acres, 5,430 acres, 4,090 acres, and 3,070 acres of poorly drained agricultural soils that could be converted to energy production crops (Table 7). Including only those fields with greater than 23% of their soils classified as poorly and very poorly drained was sufficient to achieve the total agricultural acreage conversion target of 7%. Assuming again that the whole field would be converted to energy crop production increases the total acreage available for energy crops to 13,874 acres (Figure 4). With this conversion, about 46.4% of the total converted area would be considered lowlands (6,437 poorly and very poorly drained soils/13,874 total field acreage = 46.4% poorly drained). However, there are also 3,209 acres (23.1%) of somewhat poorly drained soils that are included within selected fields, so about 69.5% of the total converted area would have somewhat to very poorly drained soils expected to have reduced yields of conventional agricultural crops.

Table 7. *Cumulative percentage of very poorly and poorly-drained soils within common land unit boundary fields of the Lower Fox River sub-basin. Total number of fields is 12,899.*

Proportion of field poorly drained	Field count	Cumulative fields equal to or better drained (%)	Cumulative fields more poorly drained (%)	Total area poorly drained soils (acres)	Total area entire field (acres)
0	9025	70.0	30.0		
0.05	1309	80.1	19.9		
0.1	522	84.2	15.8	8,368	27,108
0.15	414	87.4	12.6	7,474	19,832
0.2	**269**	**89.5**	**10.5**	**6,750**	**15,621**
0.25	**207**	**91.1**	**8.9**	**6,070**	**12,579**
0.3	171	92.4	7.6	5,430	10,234
0.35	159	93.6	6.4		
0.4	122	94.6	5.4	4,085	6,366
0.45	105	95.4	4.6		
0.5	89	96.1	3.9	3,072	4,109
0.55	63	96.6	3.4		
0.6	55	97.0	3.0	2,490	3,054
0.65	55	97.4	2.6		
0.7	36	97.7	2.3		
0.75	41	98.0	2.0	1,652	1,800
0.8	35	98.3	1.7		
0.85	30	98.5	1.5		
0.9	36	98.8	1.2	1,056	1,081
0.95	37	99.1	0.9		
More	119	100.0	0.0		

As with the first scenario, these values are for a singular optimal solution, therefore the selectable acreage was increased to fields possessing a minimum of 11.5% of their contained acreage in poorly to very poorly drained soils. Based on this relaxed constraint, but larger pool of fields, converted fields contained 33.46% poorly and very poorly drained soils and 27.04% somewhat poorly drained soils. Within a given field, somewhat poorly drained soils are often associated with poor to very poorly drained soils, so reduced yields associated with these soils were also accounted for even though this category was not specified in this scenario.

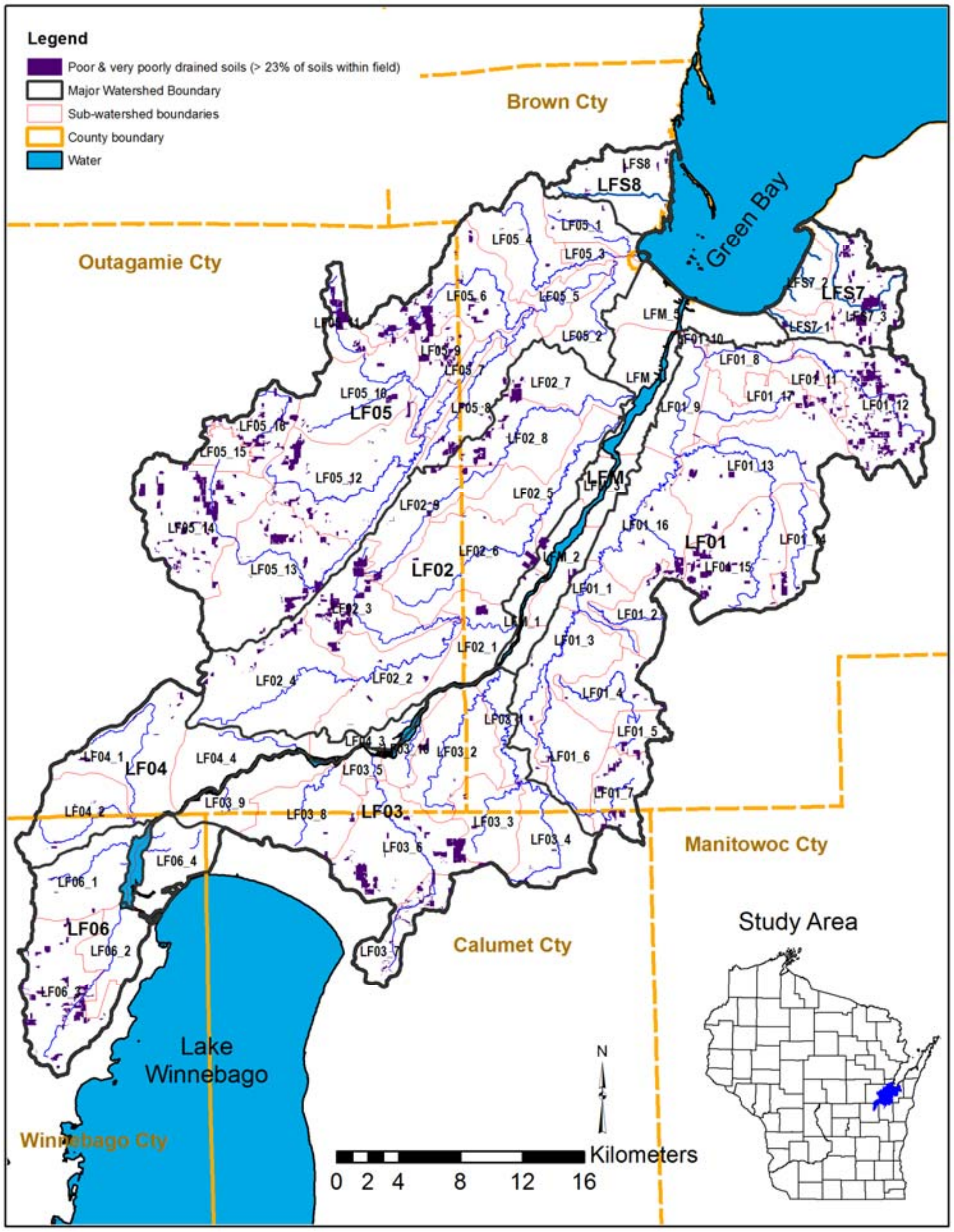

Figure 4. Agricultural fields in the Lower Fox sub-basin with greater than 23% of the soils classified as poorly or very poorly drained.

Scenario #3 - Marginal Soils and Targeted Water Quality (SVP-WQ Scenario):

The scenario that targeted marginal soils for conversion to crops was modified to also account for areas where replacing standard agricultural crops with energy crops is likely to have the greatest impact on improved water quality with regards to total phosphorus flux. To achieve these ends, an additional constraint was added whereby conversion to crops was restricted solely to sub-watersheds with SWAT-simulated phosphorus yields greater than 1.5 kg ha^{-1} (65 percentile), as determined by Baumgart (Cadmus 2011). The addition of a phosphorus yield constraint made it virtually impossible to add the poor and very poorly drained soils constraint and still attain sufficient area to meet our 7% total converted agricultural acreage target. Therefore, only the somewhat to very poorly drained soils constraint (SVP) was included in this analysis. Selection of only those sub-watersheds with simulated phosphorus yields of greater than 1.5 kg ha^{-1}, and only those fields with greater than 58% of the soils classified as somewhat to very poorly drained is sufficient to achieve the total acreage rate of 7%. A practical constraint which excluded sub-watersheds with an agricultural area of less than 2.3 sq. km was also included in this scenario to exclude small agricultural fields near urban areas. Assuming again that the whole field would be converted to energy production increases the total acreage available for energy crops to 13,900 acres (Figure 5). Assuming this conversion, about 83.4% of the total converted area would be considered lowlands (1,140 acres of poorly to very poorly drained soils and 10,460 acres of somewhat to very poorly drained soils, divided by 13,900 total field acreage = 83.4% poorly drained).

As with the previous scenarios, these values are for a singular optimal solution, therefore the selectable acreage was increased to include fields with a minimum of 36% of their soils classified as somewhat to very poorly drained. Based on this relaxed constraint, but larger pool of fields, converted fields contained 6.50% poorly and very poorly drained soils, and 60.63% somewhat poorly drained soils. Within a given field, poorly and very poorly drained soils are often associated with somewhat poorly drained soils, so reduced yields associated with the former soils were accounted for even though this category was not specified in the criteria under this scenario. These proportions, along with the reduced agricultural crop yields associated with these lowland soil categories, were applied to the economic model described under Objective 3.

Scenario #4 – Conventional Energy Crop (CEC Scenario):

Three scenarios which targeted marginal cropland for energy crop conversion were described earlier in this section. An additional conventional energy crop scenario (CEC) was simulated by having energy crops grown on one third of the area where cash-grain rotations are likely to be present, rather than having the crops grown primarily on marginal cropland. This scenario served as a comparison to see if targeting marginal soils was more or less effective in reducing phosphorus or total suspended solids (TSS) than an energy crop scenario that did not target marginal agricultural land for conversion. The total converted acreage with this scenario is 6.6% of all agricultural land, which is approximately the same as with the other scenarios (7.0%).

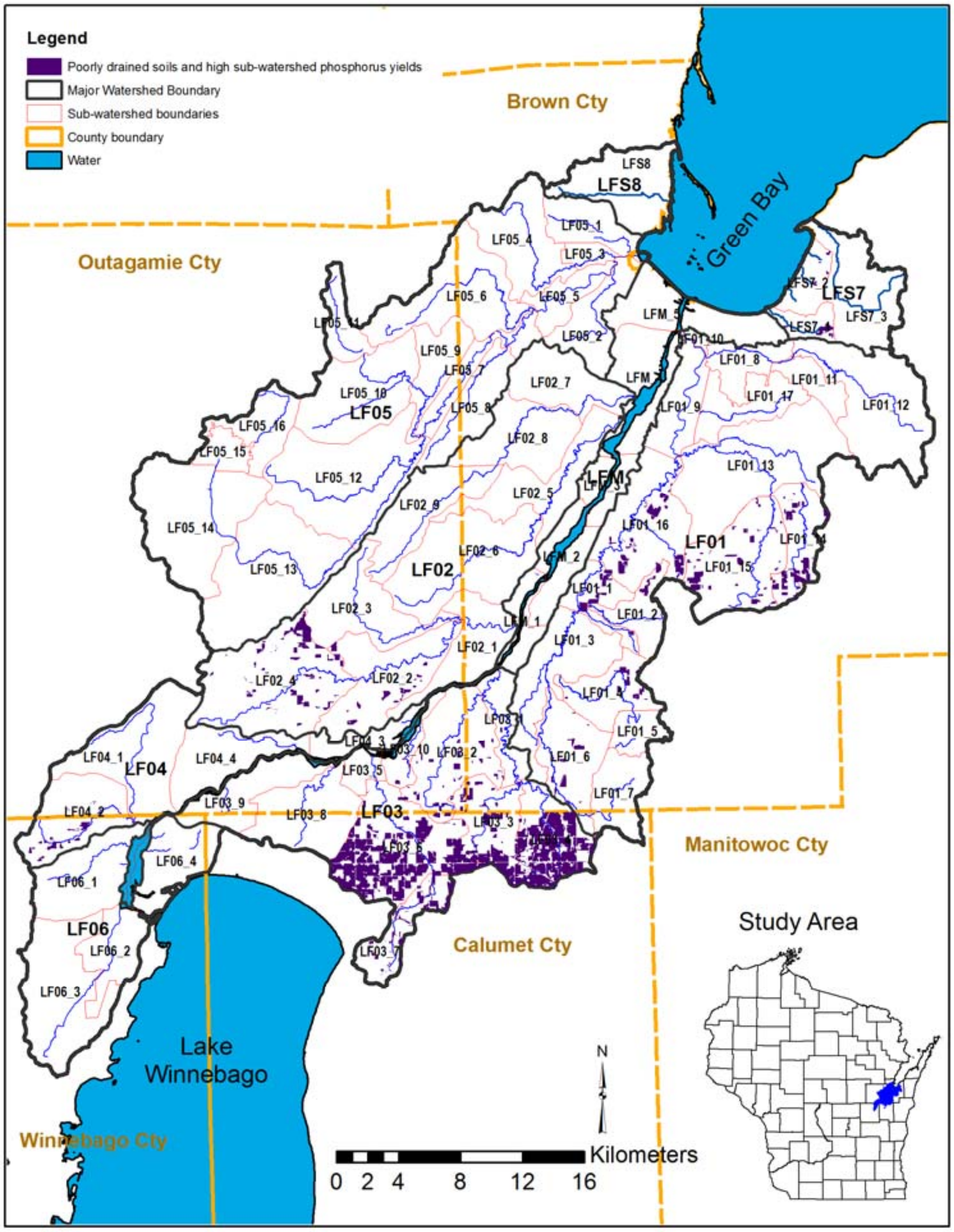

Figure 5. *Agricultural fields with greater than 58% of soils somewhat, poorly or very poorly drained; and simulated agricultural phosphorus yields > 1.5 kg ha^{-1} (65 percentile), and sub-watershed area > 2.3 km^2.*

SWAT Simulations

The USDA Soil and Water Assessment Tool (SWAT) model (Arnold et al. 1996) was applied to the Lower Fox River (LFR) sub-basin (1,630 km^2) to simulate potential water quality benefits of replacing typical agricultural crops with energy crops under four conversion scenarios. Our primary objective in this application of SWAT was to model changes in stream water quality resulting from conversion of lowland marginal crop fields to native-species biofuel grasslands in the LFR watersheds. The same model framework applied to the LFR sub-basin by Baumgart (Cadmus 2011) for the Lower Fox River and Green Bay TMDL was utilized for this project, except the model inputs were modified to include the ability to better simulate the effect of establishing biomass yielding native grasslands on marginal farmland. Model modifications required to accommodate these changes are described in this section, as well as a brief description of the SWAT model. A detailed description of inputs and methods used to create the LFR sub-basin SWAT model framework can be found in Baumgart (2005) and Cadmus (2007, 2011).

SWAT description:

SWAT is a distributed parameter, daily time step model that simulates hydrologic and related processes to predict the impact of management on water, sediment and nutrient export from primarily rural basins (Arnold et al. 1996). SWAT has been widely applied in Wisconsin by WDNR staff and throughout the world (Gassman et al. 2007). SWAT simulates nutrient uptake, crop growth and complex farm management practices, so it can represent the actual cropping, tillage and nutrient management practices typically used by both dairy and cash-crop operators in Wisconsin. SWAT can simulate the effect that converting row-crop to energy-crop grasslands has on: 1) soil erosion and runoff; 2) nutrient removal via harvesting; and 3) phosphorus and sediment flux to streams from upland source areas.

Energy crop application and SWAT input parameters:

The location and extent of marginal cropland that was converted to an energy crop under four simulation scenarios was determined on a sub-watershed basis as described in the first section under this objective. Within SWAT, an energy crop modeling unit was added to each sub-watershed. Under each scenario, the areas to be converted to energy crops were allocated to each sub-watershed by adding the energy crop area associated with a particular scenario, and subtracting the same area from the conventional agricultural crop rotation. The converted cropland area and percent area under each scenario are summarized in Table 8 by watershed unit. Again, each of these scenarios was assumed to involve converting 7% of the total agricultural land to energy crops. The percent of land converted under each cropland conversion scenario varies by watershed unit, because the amount of land that is classified as a particular soil drainage class varies substantially between watersheds. For example, watersheds such as Plum Creek that have a high fraction of somewhat poorly drained soils (Table 5) are targeted for conversion under the scenarios that include an emphasis on somewhat poorly drained fields (SVP Scenario; SVP-WQ Scenario), but this watershed is less of a priority under the PVP scenario because it has a relatively smaller fraction of poor to very poorly drained fields (PVP Scenario). In a similar vein, the variability in cropland conversion percentage between watersheds is greatly reduced under the standard energy crop conversion scenario, because this scenario does not consider whether the cropland is a marginal lowland area or not.

Table 8. *Summary of spatially explicit energy crop conversion scenarios in Lower Fox River watersheds.*

	watershed	cropland	area of converted fields					
	area	area	SVP[1]	PVP[2]	SVP-WQ[3]	cropland conversion %		
Watershed	(km^2)	(ha)	(ha)	(ha)	(ha)	SVP[1]	PVP[2]	SVP-WQ[3]
LF01 - East River	373.0	20,569	555	1,396	985	2.7%	6.8%	4.8%
LF02 - Apple and Ashwaubenon	291.2	16,611	815	869	441	4.9%	5.2%	2.7%
LF03 - Plum Creek	213.6	12,556	2,383	550	4,053	19.0%	4.4%	32.3%
LF04 - Fox River Appleton	98.2	1,819	48	47	85	2.7%	2.6%	4.7%
LF05 - Duck Creek	392.1	21,305	1,153	2,001	0	5.4%	9.4%	0.0%
LF06 - LLBDM	106.8	3,180	425	306	0	13.4%	9.6%	0.0%
LFM - Lower Fox - Main Channel	83.4	1,411	0	52	2	0.0%	3.7%	0.1%
LFS7 - East Shore Green Bay	47.2	2,475	95	354	59	3.8%	14.3%	2.4%
LFS8 - West Shore Green Bay	28.1	342	156	39	0	45.6%	11.3%	0.0%
TOTAL	1,630	80,268	5,630	5,615	5,625	7.0%	7.0%	7.0%

1) SVP = converted fields had greater than 92% of the soils classified as somewhat to very poorly drained
2) PVP = converted fields had greater than 23% of the soils classified as poorly or very poorly drained
3) SVP-WQ = converted fields had greater than 58% of the soils classified as somewhat to very poorly drained and sub-watershed phosphorus yields > 1.5 kg/ha, and sub-watershed agricultural areas > 2.3 sq. km

The SWAT crop database was modified to include an energy crop similar to a grassland mixture expected to produce good yields with low inputs (e.g. fertilizer, pesticides, etc). The SWAT model can only simulate the growth of a single crop within the smallest modeling unit, so a mixture that might include a legume to supply some of the nitrogen needs of grasses could not be directly simulated. The default switchgrass and indian grass input parameters were combined and altered to produce the simulated energy crop by: 1) substituting the average phosphorus content of the mixed native grasslands grown in our field plots, as summarized in Objective #1; 2) adjusting the radiation use efficiency variable downward to a value of 16.8 kg/ha/(MJ/m^2) so that the long-term mean crop yield was 4 tons acre^{-1} (8.99 t ha^{-1}), which is close to the mean yield found in our grass dominated field plots (see Objective #1); 3) using the nitrogen uptake parameters from the switchgrass crop, and 4) utilizing the remaining parameters from the indian grass crop. These changes were made because crop phosphorus needs and biomass yields affect the soil balance of phosphorus, the amount of production a farmer will expect from the energy crop, and the amount of protective soil cover the energy crop produces. There was no need to recalibrate the model, since the input changes that were made to better accommodate the addition of energy crops did not affect baseline model results.

Simulation method:

To determine the water quality impact of adding energy crops, the SWAT model was applied on a daily time step basis for a 25 year climatic period (1976 to 2000) using daily precipitation and temperature data from National Weather Service and cooperator stations to simulate daily flow, and loads of TSS and phosphorus. The first simulation year was used to initiate the model, so data from this year was not included in the results. Three sets of model simulations were performed: 1) baseline agricultural conditions as utilized in the LFR TMDL (Cadmus 2011); 2) three scenarios whereby marginal cropland was converted to energy crops (SVP, PVP, SVP-WQ); and 3) a conventional energy crop conversion scenario, which did not target marginal agricultural lands (CEC).

SWAT model results:

Results from the model are available at three different scales, or endpoints: 1) sub-watershed outlet; 2) watershed outlet, as the stream(s) enter the Fox River, or in some cases, directly to Green Bay; and 3) as routed to Green Bay (Figure 2). There are 69 sub-watersheds and 9 watersheds in the LFR sub-basin. Streams from some of the watersheds discharge directly to Green Bay, but most streams flow to the Fox River prior to entering the Bay. Phosphorus (P) or total suspended solids (TSS) from agriculture can best be separated out from other sources at the sub-watershed scale, so some of our results are presented at this scale. It should also be noted that, in general, net losses of phosphorus and TSS occur as water from a sub-watershed or watershed travels downstream, so the mass of phosphorus or TSS from an upstream source area is lower at endpoints downstream of the original source.

The 24-year average annual results from each energy crop conversion scenario are summarized in Table 9 for both total phosphorus and TSS, by watershed, and over the entire LFR sub-basin. Results presented in Table 9 are the percent reductions in P and TSS loads for each scenario, relative to the baseline loads (i.e. no energy crops). The baseline loads listed in Table 9 include urban, agriculture, and other rural non-point source loads in the LFR sub-basin, but point source loads are excluded. Therefore, the percent reductions would be greater if only agricultural loads were included in this analysis, but smaller if point source loads were also included. However, the mass reductions associated with each scenario do not depend on what sources are included in the baseline loads (i.e., reduced mass = baseline multiplied by the % reduction of scenario).

At the sub-watershed outlet scale, baseline P loads *from agricultural sources* were reduced by 5.2%, 4.9%, and 6.5%, while baseline loads of TSS from agricultural sources were reduced by 6.6%, 6.4%, and 8.3% for the SVP, PVP, and SVP-WQ scenarios, respectively. At the watershed outlet scale, *total non-point source* baseline loads of phosphorus were reduced by 3.6%, 3.3%, and 4.5%, while total non-point source baseline loads of TSS were reduced by 4.3%, 3.7%, and 5.3% for the SVP, PVP, and SVP-WQ scenarios, respectively. Reductions associated with energy crop conversion are not as large at the watershed scale, mostly because sources other than agriculture are also included at this scale, and only changes to agricultural land were simulated. At the watershed outlet scale, phosphorus yields from agricultural sources were reduced by an average of 0.95, 0.89 and 1.2 kg ha^{-1} under the SVP, PVP, and SVP-WQ cropland to energy crop conversion scenarios, respectively (Table 9). These phosphorus yield reductions were based on dividing the total phosphorus load reduction associated with each scenario (compared to baseline conditions), by the total converted area. If the phosphorus loads from all of the watershed outlets are routed to Green Bay, then the phosphorus yields from agricultural sources were reduced by an average of 0.91, 0.87 and 1.15 kg ha^{-1} under the SVP, PVP, and WQ-SVP cropland to energy crop conversion scenarios, respectively (Table 9). This latter set of reductions might be useful when point source phosphorus loads discharging closer to Green Bay are compared to upstream non-point source reductions from the cropland conversion scenarios.

With the exception of reduced TSS under the PVP scenario, all other phosphorus and TSS yield reductions associated with scenarios targeting marginal agricultural land for conversion to energy crops were greater than the CEC scenario, which replaced one-third of the cash-grain crops with energy crops without regard to targeting marginal agricultural land for conversion (Table 9). Again, the CEC scenario involved approximately the same amount of land conversion as the marginal land energy crop conversions.

To put the estimated reductions associated with energy crop conversion into perspective, the draft LFR TMDL calls for a 59.2% reduction of phosphorus loads and a 54.9% reduction of TSS loads from the LFR sub-basin to meet water quality targets in impaired streams and the bay of Green Bay (Cadmus 2011). Percent reductions in the draft TMDL are typically larger for agricultural sources. For example, the draft TMDL calls for agricultural phosphorus source reductions from major watershed units such as the East River, Apple Creek, Plum Creek and Duck Creek of 83.9%, 78.6%, 86.0% and 76.9%, respectively. The draft TMDL also calls for agricultural TSS source reductions from major watersheds such as the East River, Apple Creek, Plum Creek and Duck Creek of 70.6%, 56.1%, 74.6% and 58.6%, respectively. These percent reductions are much greater than those simulated under the SVP-WQ scenario for phosphorus (6.5%) and TSS (8.3%). However, our energy crop conversion scenarios directly affect only 7% of agricultural land, so the simulated reductions are effective on an area-weighted management basis. In addition, it would not be realistic to expect to attain the large reductions specified in the TMDL with a single agricultural management practice change; rather, a suite of best management practices will be necessary to achieve these ends.

Table 9. *Simulated impact of converting conventional agricultural cropland to energy crops on SWAT-derived total phosphorus (TP) and total suspended solids (TSS) loads at Lower Fox River watershed outlets.*

	NP source baseline	Phosphorus load reduction with energy crop conversion scenarios				NP source baseline	TSS load reduction with energy crop conversion scenarios			
Watershed	Load[1] TP (kg)	CEC[5] 33% of cash crops	SVP[2]	PVP[3]	SVP-WQ[4]	Load[1] TSS (1000 kg)	CEC[5] 33% of cash crops	SVP[2]	PVP[3]	SVP-WQ[4]
LF01 - East River	36,829	1.3%	1.5%	4.0%	3.2%	8,922	1.3%	1.3%	4.3%	2.5%
LF02 - Apple and Ashwaubenon	29,676	2.8%	2.6%	3.0%	1.7%	9,624	3.9%	3.0%	3.7%	2.4%
LF03 - Plum Creek	27,136	3.6%	10.3%	2.4%	18.0%	10,730	4.9%	11.4%	3.3%	19.6%
LF04 - Fox River Appleton	8,250	4.4%	0.7%	0.7%	1.3%	3,970	4.9%	0.7%	0.7%	1.5%
LF05 - Duck Creek	25,100	4.1%	2.5%	4.5%	0.0%	7,167	5.1%	3.6%	5.3%	0.0%
LF06 - LLBDM	8,984	5.6%	4.8%	3.4%	0.0%	3,978	6.1%	5.2%	3.7%	0.0%
LFM - Lower Fox Main Channel	6,804	2.6%	0.0%	0.9%	0.0%	3,505	2.5%	0.0%	0.8%	0.0%
LFS7 - East Shore Green Bay	5,498	3.6%	1.8%	6.9%	1.6%	1,064	8.6%	3.5%	13.4%	4.5%
LFS8 - West Shore Green Bay	242	0.0%	0.0%	0.0%	0.0%	886	0.0%	0.0%	0.0%	0.0%
TOTAL	148,519	3.1%	3.6%	3.3%	4.5%	49,845	4.0%	4.3%	3.7%	5.3%
weighted average yield reduction:										
to watershed outlets (kg/ha)		0.87	0.949	0.886	1.201		383	384	326	474
to Green Bay (kg/ha)		0.84	0.907	0.867	1.145		357	354	311	433

1) Baseline loads include loads from agriculture, urban and other non-point sources. Point source loads are not included.
2) SVP = fields selected for conversion had greater than 92% of the soils classified as somewhat to very poorly drained
3) PVP = fields selected for conversion had greater than 23% of the soils classified as poorly or very poorly drained
4) SVP-WQ = fields selected for conversion had greater than 58% of the soils classified as somewhat to very poorly drained and sub-watershed phosphorus yields > 1.5 kg/ha, and sub-watershed agricultural areas > 2.3 sq. km
5) CEC = conventional energy crop conversion (marginal lands not targeted)

<u>Addressing Objective 3</u>**: create an economic analysis of the combined value of harvestable aboveground production (biomass or grain yield) and ecological services (e.g., C- and P-sequestration and water quality changes) associated with converting upland and lowland crop fields into native-species grasslands for Brown Co, Wisconsin.**

Objective 3 Results Summary:

Returns for marginal low lying fields in the LFR sub-basin managed following our modeled corn silage, corn grain, soybean rotation ranged from -$51.04 to $29.13 per acre, while non-subsidized biofuel grasses in the same locations had returns of $25.52. Under the scenarios modeled, biofuel grasslands offered a viable alternative crop for the Lower Fox River sub-basin, independent of subsidies. When considering potential subsidies available, returns from planting perennial native biofuel grasses increased by up to $100 per acre, making biofuel grasses very attractive. However, this analysis is sensitive to the commodity prices assumed and recent spikes in these prices could negate most of the competitive economic advantage shown for native biofuel grasses relative to row-crops.

Regional economic impacts are based upon local expenditures and revenues. Changes in projected returns from row-crops and biofuel grassland were modeled under alternative scenarios to determine aggregate regional impacts. These modeling results indicate employment loss of approximately 115 jobs and a reduction in regional economic output of close to $2.5 million. Most of the employment and output losses would occur in the grain sector. However, addition of a Biomass Crop Assistance Program (BCAP) designation and an associated pelletizing facility to the region would create 46 direct jobs and generate close to $7.7 million in direct impact. Total economic output in the region, according to the regional impact analysis, is expected to increase by $10.1 million. However, overall employment is expected to decline, with 32 jobs lost in the region due to reduction in row crop production, which is a more labor intensive activity than growing biofuel grasses and pelletizing activities.

In summary, conversion of row-crop agriculture to perennial biofuel grasslands would potentially result in increased profits for agricultural operators. Yet, overall regional impacts would be a loss of employment under both scenarios and have a variable impact on overall regional output. For example, without a pelletizing plan, regional output would decline by $2.5 million, but with such a plant regional output would increase by close to $10 million, creating a local market to keep revenues from biofuel grass sales within the region.

Enterprise model overview:

Enterprise models estimate what an individual business can expect to experience in terms of expenses, revenues, and profits by accounting for all economic input and output variables. All data used in Enterprise models were drawn from 2000-2009, although not all data sets spanned this full period. Our LFR sub-basin study area includes portions of the Wisconsin counties of Winnebago, Outagamie, Brown, and Calumet, although no county lies entirely within the LFR sub-basin. In order to analyze economic conditions that most closely resemble the Lower Fox River (LFR) sub-basin as a whole, and unless stated elsewhere, we focused on Brown Co. data sets for our Enterprise models, as Brown Co. has the highest percentage of its land lying within the LFR sub-basin. All dollars were Consumer Price Index (CPI) adjusted to 2009 values, as data from 2010 was not yet available for most parameters.

Land conversion

This section evaluates the economic feasibility and potential impacts of increasing grassland-based biofuel production to represent 7% of current agriculture acreage in the LFR sub-basin (see Objective #2). In addition to the practical implication of our 7% conversion target highlighted under Objective #2, this acreage was selected, in part, due to its ability to support a small scale pelletizing facility. Porter et al. (2008) state that small scale pellet conversion facilities require at least 25,000 tons of grass per year. With yield expectations for biofuel grasses in our region at around 4 to 4.5 short tons per acre (Objective #1), only approximately 6,250 acres of harvestable grass would be required annually to support a small scale pelleting facility in the LFR sub-basin. Our 7% conversion target is equivalent to roughly twice this required acreage.

Of the four different scenarios produced under Objective #2 (SVP, PVP, SVP-WQ, and CEC), we restricted our economic analyses to only SVP and SVP-WQ, as the SVP scenarios represent the economically most conservative (i.e. least favorable for promoting conversion to biofuels) conversion scenarios, and the SVP-WQ scenario further emphasizes the potential environmental benefits that perennial biofuel grasslands are likely to provide. In order to calculate and contrast economic returns between a traditional row crop rotation and biofuel grasslands we first had to determine the total acreage of each major USDA-NRCS SSURGO soil drainage class included in each conversion scenario (see Objective #2). As stated under Objective #2, the SVP conversion scenario estimated that our 7% conversion target from traditional agriculture into biofuel perennial grasslands could feasibly be met with the conversion of existing agricultural fields that contain ≥75.3% of their contained area in soils classified as somewhat to very poorly drained. Following the SVP scenario, poorly to very poorly drained soils comprised 17.79% of the converted acreage, somewhat poorly to poorly drained soils were 74.07% of the acreage, and only 8.14% of the converted area was characterized as well drained (Table 10). Again, as stated in Objective #2, the SVP-WQ conversion scenario could reasonably be met by converting all fields with ≥36% of their soils classified as somewhat to very poorly drained. Under this scenario, converted fields contained 6.50% poorly and very poorly drained soils, 60.63% somewhat poorly drained soils, and 32.87% adequately drained soils (Table 10). Thus, while converted land under both scenarios (SVP and SVP-WQ) is dominated by marginal soils (somewhat to very poorly drained), the SVP-WQ scenario contains a higher proportion of higher yielding soils for row crops. These differences will have important implications for the economic feasibility of any biofuel conversion scenario.

Table 10. *Percent of each soil drainage class present in SVP and SVP-WQ row crop to biofuel conversion scenarios. In both models, 7% of current agricultural lands in the LFR-sub basin are converted to perennial biofuel grassland systems.*

Soil Drainage Type	SVP Scenario	SVP-WQ Scenario
Poor to Very Poorly Drained	17.79	6.50
Somewhat Poorly to Poorly Drained	74.07	60.63
Well Drained	8.14	32.87

Crop Acreage

Row crop agricultural in this study considers a strict rotation of corn grain, corn silage, and soybean plantings, as these crops generally offer a higher profit margin per acre than other row-crop types. Thus, economic comparisons between biofuels and row crops should be viewed as conservative comparisons, considering that other, lower value cropping systems are common in Brown Co. (See below). While Jain et al. (2010), and some other studies, have taken the approach of analyzing strictly corn and soybean rotations, this seems inappropriate for Brown Co. based on current cropping patterns. For example, on average from 2004-2008 for Brown Co., WI, corn grain was planted on 30,990 acres, corn silage on 32,790 acres, and soybean on 23,500 acres, accounting for roughly 53% of all agricultural crop land. Forage (e.g. hay and alfalfa) accounted for roughly 36% of agricultural lands, with wheat and oat comprising the remaining approximately 11% (http://www.nass.usda.gov/Data_and_Statistics/ Quick_Stats/). We utilized the relative abundance of corn grain, corn silage, and soybean plantings (Table 11) to characterize a crop rotation pattern and a realistic economic analysis of row crop systems in the LFR sub-basin.

Table 11. *Total acreage of planted corn grain, corn silage, and soybean in Brown County, WI from 2004-2008. Prevalence describes the proportion of time that a given modeled field was occupied by each crop. All data from http://www.nass.usda.gov/QuickStats/.*

Crop Type	Acres Planted	Prevalence
Corn Grain	30,990	35.51
Corn Silage	32,790	37.57
Soybean	23,500	26.92

Crop Yields

Crop yield data for Brown, Co. WI were obtained from the USDA's National Agricultural Statistics Survey (NASS) online database (http://www.nass.usda.gov/Data_and_Statistics/ Quick_Stats/). Expected crop yields for each conversion scenario were estimated through a three step process. First, we averaged the three highest yielding years between 2000 and 2009 to create a "high" crop yield value for each crop type, under the assumption that in the best production years, both poorly and well drained soils would have similar yields, thus maximizing county wide production values. "High" yields were determined to be 146 bushels acre^{-1} for corn grain, 18.67 tons acre^{-1} for corn silage, and 43.67 bushels acre^{-1} for soybean (Table 12). Second, we utilized a combination of field studies (Objective #1) and precision farming crop yield data (Appendix C), to determine appropriate yield reductions of 67%, 27%, and 0% for PVP, SVP, and well drained soils, respectively. Finally, we utilized the prevalence of each soil drainage class within our two economic analysis scenarios (SVP and SVP-WQ) to properly area-weight expected yield reductions for row crops. Grass production did not vary based on soil drainage class (see Objective #1), so we assumed "high" annual yields of 4 tons acre^{-1} across all soil drainage classes (Objective #1). Using an 11-year rotation, we adjusted this value to an average annual yield of 3.45 tons of grass per acre, assuming 0 tons per acre yield for the first (establishment) year, 2 tons per acre the second year, and 4 tons per acre every year after (USDOE 2011). By this means we were able to adjust economic returns for each scenario based on the prevalence and degree of marginal soils present (Table 12).

Table 12. *Projected crop yields after applying yield reductions based on prevalence of marginal soil drainage classes (per acre for each crop type) in SVP and SVP-WQ row crop to biofuel grassland conversion scenarios. In both models, 7% of current agricultural lands in the LFR-sub basin are converted to perennial biofuel grassland systems. "Max Yield" yield refers to the average of the highest three yielding years from 2000 to 2009 for each crop in Brown, Co., WI.*

Crop Type	"Max" Yield	SVP Scenario	SVP-WQ Scenario
Corn Grain (Bushels acre^{-1})	146.00	99.38	115.76
Corn Silage (Tons acre^{-1})	18.67	12.71	14.80
Soybean (Bushels acre^{-1})	43.67	29.72	34.62
Grasses (Tons acre^{-1})	3.45	3.45	3.45

Average Prices for Crops

Prices were collected by crop type from Brown, Co., WI during the time period of 2004-2008, and CPI adjusted to a 2009-dollar value. Corn grain had an average value of $3.27 per bushel, corn silage had an average value of $30.90 per ton, and soybean had an average value of $8.00 per bushel (Table 13). Corn silage prices were not as readily available as for other crops, so we utilized two independent methods to estimate its value. First, a general valuation method assumes that corn silage per ton is generally 8-10 times the value of a bushel of corn (Anonymous 2009), suggesting a price range of $26.16 to $32.70. Second, corn silage value was determined by assuming a 65% wet/35% dry weight value (Lauer 2000). Of the 35% dry weight, half was assumed to be corn grain and was valued at the determined corn grain value. The other half of the 35% dry weight was determined to be corn stover; and nutrient value of the corn stover was determined by using the UW-Extension Fast Facts sheet (Integrated, n.d.). The price per pound for phosphorus and potassium fertilizer was then applied to the total amount of phosphorus and potassium being removed. The corn grain value and fertilizer equivalent values were summed to develop a sale price of corn silage. Corn grain value of silage is $24.22 and fertilizer value is $6.69 for an aggregate total of $30.90, which is approximately in the midrange of our first estimate. Prices for biofuel grasses were not available, but share similar physical composition to hay grass mixes. For this reason, we utilized grass hay prices as an index of potential biofuel grass value. Grass hay in the state of WI sold for approximately $96.38 per ton (CPI adjusted) during 2004-2008 period (K. Barnett *Personal communication*). We set grass biofuel value at $75 per ton (Table 13), which is slightly more than the $60 per ton modeled in the Billion Ton Update (USDOE 2011), but less than the current value for grass hay. In addition, a $75 per ton value was used previously for biofuel grass value in a recent study focused on the LFR sub-basin (TMDL 2009)

Table 13. *Average crop market price from Brown Co., WI for 2004-2008, CPI adjusted to 2009 dollars.*

Crop Type (Units)	Price Per Unit
Corn Grain (Bushels acre^{-1})	$3.27
Corn Silage (Ton acre^{-1})	$30.90
Soybean (Bushels acre^{-1})	$8.00
Grasses (Ton acre^{-1})	$75.00

Fertilizer Prices and Application Rates

Fertilizer prices were obtained from a private study done by UW-Extension, who collected annually prices from up to 18 facilities that sell fertilizer in Wisconsin from 2008 to 2011. Prices were CPI adjusted and then averaged to create the fertilizer cost values that were used in the enterprise model (K. Erb *personal communication*). Fertilizer Application Rates were determined using the publicly available "Nutrient Management Fast Facts Sheet" created by UW-Extension (Integrated, n.d.). Fertilization rates are determined by crop type, yield expectation, and existing soil test nutrient levels. The Nutrient Management Fast Facts Sheet uses soil test categories ranging from Very Low to Extremely High. In the LFR sub-basin soil fertility is often quite high due to historic and continued manure applications (commonly located somewhere in the High to Extremely High categories). Despite the generally very high soil nutrient levels in LFR sub-basin soils, we conservatively assumed "Optimal fertility" to set fertilizer application rates in our models. For perennial grasslands, it is often recommended to apply a starter nutrient application with commercial fertilizer during the establishment year; which we follow in our models.

In dairy production regions, such as the LFR sub-basin, field application of manure fertilizer is both a common and essential practice. Field application of manure reduces the need for commercial fertilizer (N, P, and K), thus altering production costs. Nutrient credits resulting from manure application were determined from UW-Extension's "Nutrient Management Fast Facts Sheet" (Integrated, n.d.). Because the LFR sub-basin has existing phosphorus restrictions in place, in our model, manure was applied only to the point where the phosphorus supplied by the manure was equal to the annual phosphorus demand of a crop. In general, potassium demand was also fully meet, but nitrogen was supplemented with application of commercial fertilizers. Annual nutrient demands for perennial grasses could be met entirely with manure applications.

Custom Labor Rates, land rent, and interest

Custom Labor rates for each crop type were determined by UW-Extension's "Custom Rate Guide 2010" Handbook (USDA 2011). The Custom Rate Guide Handbook is updated every three years by randomly surveying Wisconsin farmers. All Custom Labor Rates were determined in 2009. Land rent prices were set at $100 per acre for both row crop and native grasslands in agreement with typical prices in the LFR sub-basin. Due to different inputs and outputs total interest costs vary by crop type. However, the interest rate was set at 8% and was applied to all of the production costs as well as 20% of the tillage costs following the scenario used by UW Extension (http://fyi.uwex.edu/cwas/2010/10/27/crop-budget-analyzer-spreadsheet/).

Subsidies

Subsidy data has been compiled by the Environmental Working Group's Farm Subsidy Database (http://farm.ewg.org/region.php?fips=55000). All corn and soybean subsidies for agricultural production were aggregated each year for Brown County for the time period of 2004-2008. Aggregate subsidies were CPI adjusted, averaged and divided by the total average acreage planted in Brown Co. for the 2004-2008 time periods. This created an average per acre per year agricultural subsidy for row crops in Brown Co., WI (Table 14).

Table 14. *Average CPI adjusted subsidies and acreage planted in Brown, Co., WI for corn and soybean production systems from 2004 to 2008.*

Category	Corn Grain	Soybean	Total
Subsidy amount	$4,407,882.49	$535,413.72	$4,943,296.21
Area planted (acres)	63,780.00	23,500.00	87,280.00
	$69.11 acre^{-1}	$22.78 acre^{-1}	$56.64 acre^{-1}

Subsidies are often needed to overcome risk-aversion tendencies that resist major changes in farming practices (i.e. conversion from row crop to biofuel; McGinnis, L. 2008). Along this line, TMDL (2009) suggested that a subsidy payment of $50-100 may be needed for landowners in the LFR sub-basin to switch from row-crop agriculture to perennial biofuel grass production. Economic recognition of the improved ecosystem services likely to follow conversion to perennial grassland may provide an important source where farmer incentives may be generated. Native grasses help provide carbon sequestration, prevent soil and phosphorus runoff, and may provide other benefits such as wildlife habitat (Dale et al. 2010).

The United States Department of Agriculture has created a financial incentive program known as the Biomass Crop Assistance Program (BCAP) (http://www.fsa.usda.gov/Internet/FSA_Federal_Notices/bcap_10_27_2010.pdf) to promote biofuel production. Agricultural areas need to apply and become accepted as a formal BCAP area prior receiving any financial assistance. There is currently funding available to designate additional BCAP areas, and it is quite probable that the LFR sub-basin would be very competitive in obtaining this designation. Once formally established as a BCAP area, farmers in the LFR sub-basin would be eligible to receive reimbursement for up to 75% of establishment costs per acre for perennial native grasses. Matching payments up to $45 per ton for the first two years following grass establishment are also available. Projected subsidy values for this study average $36.18 per year per acre for the BCAP Program (Table 15).

Perennial native grasses are also quite appealing to the general public as a non-traditional agricultural crop, due to some non-market valued externalities that are provided (Dale et al. 2010), including wildlife habitat, runoff control (including TSS and P), and carbon sequestration. Due to historic and continuing nutrient loading issues, the Lower Fox River region has targeted Total Maximum Daily Loads (TMDL) of P and TSS (Cadmus 2011). In a 2007 study, the Cadmus group estimated that the Green Bay Metropolitan Sewerage District (GBMSD) pays $240 kg^{-1} to remove P. Planting of biofuel grasslands has the potential to reduce this loading, and thus could be eligible to receive financial credits for their contribution to improved water quality. Generally, when a point source, such as GBMSD, purchases phosphorus credits from a non-point source (i.e. grasslands), it purchases them at a minimum of a 2:1 ratio (Dupuis et al. 2011), or in other words, they would purchase 2 P credits from a farmer for every 1 P credit they choose to not remove on-site. Following this strategy, GBMSD would pay a maximum of $120 kg^{-1} of P removed by farmers growing biofuel grasses ($240/2). Based on the P reductions estimated in Objective #2, this amounts to roughly $46.20-$58.20 per acre (Table 15).

Native grasses also have an extensive root system capable of sequestering significant carbon in roots and soil (Kucharik 2007). Due to the recent economic downturn and political inertia, the US carbon market is currently depressed. For this reason, inclusion of C sequestration values had no effect on our economic analyses (Table 15). This assumption could easily change in the near future, as at its peak in May of 2008, a metric ton of carbon dioxide was selling in the US for around $7.50 (http://www.chicagoclimatex.com/index.jsf).

Table 15. *Potential ecosystem service subsidies for perennial grass biofuel production in the Lower Fox River sub-basin, WI.*

Subsidy Source	Minimum	Maximum
BCAP	$36.18	$36.18
Phosphorus	$46.20	$58.20
Carbon	$0.00	$0.00
Total	$82.38	$94.38

Enterprise model results

Net economic returns, production expenses, and revenue

Land selection for each scenario (SVP or SVP-WQ), fertilizer application method (commercial fertilizer or manure), and cropping system (row crop rotation or perennial biofuel grassland) all significantly affected the projected economic returns expected by farmers in the LFR sub-basin (Table 16). The modeled average return for a row crop farmer under the SVP scenario in the LFR sub-basin was -$51.04 per acre or -$19.26 per acre depending on whether or not manure was used to meet plant nutrient requirements (Table 16). The SVP-WQ scenario produced an average row crop return of -$17.39 per acre if nutrients were met via commercial fertilization, or $29.12 with manure application (Table 16). As predicted, these results suggest that constant production costs and lower yields leave areas characterized by poorly drained, marginal soils at an economic disadvantage for row crops, and in our model, could even produce a net cost to farmers. In contrast, perennial native biofuel grass production, which was modeled with only manure applications, was consistently profitable in both scenarios. Due to the lack of response of grasses to soil drainage classes, both conversion scenarios returned $25.52 per acre for perennial biofuel grasslands (Table 16). These comparisons include standard row crop subsidies, but importantly do not include any subsidies for grass production. Addition of a BCAP subsidy of $36.18 per acre (Table 15) increases grass revenue to $61.70 per acre, while adding the lowest proposed P subsidy value of $46.20 per acre (Table 15) increases grass revenue to $71.72 (Table 16). Inclusion of both BCAP and P subsidies would conservatively increase biofuel grassland revenue to $107.90 per acre for marginal soils (Table 16). Thus, while inclusion of environmental service subsidies significantly enhances the economic attractiveness of biofuel grassland production, our analysis suggests that in 2009 dollars, biofuel grasslands can compete economically with row crops, irrespective of subsidies, in areas of the LFR sub-basin that are dominated by poorly drained soils.

Land rent was equivalent for all production systems, and interest costs were a relatively low proportion of total production expenses (Figure 6). For this reason, differences in production costs resulted primarily from differences in machinery, fertilization, and seeding costs (Figure 6). In general, the perennial nature of biofuel grasslands significantly lowered fertilizer and seed costs, relative to traditional row crops (Figure 6). Biofuel grasslands also realized a smaller machinery cost, largely restricted to a fall harvest and subsequent removal. As fuel and fertilizer prices continue to rise into the future, it seems likely that biofuel grass production costs will continue to decline relative to row crop production systems, further enhancing their economic viability. Despite higher revenue generation from the sale of row crops, simultaneous higher production expenses resulted in generally lower farm level profits in marginal lands, relative to perennial biofuel grasses (Figure 7). Profits again become notably more favorable if subsidies are available for ecosystem services such as renewable energy generation (BCAP) and water quality improvements (P credits). In contrast, recent increases in agricultural commodities prices are equally likely to alter the economic feasibility that we outline in this study.

Table 16. *Average expected return per acre for modeled row crop rotation (corn silage, corn grain, soybean) and perennial biofuel grasslands under both the SVP and SVP-WQ scenarios in the Lower Fox River sub-basin, WI. Manure application assumes that most crop nutrient demands are met with manure application, although supplemental commercial N is included, while all nutrient requirements are met via commercial fertilizer application in the alternative model option.*

	Commercial Fertilizer	Manure Application
Row Crop Rotation		
SVP Scenario	-$51.04	-$19.26
SVP-WQ Scenario	-$17.39	$29.13
Perennial Biofuel Grassland		
SVP and SVP- WQ	N/A	$25.52
BCAP with SVP and SVP- WQ	N/A	$61.70
P credit with SVP and SVP- WQ	N/A	$71.72
BCAP and P credit with SVP and SVP- WQ	N/A	$107.90

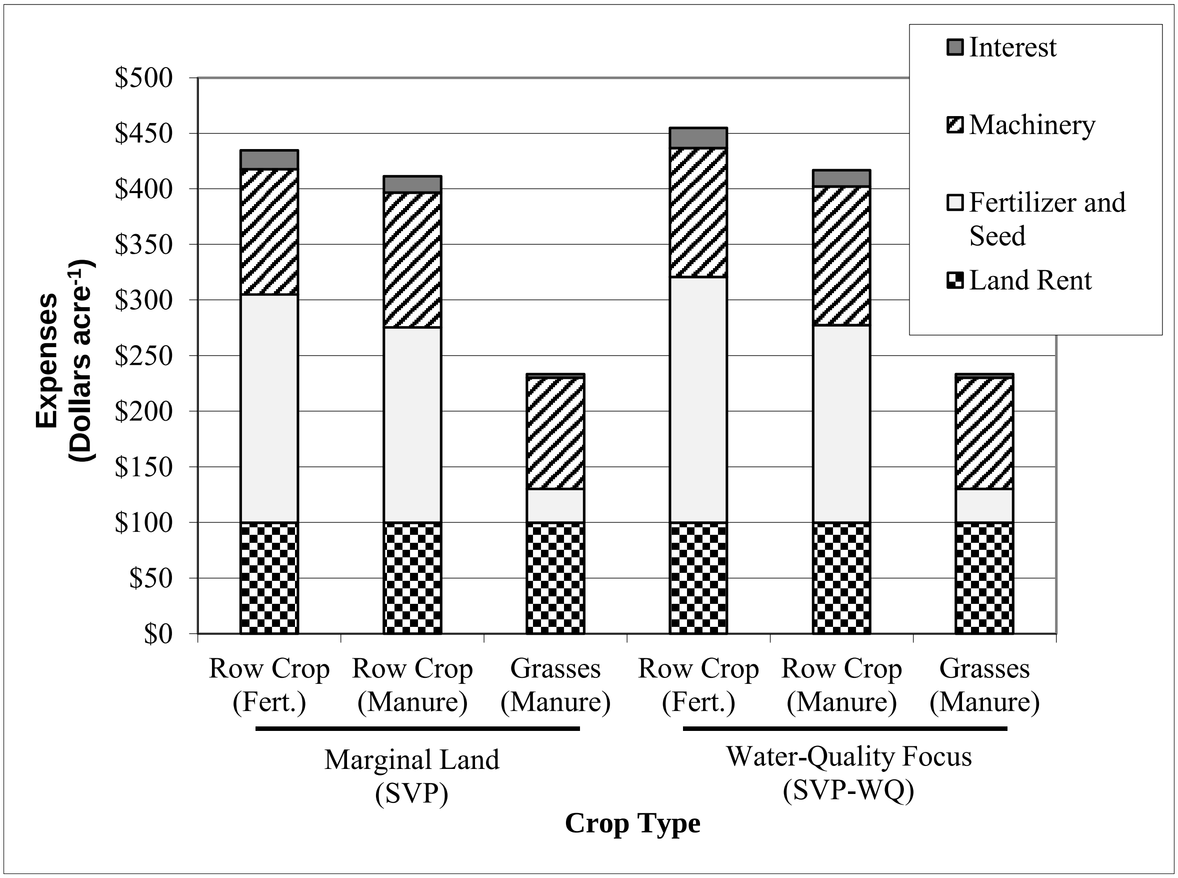

Figure 6. *Production expenses for row crop rotation (corn grain, corn silage, soybean) and perennial biofuel grasses in the Lower Fox River sub-basin, WI under two land conversion scenarios targeting poorly-drained soils throughout the sub-basin (Marginal Lands, SVP) or within the highest P-yielding sub-watersheds (Water-Quality Focus, SVP-WQ), with crops receiving either commercial fertilizers or manure applications.*

IMPLAN Regional Analysis

We utilized IMPLAN, an input-output modeling program, to determine the regional impacts of increased biofuel-grass production within the LFR sub-basin. The acronym IMPLAN is short for IMpact analysis for PLANning. IMPLAN is available from MIG, Inc., and its third edition was released in 2009 (IMPLAN Version 3.0). IMPLAN works by evaluating the interrelated purchases that occur when a final good is made. For example, when a unit of produce (e.g., lettuce) is purchased, a portion of the purchase price covers labor costs, another portion of the purchase price covers shipping costs, and so forth until the full amount of the purchase price is apportioned appropriately. Different goods will differentially proportion the purchase price, but in general, locally produced goods have more locally based expenses, which lead to more money staying local.

To determine the regional impact of any new economic activity, it is necessary to first know the associated aggregate revenue changes with the new activity. For this project, 13,900 acres (or 7%) of row-crop agriculture were targeted for conversion to biofuel grasslands. Direct changes are equal to the potential revenue generated per acre times the total acreage changed. Row crop agricultural generally has

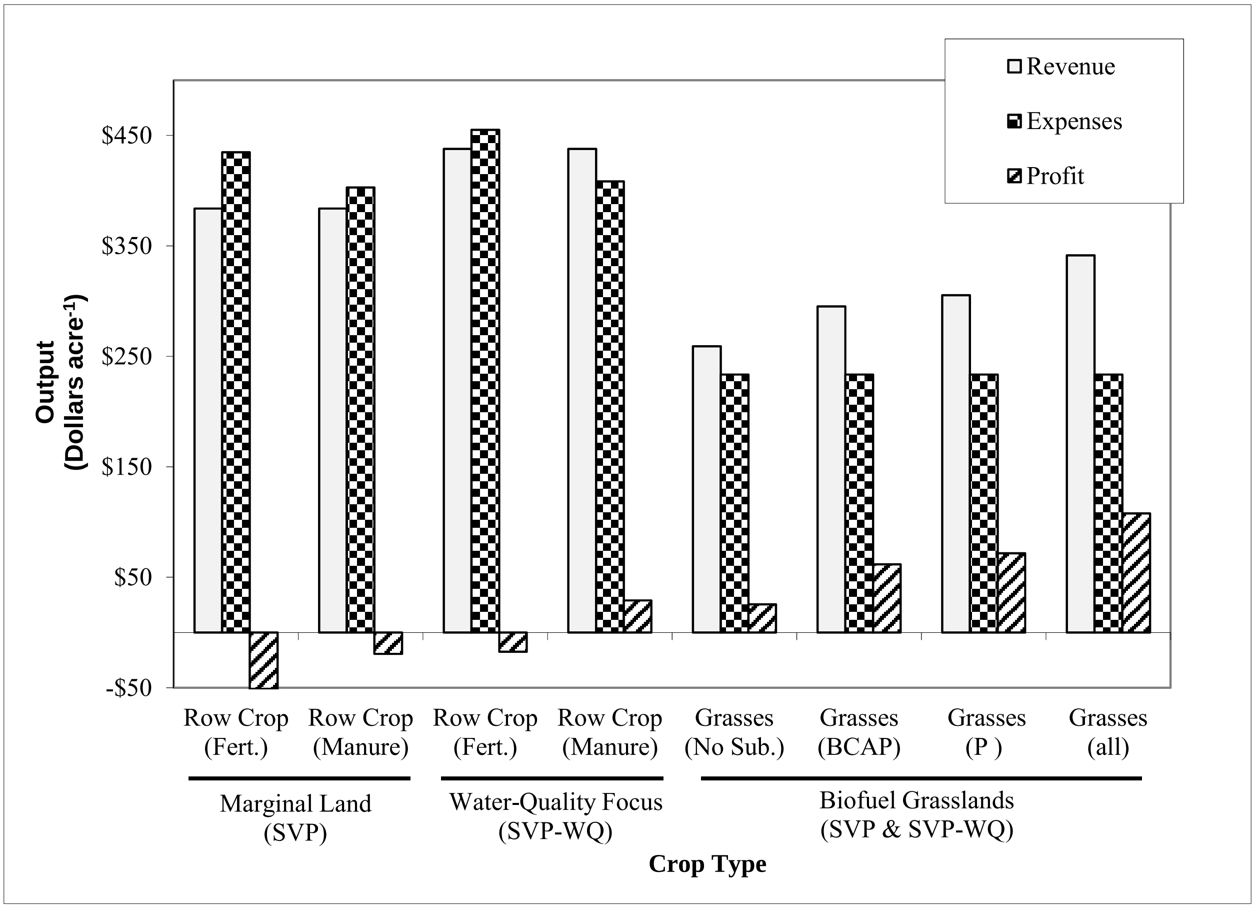

Figure 7. *Summary of revenues, expenses, and profits for row crops (corn grain, corn silage, and soybean) and perennial biofuel grasslands when grown in poorly drained soils under two conversion scenarios in the Lower Fox River sub-basin, WI. All grass stands were given the manure addition treatment (Manure), not commercial fertilizer (Fert.) Typical subsidies are included in all row crop values; grasslands were evaluated without (no sub.), with a BCAP subsidy (BCAP), with phosphorous reduction subsidies (P), or both subsidies (all).*

expenses associated with crops that are higher than those associated with native grasses, even though direct profits from biofuel grasses may be greater. Aggregate changes in the regional economy also include indirect effects, because the direct effects of an economic activity impact other seemingly unrelated sectors through input purchasing, product sales, and changes to household incomes.

Our IMPLAN model focused on the SVP scenario, as it seemed the most feasible scenario to implement within the LFR sub-basin. The regional impact analysis was conducted by comparing total revenue from native grass production to the total revenue that would have been earned maintaining current row-crop production utilizing a manure fertilizer. Thus, once again we have taken a conservative approach in our economic analysis, as manure-based fertilizer systems were generally more profitable in our row crop systems (Figure 7). Output parameters included changes in the number of jobs, the regional economic activity, and a sector analysis indicating the top five positively and top five negatively impacted sectors (as measured by both employment and dollar changes). Our first analysis assumes that biofuel grassland production is implemented without the addition of an associated regional pelletizing plant, as no such facility is currently operating within the LFR sub-basin with biofuel grasses as the primary feedstock. Based on this model, the lower absolute revenue, not profit, associated with grass biofuels appears to negatively impact the region via job losses and a reduction in total regional economic activity (Table 17). Not surprisingly, the most heavily affected sectors are those most directly associated with current agricultural activities, such as grain farming (Table 17). While jobs are created in response to biofuel grassland implementation, they did not surpass those lost to grain farming, due to grain farming's labor intensive nature.

Land conversion to grassland biofuel is unlikely to occur without both the presence of federal subsidies (BCAP) and an associated pelleting plant to process biofuel grass feedstock within the LFR sub-basin. For this reason, we ran a second regional economic scenario with IMPLAN that incorporated a subsidy value (BCAP) of $36.18 per acre for 13,900 acres, and a pelleting plant (added to the Brown Co. IMPLAN database). Revenue from a pelleting facility was determined by dividing the total amount of grass biofuel produced by 1.18, the conversion factor for converting feedstock into manufactured pellets (Snippen 2011). The subsequent quantity of manufactured pellets was then multiplied by a $200 ton-1 sale price for pellets. Direct changes to the region from addition of a pelleting plant are estimated to be $7,681,487 (Table 18). Under this scenario grain farming is the only sector that suffers substantial losses to both jobs and economic impact, and while a loss of some jobs still occurs, an overall increase in net regional economic impact of close to $10 million occurs (Table 18).

If data had been available for the more expansive LFR sub-basin that encompasses portions of Calumet, Outagamie and Winnebago Counties in addition to Brown County, then changes in total regional impacts may have been more positive than what was originally modeled by only using Brown County. Assuming the pelleting plant would still be located in Brown County, direct changes would be unaltered with the creation 45.9 jobs and $7,681,487 in regional output. However, the indirect job creation and regional output would likely increase as the "leakage" from the region would be smaller and lead to greater within region impacts. Under current modeling, any money or jobs located outside of Brown County would not be counted. Some of these jobs and output changes are likely located within the Lower Fox River Basin, yet not within Brown County itself. Regardless, the coupled conversion to biofuel grasslands with BCAP designation and the creation of a pelleting plant would result in the most positive job creation and regional economic impact.

Table 17. *IMPLAN modeled regional economic impact of implementing a 7% change in current agricultural land within the Lower Fox River sub-basin from row crop agriculture to biofuel grasslands. Importantly this model assumes no associated pelletizing plant within the region.*

No Subsidy or Pelleting Plant Scenario:
Regional Impacts from Converting Row-Crop Agricultural Land to Perennial Native Grass Production (measured in 2009 Dollars)

	Direct	Total
Jobs	**-107.00**	**-114.90**
Dollars	-$1,732,913	-$2,482,677

Top 5 Positively Impacted Industry Sectors (measured in 2009 Dollars)

Jobs		Economic Impact	
Industry Sector	**Direct Job Impact**	**Industry Sector**	**Direct Dollar Impact**
Perennial Native Grass Production	19.5	Perennial Native Grass Production	$3,601,346
Support Activities for Agriculture and Forestry	0.3	Electric Power Generation, Transmission and Distribution	$51,592
Electric Power Generation, Transmission and Distribution	0.1	Support Activities for Agriculture and Forestry	$6,975
		Transport by Truck	$3,980
		Commercial and Industrial Machinery and Equipment Rental and Leasing	$1,635

Top 5 Negatively Impacted Industry Sectors (measured in 2009 Dollars)

Jobs		Economic Impact	
Industry Sector	**Direct Job Impact**	**Industry Sector**	**Direct Dollar Impact**
Grain Farming	-126.5	Grain Farming	-$5,333,629
Real Estate Establishments	-2.3	Real Estate Establishments	-$176,770
Imputed Rental Activity for Owner-Occupied Rental Buildings	-0.8	Imputed Rental Activity for Owner-Occupied Rental Buildings	-$90,848
Wholesale Trade Business	-0.4	Wholesale Trade Business	-$58,898
Private Hospitals	-0.3	Private Hospitals	-$49,991

Source: IMPLAN 3.0 model run of Watershed Scenario (with land conversion from row-crop to native grasses within the entire LFRR)

Table 18. *IMPLAN modeled regional economic impact of implementing a 7% change in current agricultural land within the Lower Fox River sub-basin from row crop agriculture to biofuel grasslands, including both a BCAP designation and an associated pelletizing plant in Brown Co., WI.*

BCAP Subsidy and Brown County Pelleting Plant Scenario: **Regional Impacts from Converting Row-Crop Agricultural Land to Perennial Native Grass Production (measured in 2009 Dollars)**			
	Direct		**Total**
Jobs	-63.3		-31.9
Dollars	$6,385,920		$10,104,655
Top 5 Positively Impacted Industry Sectors (measured in 2009 Dollars)			
Jobs		**Economic Impact**	
Industry Sector	**Direct Job Impact**	**Industry Sector**	**Direct Dollar Impact**
Pellet Plant	45.9	Pellet Plant	$7,681,487
Perennial Native Grass Production	23.3	Perennial Native Grass Production	$4,299,372
Wholesale Trade Business	2.6	Wholesale Trade Business	$466,859
Food Services and Drinking Places	2.6	Electric Power Generation, Transmission and Distribution	$235,346
Services to Buildings and Dwellings	1.3	Imputed Rental Activity for Owner-Occupied Rental Buildings	$189,473
Top 5 Negatively Impacted Industry Sectors (measured in 2009 Dollars)			
Jobs		**Economic Impact**	
Industry Sector	**Direct Job Impact**	**Industry Sector**	**Direct Dollar Impact**
Grain Farming	-132.4	Grain Farming	-$5,584,339
		Soap and Cleaning Components	-$2,030
		Mining and Quarrying Stone	-$38
Source: IMPLAN 3.0 model run of Watershed Scenario (with land conversion from row-crop to native grasses within the entire LFRR)			

Conclusion:

Biofuel grass production in the marginal fields of NE Wisconsin, defined as those fields containing a significant portion of lowland, seasonally wet soils, appears competitive from a production standpoint with values reported elsewhere in the Midwest United States. Realization of these yields is most likely met with the use of mixed-species graminoid plantings, and we suggest greater research into the potential of specific legume selection and inclusion to meet nitrogen demands. In contrast, row crop yields in similar, marginal, fields were not economically competitive, supporting biofuel grasslands as a viable alternative crop on marginal lands in NE Wisconsin. This conclusion was further supported by farm gate economic analyses, which suggested economic competitiveness with row crops at biofuel grassland yields similar to those we reported from our minimally managed grassland study sites. Biofuel grasslands provided additional benefits to soil quality (e.g. bulk density) and sequestered significant quantities of C and P in perennial root systems. These changes were reflected in our watershed modeling, where conversion of 7% of current row crop acreage into biofuel grasslands significantly reduced total P and suspended sediment loads into regional water bodies. These ecosystem services provide an additional value to NE Wisconsin beyond direct biomass sales, and incorporation of the value associated with P reduction alone further enhanced the economic attractiveness of biofuels in NE Wisconsin. The greatest economic benefits would result from a regional Biomass Crop Assistance Program (BCAP) designation, and the establishment of a pelleting facility in the LFR sub-basin to enhance the value of locally produced biofuel biomass. We conclude that NE Wisconsin's location on the margin of the Corn Belt makes it an ideal location for the development of biofuel industries, largely due to the lower potential return from row crops. All economic analyses are further strengthened by the complimentary benefits to water quality resulting from expansion of biofuel grasslands in NE Wisconsin.

Literature Cited:

Abrams, M.D., A.K. Knapp, and L.C. Hulbert. 1986. A ten-year record of aboveground biomass in a Kansas tallgrass prairie: effects of fire and topography. American Journal of Botany 73: 1509-1515.

Anonymous. 2007. University of Wisconsin – Madison Soil and Plant Analysis Lab. Sample Preparation & Lab Dry Matter for Feed and Forage. http://uwlab.soils.wisc.edu/files/procedures/forage_prep.pdf

Anonymous. 2009. University of Kentucky – Cooperative Extension Service, College of Agriculture. 2009. Valuing Corn Silage for Beef Cattle Feed, 2009 Guide. Publication AEC 2009-12. Produced by the Department of Agricultural Economics, University of Kentucky (8/18/09) http://ces.ca.uky.edu/wayne-files/ANR/NewslettersFlyers/Valuing_Corn_Silage_for_Beef_Cattle_Feed.pdf

Arnold, J.G., J.R. Williams, R. Srinivasan, and K.W. King. 1996. SWAT: Soil and Water Assessment Tool. Model documentation. USDA, Agricultural Research Service. Grassland Soil and Water Research Lab, Temple, Texas.

Baer, S.G., D.J. Kitchen, J.M. Blair, and C.W. Rice. 2002. Changes in ecosystem structure and function along a chronosequence of restored grasslands. Ecological Applications 12; 1688-1701.

Baer, S.G., J.M. Blair, S.L. Collins, and A.K. Knapp. 2003. Soil resources regulate productivity and diversity in newly established tallgrass prairie. Ecology 84: 724-735.

Baumgart, P. 2005. Source Allocation of Suspended Sediment and Phosphorus Loads to Green Bay from the Lower Fox River Sub-basin Using the Soil and Water Assessment Tool (SWAT)- Lower Green Bay and Lower Fox Tributary Modeling Report. Joint Conference: Lake Michigan, State of the Lake and Great Lakes Beach Association, Green Bay, Wisconsin, November 2-3, 2005. (full report and presentation available at: ww.uwgb.edu/watershed/REPORTS/Related_reports/Load-Allocation/LowerFox_TSS-P_Load-Allocation.pdf).

Becker, D.A., and J.J. Crocket. 1976. Nitrogen fixation in some prairie legumes. American Midland Naturalist 96: 133-143.

Buyanovsky, G.A., C.L. Kucera, and G.H. Wagner. 1987. Comparative analyses of carbon dynamics in native and cultivated ecosystems. Ecology 68: 2023-2031.

The Cadmus Group (Cadmus). 2007. Integrated Watershed Approach Demonstration Project: A Pollutant Reduction Optimization Analysis for the Lower Fox River Basin and the Green Bay AOC. August 2007. Prepared for U.S. EPA (contract 68-C-02-109). Report prepared by Laura Blake of The Cadmus Group, Inc., with contributions by Paul Baumgart of the University of Wisconsin – Green Bay and Dr. Samuel Ratick of The Cadmus Group, Inc. Accompanying reports which describe the SWAT application include Appendix A, Quality Assurance Project Plan (QAPP) and Appendix B, SWAT Model Refinements.

The Cadmus Group (Cadmus). 2011. Total Maximum Daily Load and Watershed Management Plan for Total Phosphorus and Total Suspended Solids in the Lower Fox River Basin and Lower Green Bay. DRAFT August 2011. Prepared for U.S. Environmental Protection Agency, Wisconsin Department of Natural Resources, Oneida Tribe of Indians of Wisconsin.

Conley, S., P. Esker, M. Martinka, J. Gaska, and K. Lackerman. 2010. Wisconsin winter wheat performance tests – 2010. UW-Extension document A3868.

Dale, V.H., K.L. Kline. J. Wiens, and J. Fargione. 2010. Biofuels: implications for land use and biodiversity. Biofuels and Sustainability Reports, Ecological Society of America.

Dornbush, M.E., T.M. Eisenhardt, and J.W. Raich. 2002. Quantifying fine root decomposition: an alternative to buried litterbags. Ecology 83: 2985-2990.

Dupuis, T., L. Bacon, and B. Brown. 2011. Water quality trading white paper prepared for the Green Bay Metropolitan Sewerage District (GBMSD).

Fornara, D.A., and D. Tilman. 2008. Plant functional composition influences rates of soil carbon and nitrogen accumulation. Journal of Ecology 96: 314-322.

Gassman P.W., M.R. Reyes, C.H. Green, and J.G. Arnold. 2007. The Soil and Water Assessment Tool: Historical development, applications, and future directions. Trans. ASABE 50(4) 1211-1250.

Gibson, L. 2007. Using science to fuel and feed our global society: switchgrass. Iowa State University Extension.

Heaton, E.A., F.G. Dohleman, and S.P. Long. 2009. Seasonal nitrogen dynamics of *Miscanthus x giganteus* and *Panicum virgatum*. Global Change Biology Bioenergy 1: 297-307.

Integrated Pest and Crop Management. (n.d.) Nutrient Management Fast Facts Sheet. UW Extension. Retrieved from http://144.92.93.211/downloads/nutrient-managment/

Jain, A.T., M. Khanna, M. Erickson, and H. Huang. 2010. An integrated biogeochemical and economic analysis of bioenergy crops in the Midwest United States. Bioenergy 2: 217-234.

Jobbágy, E.G., and R.B. Jackson. 2000. The vertical distribution of soil organic carbon and its relation to climate and vegetation. Ecological Applications 10: 423-436.

Jordan, C.F., and G. Escalante. 1980. Root productivity in an Amazonian rain forest. Ecology 61: 14-18.

Knapp, A.K., J.M. Briggs, J.M. Blair, and C.L. Turner. 1998. Patterns and controls of aboveground net primary production in tallgrass prairie. Pp. 193-221 *IN* A.K. Knapp, et al.'s Grassland Dynamics: Long-term Ecological Research in Tallgrass Prairie. Oxford Press, New York.

Kucharik, C.J. 2007. Impact of prairie age and soil order on carbon and nitrogen sequestration. Soil Science Society of America Journal 71: 430-441.

Kucharik, C.J. and S.P. Serbin. 2008. Impacts of recent climate change on Wisconsin corn and soybean yield trends. Environmental Research Letters 3: 1-10.

Lauer, J. 2000. The relationship between corn grain and silage yield. UW-Extension Focus on Forage 3(7): 1-2. http://www.uwex.edu/ces/crops/uwforage/Grain_vs_Silage.pdf

Lehmann, J. 2007. Bio-energy in the black. Frontiers in Ecology and The Environment 7: 381-387.

Lemus, R., E.C. Brummer, C.L. Burras, K.J. Moore, M.F. Barker, N.E. Molstad. 2008. Effects of nitrogen fertilization on biomass yield and quality in large fields of established switchgrass in southern Iowa,USA. Biomass and Bioenergy 32: 1187-1194.

Lovell, S.T., and W.C. Sullivan. 2006. Environmental benefits of conservation buffers in the United States: evidence, promise, and open questions. Agriculture, Ecosystems and Environment 112: 249-260.

Matamala, R., J.D. Jastrow, R.M. Miller, and C.T. Garten. 2008. Temporal changes in C and N stocks of restored prairie: implications for C sequestration strategies. Ecological Applications 18: 1470-1488.

McGinnis, L. 2008. Assessing biofuels' sustainability: economic and biophysical models aid the process. Issue of Agricultural Research Magazine (Oct).

Odum, H.T. 2007. Environment, power, and society for the twenty-first century: the hierarchy of energy. Columbia University Press, New York.

Olsen, A. 2001. Co-burning biomass opportunities in Wisconsin: a strategic assessment. Final Report No. 80081 for the Division of Energy, Wisconsin Department of Administration.

Parrish, D. J., and J.H Fike, 2005. The biology and agronomy of switchgrass for biofuels. Critical Reviews in Plant Sciences 24:423-459.

Paul, E.A., S.J. Morris, and S. Böhm. 2001. The determination of soil C pool sizes and turnover rates: biophysical fractionation and tracers. Pp. 193-206 *IN* Lal et al. (eds) Assessment Methods for Soil Carbon. Advances in Soil Science. CRC Press, Boca Raton, FL.

Porter, P. A., J. Barry, R. Samson, and M. Doudlah, M. 2008. Growing Wisconsin Energy. A Native Grass Pellet Bio-Heat Roadmap for Wisconsin. Agrecol Corporation

Renz, M., D. Undersander, and M. Casler. 2009. Establishing and managing switchgrass. University of Wiscosin-Extension Factsheet.

Robertson, G.P., S.K. Hamilton, S.J. Del Grosso, and W.J. Parton. 2011. The biogeochemistry of bioenergy landscapes: carbon, nitrogen, and water considerations. Ecological Applications 21: 1055-1067.

Russell, A.E., C.A. Cambardella, D.A Laird, D. B. Jaynes, and D. W. Meek. 2009. Nitrogen fertilizer effects on soil carbon balances in Midwestern US agricultural systems. Ecological Applications 19: 1102-1113.

Sala, O.E., W.J. Parton, L.A. Joyce, and W.K. Lauenroth. 1988. Primary production of the central grassland region of the United States. Ecology 69: 40-45.

Schimel, D.S., M.A. Stillwell, and R.G. Woodmansee. 1985. Biogeochemistry of C, N, and P in a soil catena of the shortgrass steppe. Ecology 66: 276-282.

Schulte E.E, J.B. Peters, and P.R. Hodgson. 1987. Wisconsin Procedures for Soil Testing, Plant Analysis and Feed & Forage Analysis, No. 6, Soil Fertility Series.

Schultz, R.C., J.P. Colletti, T.M. Isenhart, C.O. Marquez, W.W. Simpkins, and C.J. Ball. 2000. Riparian forest buffer practices. IN North American agroforestry: an integrated science and practice. H.E. Garrett, W.J. Rietveld, and R.F. Fisher. Soil Science Society of America, Madison, WI.

Seadstedt, T.R., J.M. Brigs, and D.J. Gibson. 1991. Controls on nitrogen limitation in tallgrass prairie. Oecologia 87: 72-79.

Snippen, A. 2011. Life-Cycle Inventory of Wood Pellet Fuel Manufacturing in Wisconsin. M.S. Thesis, Environmental Science & Policy Graduate Program, University of Wisconsin-Green Bay.

Soil Survey Division Staff. 1993. Soil survey manual. Soil Conservation Service. U.S. Department of Agriculture Handbook 18.

Teel, A. 1998. Management guide for the production of switchgrass for biomass fuel production in southern Iowa. Paper presented at BioEnergy ‘98, Madison, WI.

Thelemann, R., G. Johnson, C. Sheaffer, S. Banerjee, H.W. Cai, and D. 2010. The effect of landscape position on biomass crop yield. Agronomy Journal 102: 513-522.

Tilman, D., J. Knops, D. Wedin, P. Reich, M. Ritchie, and E. Siemann. 1997. The influence of functional diversity and composition on ecosystem processes. Science 277: 1300-1302.

Tilman, D., P.B. Reich, J. Knops, D. Wedin, T. Mielke, and C. Lehman. 2001. Diversity and productivity in a long-term grassland experiment. Science 294: 843-845.

Tilman, D., J. Hill, and C. Lehman. 2006a. Carbon-negative biofuels from low-input high-diversity grassland biomass. Science 314: 1598-1600.

Tilman, D., P.B. Reich, J.M.H. Knops. 2006b. Biodiversity and ecosystem stability in a decade-long grassland experiment. Nature 441: 629-632.

Tlusty, B., J.M. Grossman, and P.H. Graham. 2004. Selection of rhizobia for prairie legumes used in restoration and reconstruction programs in Minnesota. Canadian Journal of Microbiology 50: 977-983.

TMDL. 2009. The Lower Fox River and Green Bay TMDL project agricultural management practices costs and implementation rates. http://www.co.brown.wi.us/i_brown/d/land__water_conservation/agricultural_management_practices_summary_%28draft_9-18-09%29.pdf

Tufekcioglu, A., J.W. Raich, T.M. Isenhart, and R.C. Schultz. 2003. Biomass, carbon and nitrogen dynamics of multi-species riparian buffers within an agricultural watershed in Iowa, USA. Agroforestry Systems 57: 187-198.

Turner, J.A. 1999. A realizable renewable energy future. Science 28: 687-689.

U.S. Department of Agriculture. 2011. National Agricultural Statistics Service. Custom Rate Guide 2010.

U.S. Department of Energy. 2011. U.S. Billion-Ton Update: Biomass Supply for a Bioenergy and Bioproducts Industry. R.D. Perlack and B.J. Stokes (Leads), ORNL/TM-2011/224. Oak Ridge National Laboratory, Oak Ridge, TN. 227p.

Wang, D., D.S. Lebauer, and M.C. Dietze. 2010. A quantitative review comparing the yield of switchgrass in monocultures and mixtures in relation to climate and management factors. GCB Bioenergy 2: 16-25.

Zavaleta, E.S., J.R. Pasari, K.B. Hulvey, and G.D. Tilman. 2010. Sustaining multiple ecosystem functions in grassland communities requires higher biodiversity. PNAS 107: 1443-1446.

Appendix A: Study sites

The perennial native grassland study site is located on the University of Wisconsin – Green Bay campus in Green Bay, Brown Co., WI, USA (44.527743°N, 87.926365°W). Row Crop study plots are located within 22 km of grassland sites, on the Oneida Nation Reservation, Brown Co., WI, USA (44.465978°N, 88.180397°W). Study plots are located on the Kewaunee/Manawa silt loam soil association that is common in Northeast Wisconsin. Kewaunee soils are classified as fine, mixed, active, mesic Typic Hapludalfs and are associated with well drained upland and slope landscape positions (Table A1). Manawa soils are classified as fine, mixed, active, mesic Aquollic Hapludalfs and are associated with somewhat poorly drained lowland and level landscape positions (Table A1). This soil association was selected to study the effects of soil moisture while controlling for soil texture.

Six paired upland and lowland plots were established in the summer of 2009 on historically cultivated land that have been planted to native tallgrass prairie or remain in active row crop production. Grassland plots established in prairie are 15 x 5-m, while plots established in active row crop fields are 15 x 10-m. Since 2005, typical crop rotation for row crop sites included three years of alfalfa, followed by one year of corn grain, one year of corn silage, and on year of winter wheat. Our study included corn silage and winter wheat plantings. Grassland plots are burned approximately every 3-5 years to maintain species composition. Pairs of two plots were established in three distinct crop and grassland sites, with each grassland site pertaining to an independent historical farm field that was converted to prairie 27, 31, or 36 years prior to plot installation. Within each site, one plot was established on well-drained, upland Kewaunee soils, while the other was established on somewhat poorly drained, lowland Manawa soils, with the exception of one plot per crop type (Table A1). Thus, the plots encompass the natural soil moisture gradient of the grassland.

Table A1. *Soil properties of the six native grassland and six row crop study plots. All plots are located in Brown, Co., WI. Numbers following topographic position designated pairing of upland and lowland plots. Soil series, drainage class, slope, and map unit are taken from http://websoilsurvey.nrcs.usda.gov/, reflecting the lower resolution of standard soil mapping.*

Vegetation Type	Topographic Position	Soil Series	Drainage Class	Slope (%)
Grassland	Upland-1	Kewaunee silt loam (eroded)	Well drained	2-6
Grassland	Upland-2	Kewaunee sandy loam	Well drained	2-6
Grassland	Upland-3	Kewaunee silt loam	Well drained	2-6
Grassland	Lowland-1	Kewaunee silt loam (eroded)	Well drained	2-6
Grassland	Lowland-2	Manawa silty clay loam	Somewhat poorly drained	1-3
Grassland	Lowland-3	Kewaunee silt loam (eroded)	Well drained	6-12
Row Crop	Upland-1	Kewaunee silt loam	Well drained	2-6
Row Crop	Upland-2	Kewaunee silt loam	Well drained	2-6
Row Crop	Upland-3	Kewaunee silt loam	Well drained	2-6
Row Crop	Lowland-1	Manawa silty clay loam	Somewhat poorly Drained	1-3
Row Crop	Lowland-2	Kewaunee silt loam	Well drained	2-6
Row Crop	Lowland-3	Manawa silty clay loam	Somewhat poorly Drained	1-3

Appendix B: Climatic conditions

The overall average temperature for both sites is 6.9°C with a low monthly average temperature of -9.2°C in January and high monthly average temperature of 21.1°C in July. The average total precipitation is 741.1-mm per year. The study took place over the course of two years with contrasting weather patterns occurring between years. Seasonal average temperature was 6.4°C and total precipitation was 703.6-mm in 2009, resulting a slightly drier than normal year. However, seasonal average temperature was 8.3°C and total precipitation was 970.0-mm in 2010, making it the second wettest year on record. A central challenge of interpreting the results of our study was identifying the relative frequency of climatic years similar to those that we observed in our study. To address this issue, we produced histograms built from 25 mm precipitation bins derived from the Green Bay Austin Straubel International Airport (KGRB) weather station between 1971 and 2010. These analyses were conducted for the entire 2009 and 2010 calendar years, spring (March, April, May), summer (June, July, August), fall (September, October, November), and winter (December, January, February) of both years (Table B1). These periods were selected based on the seasonal patterns of precipitation and maximum temperature (Figure B1a, B1b).

Table B1. *Annual and seasonal precipitation during the 2009 and 2010 study growing seasons relative to long-term (1971-2010) trends in Brown, Co. WI.*

Period	2009 Precipitation (mm)	2009 % Drier	2010 Precipitation (mm)	2010 % Drier
Total	703.6	30.0	970.0	100.0
Spring (Mar, Apr, May)	208.9	60	150.9	17.5
Summer (Jun, July, Aug)	183.1	12.5	525.1	100
Fall (Sept, Oct, Nov)	197.3	62.5	201.6	62.5
Winter (Dec, Jan, Feb)	114.3	57.5 to 80	92.4	57.5

The 2009 calendar year was, on average, a drier than typical year, with only 30% the years from 1971 to 2010 receiving less precipitation than 2009. However, this value is a bit misleading, in that 2009 actually had relatively average precipitation for spring, fall, and winter, with a notably dry summer (Table B1). In fact, only 12.5% of summers from 1971 to 2010 were drier than in 2009. In contrast, the 2010 calendar year was the second wettest year recorded during the 1971 to 2010 climate period, with only 1985 receiving more annual precipitation at 797.2 mm. However, as with 2009, moisture was not evenly distributed, and 2010 had a dry spring, relatively average fall and winter seasons, and the wettest summer recorded during our included time period (Table B1).

Simple comparisons of crop yield data with precipitation is a complicated matter. For example, wet spring may reduce yields due to delayed planting, or drown seeds in lowland areas. Likewise, a wet summer can similarly reduce crop yields by drowning low lying areas, and reducing N availability. However, a similar crop yield could also result from a midsummer drought, which likewise reduces

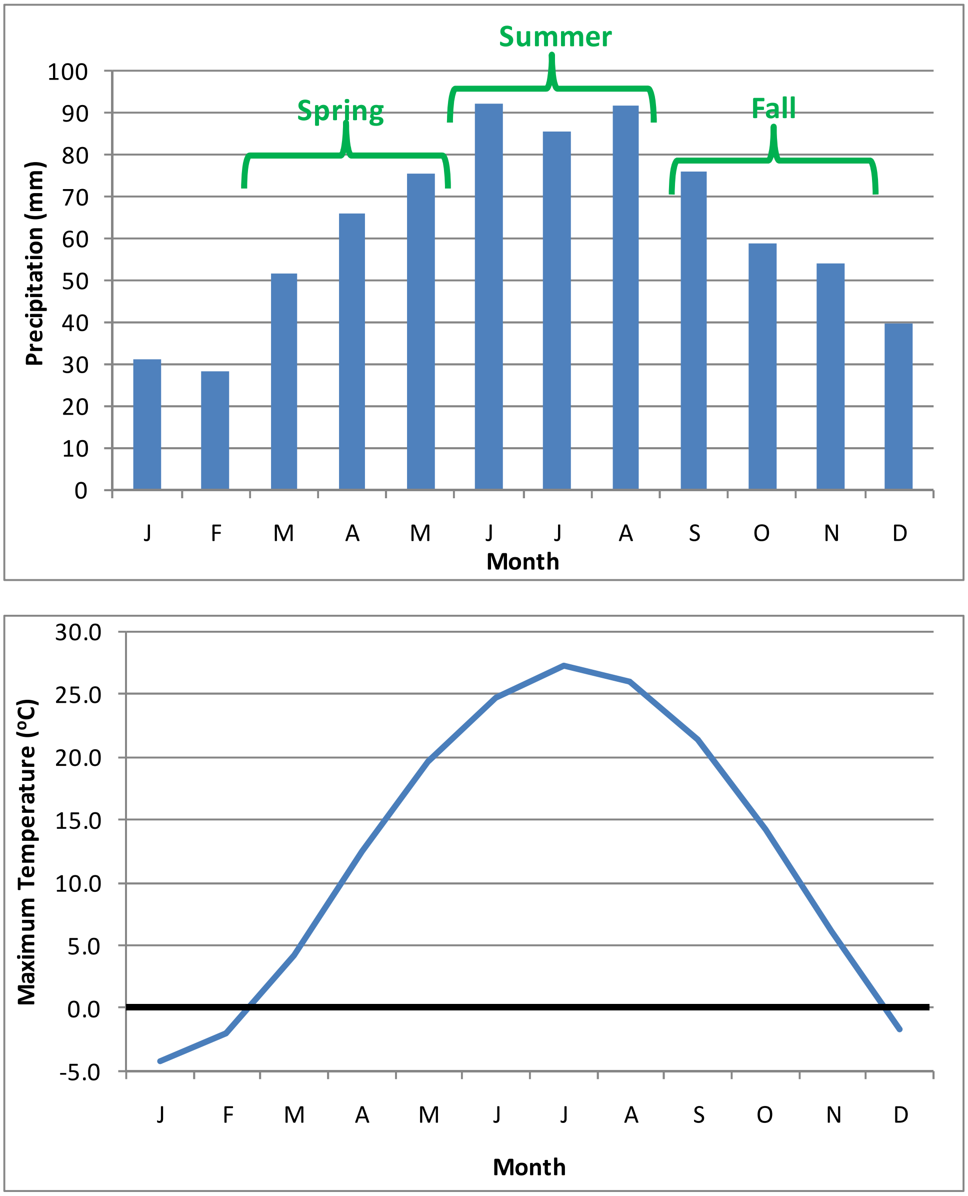

Figure B1. a) *Seasonal precipitation (mm) patterns and* ***b)*** *maximum temperature (^{o}C) for Brown County, Wisconsin based on data collected from Austin Straubel International Airport weather station between 1971 and 2010.*

nutrient availability and reduces crop carbon gain. Our objective was not to provide detailed crop yield models based on climatic factors. However, the limited interannual sample size of this study requires that we in some way identify how typical, or atypical, yields were for the 2009 and 2010 study years. We utilized corn grain yield data from the National Agricultural Statistics Service (http://www.nass.usda.gov/) between 1956 and 2010 to determine the relative qualities of our two studied growing seasons. Significant enhancement of corn yields from 1956 to present required an adjustment to account for improved seed technology, changes in growing season length, nutrient management, and other on-farm improvements (Kucharik and Serbin 2008). Simple linear regression suggests that corn grain yield has increased at a rate of 1.36 bu per acre since 1956 ($R^2 = 0.69$) in Brown County, WI. Using this regression to adjust historic crop yields to present values, suggests that despite significantly different climatic conditions in 2009 and 2010, corn grain yield was surprisingly average in both years (Table B2). Specifically, we found that corn grain yield in both 2009 and 2010 produced yields greater than 47% of all years, or yielded less than 53% of all years included in our analysis. In summary, despite significant differences in growing season climate between 2009 and 2010, these two years appear to have yielding surprisingly average row crop yields in Brown Co., WI.

Table B2. *Raw and adjusted average corn grain yields during the two year study period relative to the 1956 to 2009 average corn yields for Brown, Co., WI. Long-term changes in grain yield we corrected with simple linear regression using an average increase of 1.36 bu/year (R^2 = 0.69).*

Category	2009 (bu/acre)	2009 % lower yield	2010 (bu/acre)	2010 % lower yield
Raw Yield (bu/ acre)	133	NA	135.4	NA
Adjusted Yield (bu/acre)	134.4	47.3	135.4	47.3

Appendix C: Precision farming crop yields - assigning yields from somewhat poorly drained soils

The economic models utilized in our study required data to estimate yield reductions associated with conventional crops grown on marginal soils, as compared to well-drained soils. As mentioned under Objective #3, conventional crop yield reductions from poorly and very poorly drained soil classes were based on the mean yield reductions observed in field plots from our study (-67%; see Objective #1). The USDA-NRCS SSURGO soils database estimates crop yields associated with different soil map units. However, our GIS analysis of SSURGO-based corn grain and silage yields found that somewhat poorly drained or poorly drained soils in the LFR sub-basin had SSURGO-estimated yields that were reduced by no more than 3% compared to yields from well-drained soils. Only excessively drained or very poorly drained soils had substantially reduced yields with the SSURGO-based crop yields. Even then, crop yields were not available for 70% of the very poorly drained soil class in the LFR-sub-basin. Therefore, we needed another way to assign yield reductions to conventional crops grown on somewhat poorly drained soils. To accomplish this task, crop yields were obtained from a farm operator who utilized precision farming equipment to get highly accurate, spatially sensitive crop yields. This GIS-based crop yield data came from land located just west of the LFR sub-basin, and it was used to estimate crop yields from marginal lands. The name and location of the farm operator are confidential, so some of the data we obtained are not provided in this report.

Yield data were obtained for both 2009 and 2010 from 575 acres of farmland composed of 16 fields spread over a distance ranging up to 4.6 miles apart. Crop yield data were received as points and these data were converted into a GIS raster using the ArcGIS topo-to-raster tool prior to analysis. Unfortunately, the relatively coarse spatial scale of the USDA-NRCS SSURGO soil mapping units does not match the fine scale of the precision crop yield data. While spatial patterns are visibly quite apparent in the mapped precision farming crop yields, these patterns often do not match up well with the relatively coarse scale SSURGO soil drainage classification. For example, within the farm unit shown in Figure C1, spatial patterns of precision farming crop yields can be readily observed in 2009 (Figure C1a), and patterns are even more apparent in 2010 (Figure C1b), and between the relative crop yields of 2009 and 2010 (Figure C1c). These patterns of lower and higher yield correspond closely to expectations of the current farm operator and former farm operator, and they agreed that the lower yielding areas depicted in Figure C1 (and other fields) are mostly related to poorly drained shallow sloped soils, or depressions. However, GIS analysis that compared SSURGO soil drainage classes to the precision crop yields from the farm unit mapped in Figure C1 showed that corn grain yields were only 2.1% and 8.6% lower in areas with soils classified as somewhat poorly drained, compared to the well-drained areas in 2009 and 2010, respectively. Generally no more than a 10% difference in corn grain yields was found between SSURGO-classified well drained soil areas and somewhat poorly drained soils in the studied area. We attribute this disconnect to the difference in spatial scale of the parent data sources. Given these spatial scale limitations, we conducted our analysis of the precision crop yield data by simply classifying data as coming from either mostly well-drained or mostly poorly drained *whole field units*, rather than distinguishing the areas within each field directly by SSURGO soil drainage class. We further presumed that the poorly drained whole field class could be categorized most closely with somewhat poorly drained soils, so we would have a basis for assigning an estimated yield difference between well-drained and somewhat poorly drained soils.

As summarized in Table C1, area-weighted mean corn grain yields dropped 44.4% between 2009 and 2010 for those fields with corn grown in both years. Furthermore, corn grain yields in 2010 fell by a greater percentage on those fields with a greater proportion of somewhat poorly drained soils. For example, mean area-weighted corn grain yields were reduced by 55% in 2010 on fields that were considered mostly somewhat poorly drained compared to a 42% reduction from fields with better drainage (fields where corn grain was harvested on same field for both years). In addition, for the six fields where corn was harvested in both 2009 and 2010, the area-weighted average corn grain yields from three fields with poorly drained soils were 18.2% lower in 2009 and 37.5% lower in 2010 compared to three fields with better drainage. When all corn fields were considered, the area-weighted average grain yields from somewhat poorly drained fields were 22.9% lower in 2009 (10 total fields) and 32.4% lower in 2010 (9 fields), compared to fields with better soil drainage. When both years were averaged, the mean yield reduction from fields with mostly somewhat poorly drained soils, compared to mostly well-drained fields was about 27.7% for both of these averaging methods. On this basis, we utilized the average reduced corn grain yield of 27% that was obtained from fields we designated as having mostly somewhat poorly drained soils, as compared to well-drained fields. This value was utilized in our economic model for somewhat poorly drained soils. Less than 2% of these fields were classified as “poorly drained” and none were classified as “very poorly drained”, so the vast majority of any yield reduction could be attributed to those areas that were less well-drained, but not poorly or very poorly drained. Importantly, these comparisons of whole field units tend to reduce the relative yield differences, because each field contains a mix of poorly drained and well drained soils, so our reduction estimate is conservative.

Table C1. *Precision farming corn grain crop yields from fields in N.E. Wisconsin.*

	Crop Year		**Mean Yield (bu/acre)**			**dominant**
Farm Field	**2009**	**2010**	**2009**	**2010**	**2009 vs 2010 yields**	**drainage**
1	corn	corn	163.2	81.1	-50.3%	well drained
2	corn	corn	171.1	108.2	-36.8%	well drained
3	corn	corn	170.0	107.5	-36.8%	well drained
4	corn	corn	105.6	61.7	-41.6%	somewhat poorly drained
5	corn	corn	144.7	78.4	-45.8%	somewhat poorly drained
6	corn	corn	137.9	47.5	-65.5%	somewhat poorly drained
7		corn		140.6		well drained
8		corn		132.5		well drained
9	corn		172.7			well drained
10	corn		179.3			well drained
11		corn		100.8		somewhat poorly drained
12	corn		127.0			somewhat poorly drained
13	corn		133.6			somewhat poorly drained
Wt. Average (corn both years on same 6 fields)			160.9	89.5	-44.4%	
Wt. Average (corn, all fields included)			153.0	106.0	-30.7%	
Wt. Average (3 well drained fields, corn both years)			167.9	97.9	-41.7%	
Wt. Average (3 somewhat poorly drained fields, corn both years)			137.3	61.3	-55.4%	
Yield difference: well drained vs. somewhat poorly drained (corn both years)			*-18.2%*	*-37.5%*	***-27.8%***	**average of 2 years**
Wt. Average (well drained fields, all fields included)			170.7	114.4	-33.0%	
Wt. Average (somewhat poorly drained fields, all fields included)			131.5	77.4	-41.2%	
Yield difference: well drained vs. somewhat poorly drained (all fields)			*-22.9%*	*-32.4%*	***-27.7%***	**average of 2 years**

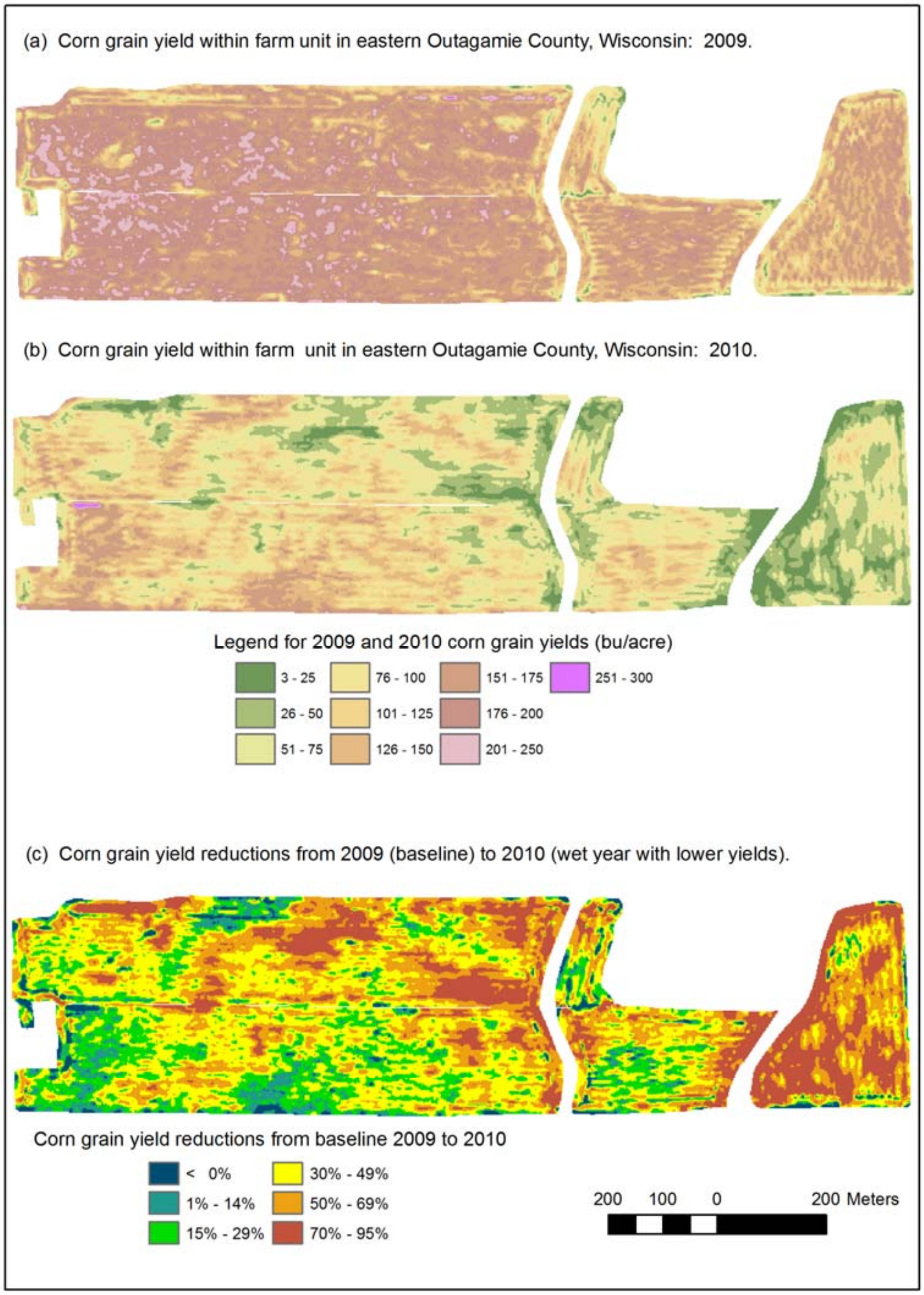

Figure C1. *Precision farming corn grain yields from farm unit in N.E. Wisconsin.*