PRAIRIE POWER PROJECT
Determining Maximum Sustainable Production of Biomass With a Mixture of Prairie Species

Phase I and II (2008-2015)
Iowa Economic Development Authority grant number: 11-04-1339

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SECTION A

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SECTION B

Background and Overview

Native prairie species mixtures appear to have great promise as bioenergy feedstocks. These perennial plants store carbon and produce greater net energy than row crops because: (1) after initial establishment they require little or no energy input such as cultivation, fertilizer, pesticides and irrigation; (2) they sequester excess CO_2; and (3) all above ground biomass is used rather than just the seed. Furthermore, prairie grows well on non-prime, nutrient-poor, agricultural soils and will not displace food crops from higher quality agricultural land.

In their 2006 *Science* paper, Tilman, Hill and Lehman demonstrated that mixtures of prairie perennials produce significantly more biomass than monocultures of row crops or native species. The Prairie Power Project was designed to verify their work on an applied agricultural production scale and determine an optimal mixture of prairie plants for maximum production of biomass on non-prime agriculture land while maintaining quality wildlife habitat.

Our study site, the Cedar River Ecological Research Site (CRERS), is located within Black Hawk County's Cedar River Natural Resource Area (CRNRA) near La Porte City, IA on the floodplain near the Cedar River. Soil types on the site are distributed such that we could study biomass production and animal response to habitat of four diversity treatments on three soil types. The four treatments of differing diversity were: 1 species - a switchgrass monoculture; 5 species - a mix of C_4 grasses; 16 species - a mix of grasses, forbs (including legumes); and 32 species - a mix of grasses, forbs (including legumes), and sedges. These mixtures were all specifically designed to assess their potential value as biomass feedstocks. Each diversity treatment was replicated four times on the three soil types for a total of 48 research plots (0.33 – 0.56 ha each; Figure 1). The plots initially seeded in 2008 were wiped out by the flood of June 2008 and were reseeded in late May and early June 2009.

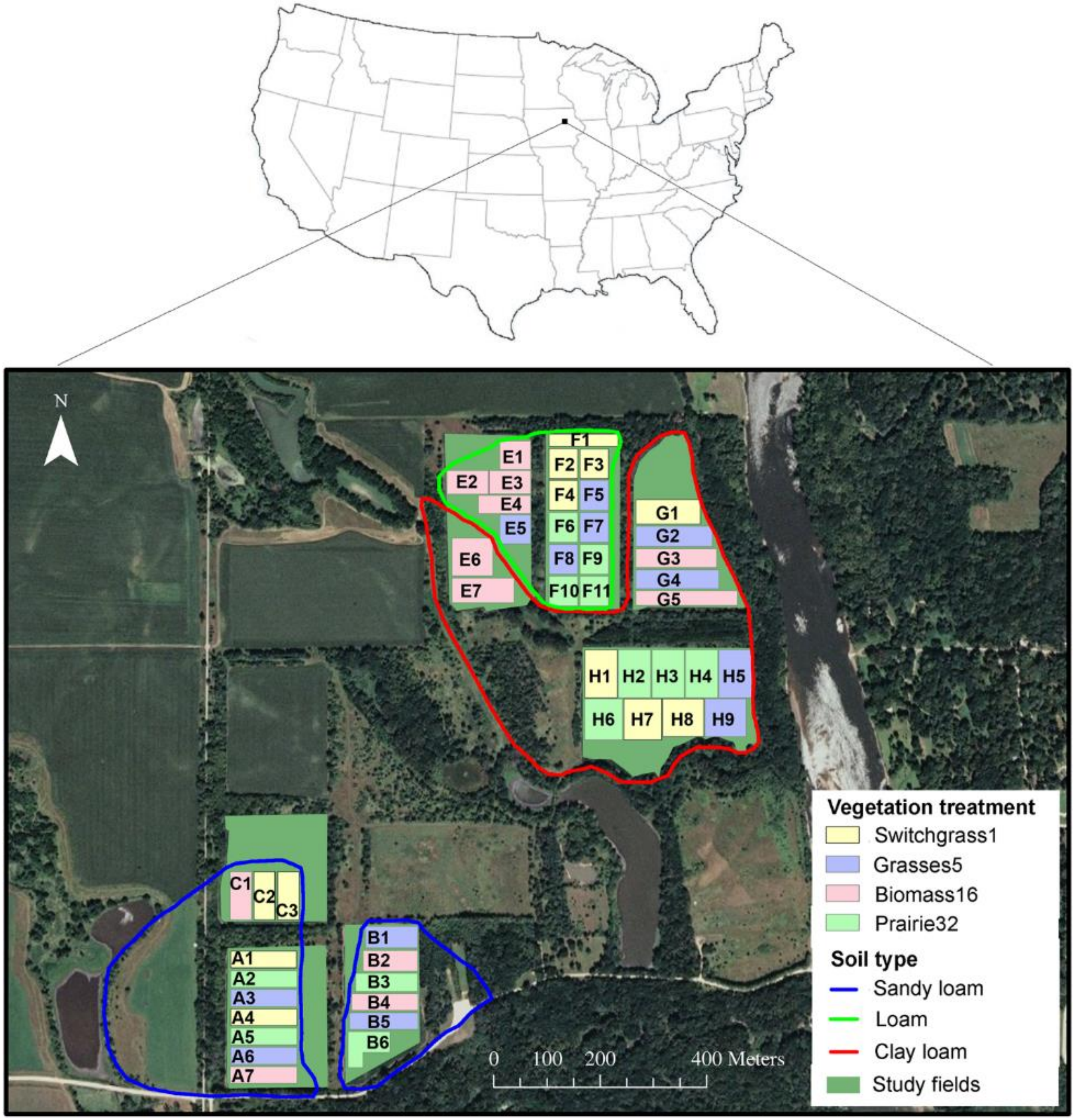


Figure 1. Map of the Cedar River Ecological Research Site (CRERS). Each diversity treatment was replicated four times on three soil types (4 vegetation treatments × 3 soil types × 4 replicates per soil type = 48 plots total). Each plot is labeled with a unique alphanumeric identifier (adapted from Myers et al. 2015; Appendix E).

During the study period, the research plots on the floodplain were exposed to a wide range of climatic conditions: 1) an establishment year-normal weather, 2) a normal weather year, 3) a drought year, 4) an extended flooding and inundation year, and 5) a moderate flooding year. Thus the average production over the five years is a reflection of a composite of numerous factors that influence production.

We compared biomass production, year-to-year variation in biomass production, and resistance to weed invasion in the four prairie biomass feedstocks across soil types from 2010-2014. The results and recommendations of this work are summarized in Section C. In brief, we found that the high-diversity mixtures (16- and 32-species) were as productive as the switchgrass monoculture, but the 5-species grass mixture was less productive than the switchgrass monoculture. Collectively these productivity and ecosystem service results indicate that a diverse prairie mixture (i.e. the 16- or 32-species mixtures) would be an effective bioenergy feedstock in the Midwestern United States. A summary of the relative trade-offs (yield, cost, weed/flood/drought resistance of each feedstock is provided in Section C - Table 1. The rank order of the four diversity treatments differed between soil types, indicating that soil type influences the relative performance of the four feedstocks. This result suggests biomass seed mixes should be specifically tailored to site characteristics for maximum productivity and stand success.

We assessed wildlife use of CRERS and the results of this research are detailed in Section E. Both birds and butterflies rapidly colonized the site with the plots supporting diverse assemblages of both. Abundance peaked in the first year after seeding and declined consistently thereafter, though the proportion of birds defined as obligate grassland species or species of conservation concern increased at the site over time. Generally, the diverse 16- and 32-species prairie mixes supported more abundant and diverse bird and butterfly assemblages.

We observed changes in soil profile carbon and nitrogen in the five year period following planting of the perennial cropping systems. The results of this research are detailed in Section F. In brief, surface soil C concentrations increased from 2008 to 2014 for all three soil types. The 16- and 32- species mixes fostered greater increases in soil C concentration than the 5-species mix and the switchgrass monoculture. We observed an increase of ~0.4 tons C/acre, averaged across the four perennial cropping systems, for the five-year period from May 2008 to May 2014.

To test the viability of the prairie biomass for electrical generation, a standardized test-burn was conducted by Cedar Falls Utilities. The process of harvesting, pelletizing and burning of the prairie biomass provided valuable information. Combustion of the prairie biomass yielded about 57% of the energy value of coal; however, stack emissions air pollutants and the potential for slagging and fouling were lower. Our methods and results from this aspect of the project are detailed in Section G.

An intended aspect of the study was to determine the best frequency and pattern of harvest of the prairie vegetation for maximum sustainable production of biomass and maintenance of wildlife habitat. However, sub-dividing the area into 48 plots for studying four treatments on three soil types left insufficient acreage to include this while maintaining the agricultural production scale of the plots. Instead, we conducted several experiments at CRERS between 2010 – 2014 that focused on topics such as: testing for evidence of contrasting rates of nitrogen depletion in the four different feedstocks, differences in carbon cycling and litter decomposition between treatment combinations, and the influence of diversity and soil type on the evolution of physiology in tallgrass prairie species. A brief summary of these additional experiments is provided in Section H.

Information and educational outreach to increase awareness and understanding of the use and benefits of prairie biomass has been and is being provided to the general public, prairie proponents and potential biomass producers through field trips and field days, via the web, newsletters, workshops and conferences as well as seminars and other outreach activities. Additional details are provided in Section I. Information provided to the research community includes three published papers and one accepted for publication, twenty-two presentations at conferences and five Masters theses (Section J). Other publications will be forthcoming.

Section C

Summary of Technical Results and Management Considerations

Biomass production

- All four diversity mixtures are productive on marginal farmland. Five year averages for clip plots were: switchgrass 3.67 tons/acre, 5-grass mixture 3.20 ton/acre, 16-species mixture 3.58 tons/acre and 32-species mixture 3.53 tons/acre. Literature suggests regular harvest yield would be ~18% less.

- The high-diversity mixtures (16- and 32-species) are as productive as a switchgrass monoculture and are more resistant to weedy invasion.

- The relative productivity of the four diversity treatments differs between soil types suggesting that seeding mixtures designed for biomass production should be specifically tailored to each site to maximize productivity and stand success.

- Switchgrass monocultures are drought tolerant, recover well from flooding, and are not subject to changes in species composition. In contrast, flooding drastically altered the species composition of the high-diversity mixtures suggesting that the additional cost of these seed mixes may not be worth the risk in a floodplain.

- Fall harvests capture more biomass than spring harvests (more foliage on stems). Slagging potential for fall-harvested biomass is equivalent to spring harvest; however, the fouling potential for fall harvests is medium compared to low for spring harvests. Fall harvests remove winter cover that could be used by wildlife.

- It is easier to form smaller pellets (1/4 in.) from prairie biomass. Densification of pellets larger than 1/4 in. was difficult due to stems that resisted grinding. The smaller pellets remained intact through several stages of handling, various forms of transport, and storage.

Wildlife habitat

- The 16- and 32-species mixes provided similar habitat conditions and generally supported more abundant and diverse bird and butterfly assemblages than the 5-species grass mix and switchgrass monoculture.

- Compared to adjacent corn and soybean fields, 2010 breeding bird abundance and species richness were approximately two times greater in switchgrass and the 5-species grass mixture and three times greater in the 16- and 32-species prairie mixtures.

- Grassland birds nested in all diversity mixtures. Dickcissel (*Spiza Americana*) nest success rates were similar among diversity mixtures (28-35%) and were comparable to those reported for other Midwestern grassland habitats.

Soil carbon and nitrogen dynamics

- Surface soil C concentration increased from 2008-2014 for all three soil types. Nearly all of the observed increases in soil C concentration were driven by changes in the top 3 inches of soil.

- Percent increases in surface soil C concentration from 2008 to 2014 were greatest for the sandy loam soil, ranging from 13.2% under the switchgrass monoculture to 26.6% for the 16-species mix. The sandy loam soil is the most depleted in soil C compared to the other two soil types. This result demonstrates that planting perennial cropping systems on marginal agricultural land can enrich depleted soils with organic carbon.

- The 16- and 32-species mixes fostered greater increases in soil C concentration than the 5-species mix and the switchgrass monoculture.

- Surface soil N concentrations decreased from 2008-2014 under all vegetation treatments; the 16-species mix reduced N concentration the least.

- We observed an increase of ~0.4 ton C/ac in sandy loam surface soil, averaged across the four perennial cropping systems, for the 5-year period beginning in May 2008 and ending in May 2014. The results demonstrate a strong potential for these unfertilized perennial systems to enhance C sequestration in the 5-year period following grass planting.

Table 1. Comparison of Biomass Feedstocks

Feedstock	Advantages	Disadvantage
Switchgrass monoculture	Lowest seed cost / acre	Susceptible to weed invasion
	Drought and flood resistant	May require fertilizer
	Highly productive	Provides little in ecological services
	Consistent annual yields	
5 C_4 Grass Mixture	2nd lowest seed cost/acre	Lowest Yields
	Resistant to weed invasion	Likely to require fertilizer
	Previously established on CRP	Not flood resistant
	Drought resistant	Limited ecological services

16 Species Mixture	Provides ecological services Highly productive – w/o fertilizer Resistant to weed invasion	2nd highest seed cost/acre Resistant to drought but not flooding
32 Species Mixture	Provides best ecological services Resistant to weed invasion Good Productivity – w/o fertilizer	Highest seed cost/acre Resistant to drought but not flooding

Section D

Assessing the Productivity and Resistance to Weed Invasion of Diverse Biomass Energy Prairie Plantings

This section of the report describes our efforts to monitor biomass production and resistance to weed invasion in the four prairie biomass feedstocks at CRERS from 2010 – 2014 and major results of the research during the 5-year grant period.

Fieldwork and Major Results

To compare productivity between treatment combinations, we harvested biomass between August 25 and September 27 in each year of the study (2010 – 2014). In 2010 – 2012, ten 0.1-m^2 quadrats were randomly sampled from each plot and all standing biomass was cut to ground level. In 2013 and 2014, the quadrat size was increased to 0.3m^2 to obtain more material. The biomass was divided into functional groups: C_4 grasses, C_3 grasses, forbs, legumes, and weeds, dried to a constant mass and weighed. Weed biomass was measured as a subset of total biomass.

To examine changes in species composition over the 5-yr study, basal area coverage of every species was measured each year in July. Two 10m transects were established in random positions in each plot, a 0.1-m^2 quadrat (20cm x 50cm) was placed at one meter intervals along each transect, and basal area coverage of each planted species was estimated one inch above the ground. The percentage of bare ground was measured in 2012-2014 during this sampling period to assess vulnerability to weed invasion.

Aboveground biomass differed between diversity treatments, soil types, and years (Figure 1). The diversity treatment effect was driven by the poor performance of the 5 grass mixture. The 16- and 32-species treatments produced the same amount of biomass as the switchgrass monoculture, but the switchgrass monoculture produced significantly more biomass than the 5-species treatment. In terms of the soil effect, less biomass was produced on the sand soil than the loam soil while the clay soil was intermediate and not significantly different from either other soil type. This result is consistent with the differences in corn suitability ratings between these soil types. 2011 was the most productive year at the site because it had high rainfall, no flooding, and was not an establishment year. Other years were less productive than 2011 because they were an establishment year (2010), a drought year (2012), or a severe flood year (2013 and 2014).

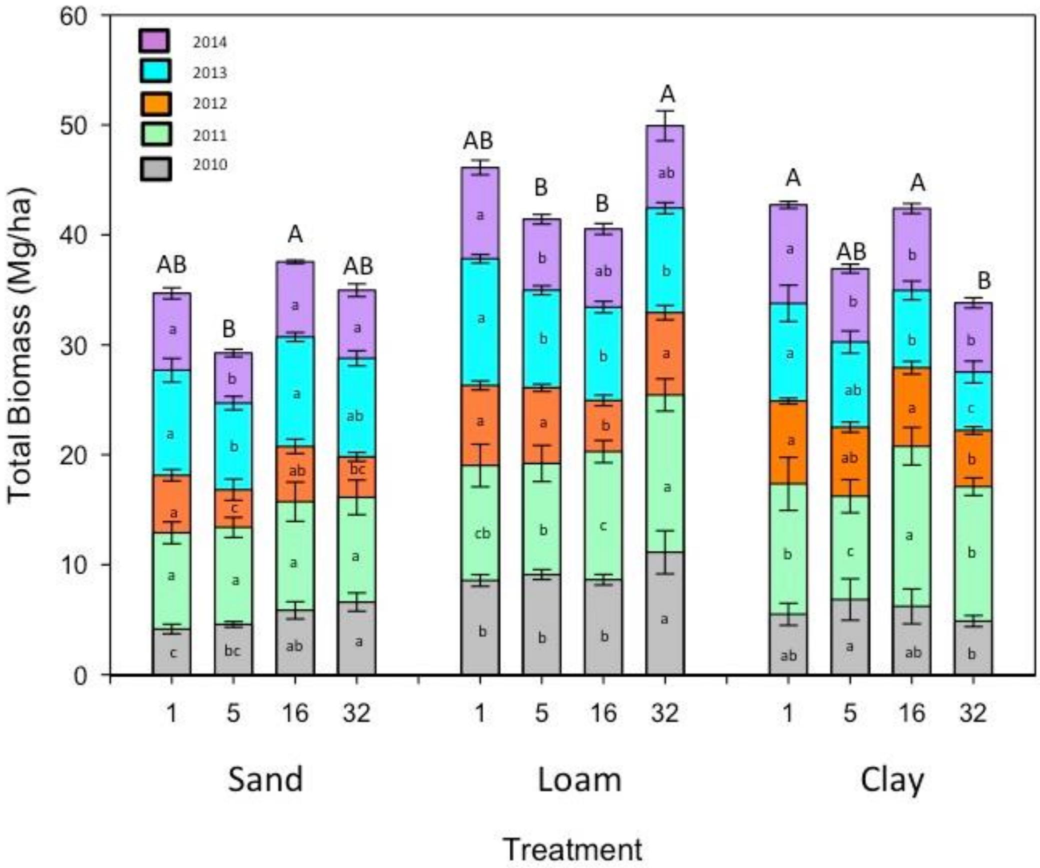


Figure 1. Biomass production at CRERS from 2010 – 2014. The bars in each stack represent annual averages (+ 1SE). Capital letters indicate significant differences in *total* biomass production between diversity treatments over the 5-yr study and lower-case letters indicate significant differences in *annual* biomass production between diversity treatments. (Figure accepted for publication in *Global Change Biology: Bioenergy*.)

Our results indicate that soil type influences the relative performance of the biomass feedstocks, as the rank order of the four diversity treatments differed between soil types (Figure 2). For example, the 16-species treatment produced more biomass than the 32-species on the clay soil but less than the 32-species treatment on the loam soil. Soil fertility can influence the relationship between species richness and productivity, which might account for some of the variation in our study. In natural systems, low phosphorous / high potassium soils, such as our loam soil (Section F), tend to support communities of greater species richness, which could explain the strong performance of our 32-species treatment on the loam soil. From a management standpoint, the contrasting performance of our four diversity treatments on different soil types suggests that seed mixes designed for bioenergy must be specifically tailored to the soil characteristics of a site for maximum productivity and stand success.

Weed biomass was higher in the 1-species treatment than in the 5-, 16-, and 32-species treatments (7.33%, 3.10%, 2.46%, and 2.53% respectively; Figure 3). This may have been driven by the higher percentage of bare ground in the switchgrass monocultures than in other diversity treatments. High light availability can promote weed invasion. Weed biomass was higher on the clay soil (5.47%) than on the sand soil (2.84%, Figure 2). Weed biomass decreased every year until 2013, when severe flooding occurred at the site and caused an increase in weed biomass.

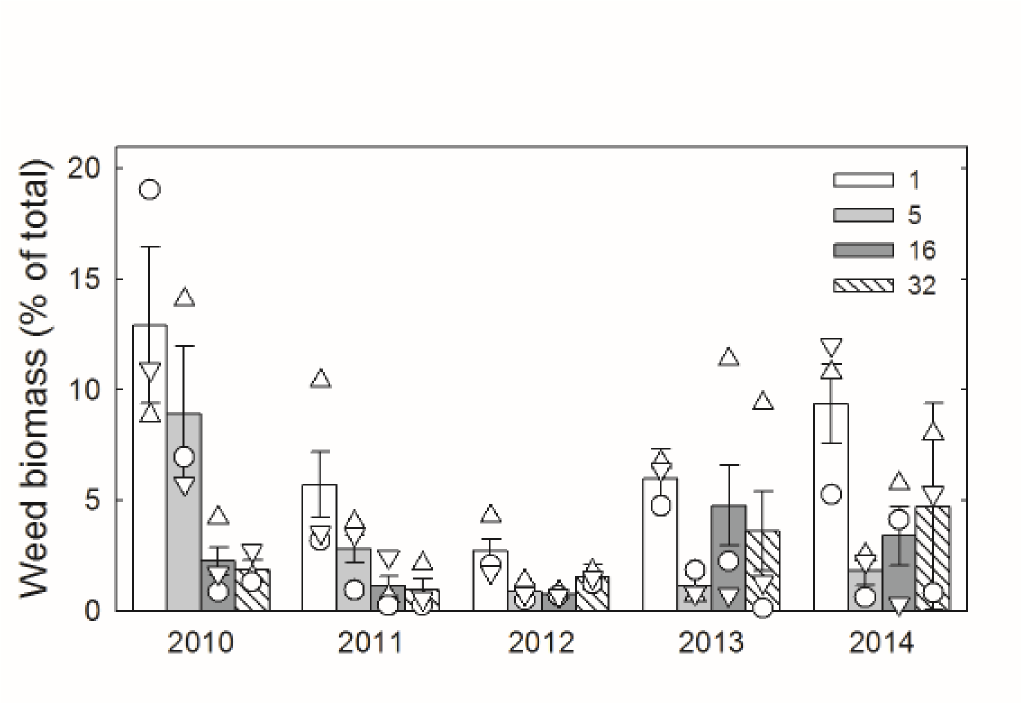


Figure 2. Weed biomass at CRERS from 2010 – 2014. Bars represent mean weed biomass for each diversity treatment in each year of the study. Symbols represent weed biomass within a soil type: circles = sand; down triangles =loam; up triangles = clay loam. (Figure currently submitted to *Global Change Biology: Bioenergy*)

The species composition of the 5-, 16-, and 32-species treatments changed over the 5-yr study. The most dramatic changes in species composition occurred in the 16- and 32-species treatments on the clay soil after the flooding in 2013. In terms of relating species composition to annual productivity, in the 16- and 32-species treatments, years in which big bluestem and Indian grass had high basal area coverage were years with high productivity and years in which little bluestem had high basal area coverages were years with low productivity (Figure 3). The basal area coverages of showy tick-trefoil and ox-eye sunflower decreased after 2011, which could be part of the reason the productivity values peaked in 2011. The basal area coverage of switchgrass increased after the 2013 flood.

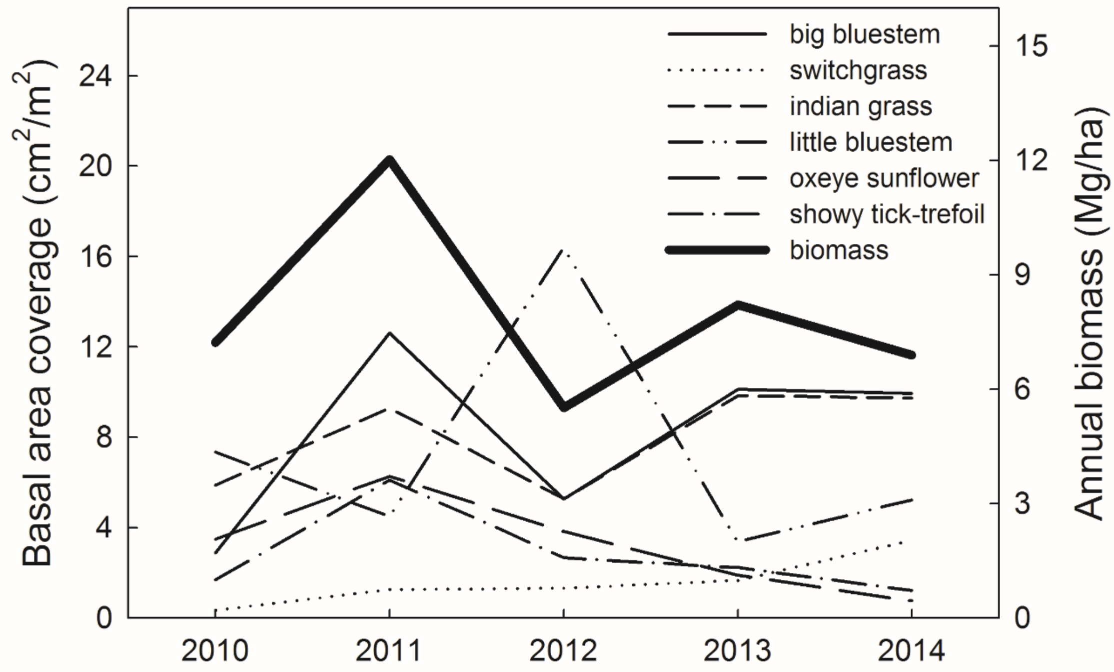


Figure 3. Basal area coverage of select species in the 16- and 32-species treatment plots on all three soil types. Average annual biomass production of all treatment combinations is provided for reference. (Figure accepted for publication in *Global Change Biology: Bioenergy*)

In conclusion, our results indicate that high-diversity prairie mixtures (the 16- and 32-species mixtures) produce the same amount of biomass as a switchgrass monoculture on a range of soil types and are more resistant to weed invasion. Collectively, these results support the conclusion that a high-diversity prairie mixture would be an effective and valuable biomass feedstock in the Midwestern United States. This research has been submitted to *Global Change Biology: Bioenergy* and is currently accepted pending minor revisions.

SECTION E

Assessing the Wildlife Habitat Value of Diverse Biomass Energy Prairie Plantings

The following section of the report describes activities undertaken to monitor wildlife and wildlife habitat at the CRERS from 2009-2014 and major results of the research during the 5-year grant period.

Fieldwork and Major Results

During the 2009-2014 growing seasons, our group spent >12,000 person hours monitoring vegetation characteristics and bird and butterfly community dynamics at CRERS. Over the course of the study we quantified vegetation structural characteristics in ~3600 and floral resources in ~24,000 1-m^2 quadrats. We visually surveyed birds and butterflies along ~160 km and ~120 km of line transects respectively, and recorded 2,726 bird sightings representing 33 species and 4,768 butterfly sightings representing 41 species.

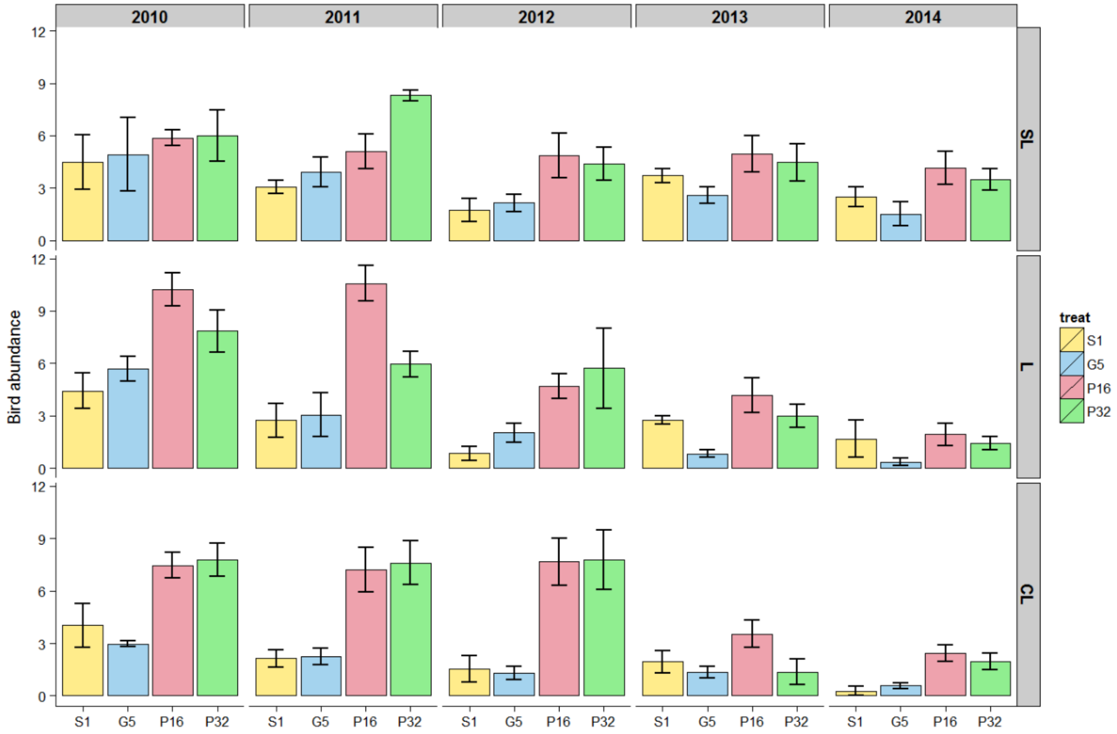
Both birds and butterflies rapidly colonized the site, and the plots supported diverse assemblages of both within one year of seeding. Generally, the diverse 16- and 32-species prairie mixes supported more abundant and diverse bird and butterfly assemblages than the 1- and 5-species grass plots, though the magnitude of this effect varied somewhat among years and soil types (Figures 1 & 2). In 2010, butterflies were six times more abundant and twice as species rich in the 16- and 32-species mixes compared to the 1- and 5-species grass plots (Myers *et al.* 2012, Section J). Compared to adjacent corn and soybean fields, 2010 breeding bird abundance and species richness were approximately two times greater in the low-diversity and three times greater in high-diversity perennial crops. Contrary to our expectations, bird and butterfly abundance peaked in the first year after seeding and declined consistently thereafter (Figures 1 & 2), though the proportion of birds defined as obligate grassland species or species of conservation concern increased at the site over time. Grassland birds of conservation concern, including Dickcissel (*Spiza americana*), Sedge Wren (*Cistothorus* *plattensis*), Grasshopper Sparrow (*Ammodramus savannarum*), and Henslow's sparrow (*Ammodramus henslowii*) nested at the research site. Dickcissel nest success rates (Mayfield method: 35%; logistic exposure method: 28%) were similar to those reported from other Midwestern grassland habitats.

One of the most surprising and novel aspects of our research was that we were able to document indirect, vegetation-mediated effects of soil properties on the spatial distribution of birds and butterflies. Though all plots were established and managed using the exact same methods, crops on sandy loam, the driest, most acidic soil with the lowest nutrient content (Section F), developed shorter, less dense vegetation with sparse litter accumulation and more bare ground compared to crops on loam and clay loam. Birds and butterflies responded to differences in vegetation structure and composition among soils. While bird and butterfly abundance and species richness were similar on all three soil types, their assemblage compositions varied among soils in certain vegetation treatments. In low-diversity grass crops, bird assemblages using sandy loam were dominated by species (*Chondestes grammacus*, *Spizella passerina*, *Zenaida macroura*, and *Molothrus ater*) preferring open ground and sparse vegetation for foraging and nesting, whereas assemblages using loam and clay loam were dominated by birds (*C. platensis*, *Melospiza melodia*, *Spinus tristis*, *Passerina cyanea*, and *Geothylpis trichas*) preferring tall, dense vegetation with abundant litter. In high-diversity prairie crops, the species composition of forbs in bloom varied among soils and strongly influenced butterfly assemblages (see Myers *et al.* 2015, Section J). Our study is the first to document such indirect, vegetation-mediated effects of soils on the spatial distribution of birds and butterflies using an experimental approach.

Finally, in June 2013 and 2014, the Cedar River experienced top-20 historical floods, inundating our plots at various depths and durations depending on their landscape position and soil type and creating a "natural experiment" that allowed us to document the effects of early-summer floods on the plants and wildlife assemblages using the plots. For example, while we monitored 61 active Dickcissel (*S. americana*) nests at the site in 2011-2012, in 2013-2014, we recorded only 6, all of which failed due to flooding, and

Dickcissels did not attempt to re-nest at the site in 2013-2014 even after floodwaters receded. We also documented long-term shifts in the plant communities of the severely flooded plots, including increases in switchgrass (*P. virgatum*) and annual weed cover and decreases in many sown forb species. These changes in plant community composition reduced floral abundance in the plots, which was associated with declines in butterfly abundance throughout the 2013 and 2014 growing seasons (Figure 2).

Figure 1. Bird average abundance (top) and species richness (bottom) by agrofuel crop, year (2010-2014), and soil type. S1: switchgrass monoculture; G5: 5-species warm-season grass mix; P16: 16-species prairie mix; P32: 32-species prairie mix. SL: sandy loam; L: loam; CL: clay loam.



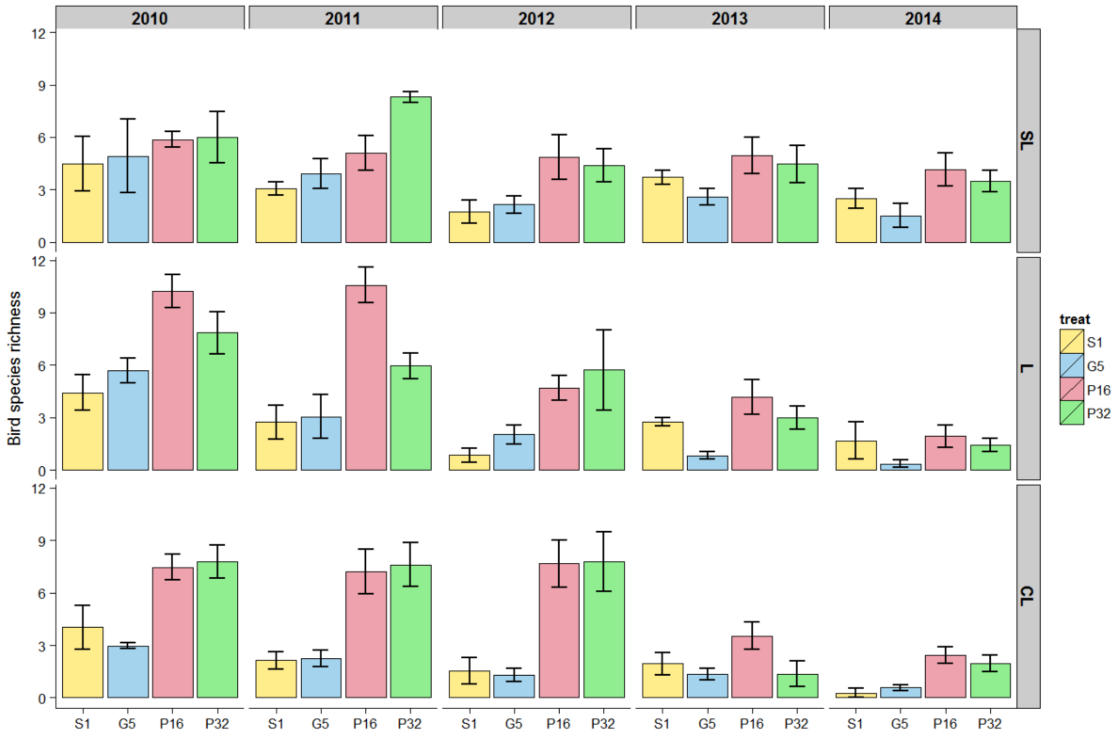
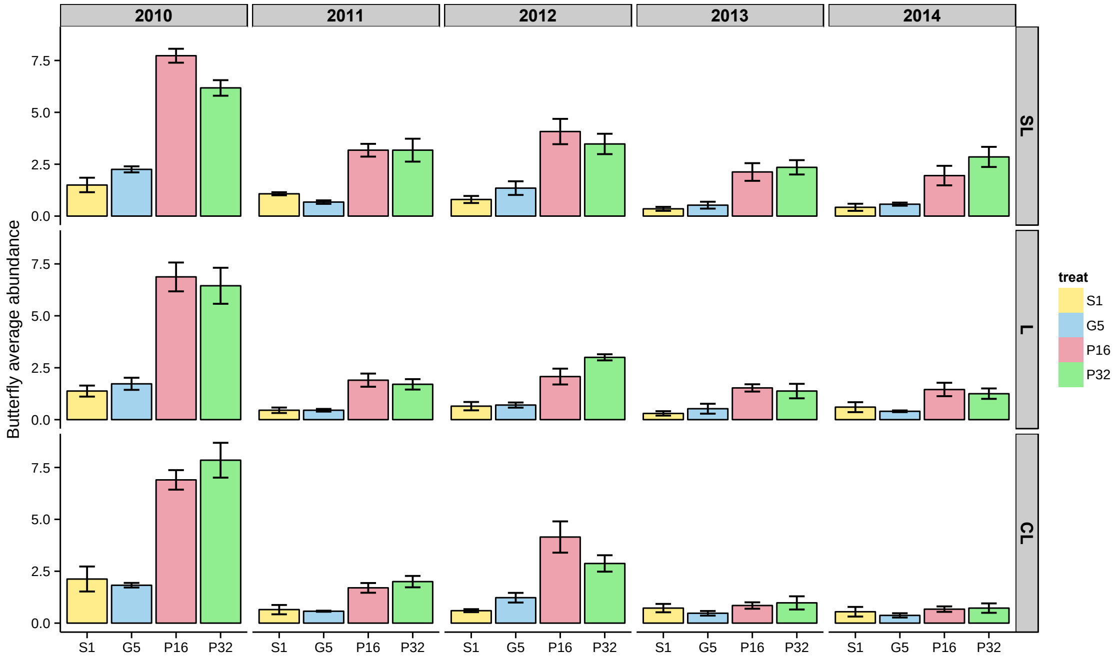


Figure 2. Butterfly average abundance (top) and species richness (bottom) by agrofuel crop, year (2010-2014), and soil type.



SECTION F

Soil Carbon and Nitrogen Changes Under Different Mixtures of Prairie Species

The primary objectives of the soil component of this research were (1) to quantify differential effects of 4 vegetation treatments on soil profile carbon (C) and nitrogen (N) concentration 5 years after planting; (2) to assess changes across time in soil C and N concentration for each of the 4 vegetation treatments; and (3) to evaluate the interactive effect of soil type on soil C and N response across time to the vegetation treatments. Secondary objectives included characterization of soil profile pH and macro- and micronutrient concentrations prior to planting the vegetation treatments and; evaluation of the impact of the 2008 flood on surface soil properties.

Field plots were established at CRERS in the fall of 2007 stratified by soil type for a total of 48 treatment plots, 16 on each soil type. Baseline soil cores were collected in May 2008 to a depth of 90 cm with a truck-mounted hydraulically-driven soil probe (inner diameter of probe tip 3.9 cm). Three to eight soil cores were collected from each research plot depending on the area of the plot and each coring location was geo-referenced using a handheld GPS unit. In May 2014, we returned to the same coring locations and repeated the core sampling. In both sampling years, 62 soil cores were taken from 16 plots within 3 field sites on Flager sandy loam (SL) soils; 82 cores were taken from 16 plots within 3 field sites on Spillville/Coland alluvial clay loam (C) soils; and 55 cores were taken from 16 plots within 2 field sites on Waukee loam (L) soils. The cores were frozen, cut into 4 depth increments (0–15, 15–30, 30–60, and 60–90 cm) and stored at -20°C. Frozen core increments were thawed at 4°C immediately prior to processing.

The Cedar River flooded in June 2008 and the plots were underwater for approximately 3 weeks. Because of the flood, the experiment was delayed and vegetation treatments were not established until spring 2009. To ensure that we had accurate baseline surface soil data at the start of the experiment, we re-sampled the top 15 cm of soil before seeding in

May 2009. At that time, and also in May 2014, we returned to the original deep core sampling locations and collected surface soil cores to 15 cm depth using a 3.2 cm inner-diameter hand-held soil probe. Three surface cores were collected from soil directly adjacent to each deep core sampling location. The three cores from each location were cut into two depth increments (0–7.5 and 7.5–15 cm) and the soil samples from each depth increment were mixed together to produce one composite soil sample for each depth increment for each coring location. Soil samples were stored at -20°C and thawed at 4°C immediately prior to processing.

We quantified total soil carbon (TC), total soil nitrogen (TN), bulk density, and field moisture content for all samples. Soil pH and Mehlich extractable macro- and micro-nutrients were quantified for all surface soil samples and for a representative sub-set of deep core samples that included at least 2 plots from each soil type/vegetation treatment combination.

Field-moist soil samples were pushed through an 8-mm-diameter sieve and a portion of the 8-mm sieved soil was pushed through a 2-mm sieve and air-dried. Soil water content was determined gravimetrically after oven drying overnight at 105ºC. Bulk density was estimated using the total volume of soil associated with the core samples, the total dry weight of soil, and the water content measurements (Blake and Hartge, 1986). Soil pH was measured using a 1:2 soil-to-water ratio (Watson & Brown 1998). Mehlich-III extractable macro- (P, K, Ca, Mg, and S) and micronutrients (B, Cu, Fe, Mn, and Zn) were quantified using inductively coupled plasma-optical emission spectroscopy (Whitney 1998; Tran & Simard 1993). A sub-sample of air-dried, 2-mm sieved soil was pulverized prior to quantification of total soil C and N using dry combustion methods in a Fison NA 15000 Elemental Analyzer (ThermoQuest Corp., Austin, TX). Soil properties are expressed per kg of oven-dry soil.

Results

We observed statistically significant differences for total soil C (TC), total soil N (TN), and soil C-to-N ratios among soil depths averaged across soil types for the May 2008 sampling (Table 2). Total soil C and N concentrations decreased significantly with each depth increment. The C:N ratio was highest in the top 2 soil depths and lowest in the bottom 2 depths of the soil profile, with the 30-60 cm depth falling in between.

Table 2. Cedar River Deep Soil Cores (sampled May 2008). Averaged across soil types.
Data expressed as g of C or N per kg of dry soil.

Soil depth	n	TC	TN	C:N
0-15 cm	199	18.98 a†	1.73 a	10.90 a
15-30 cm	199	16.95 b	1.54 b	10.95 a
30-60 cm	199	11.06 c	1.03 c	10.41 b
60-90 cm	198	5.02 d	0.57 d	9.04 c

†Means in the same column followed by the same lower case letter are not significantly different at $p \leq 0.05$ (Tukey's HSD)

Total soil C and N concentrations and soil C-to-N ratios were significantly different among the three soil types for all soil depths (Table 3). Concentrations for all soil depths were greatest in the clay loam soils, lowest for sandy loam soils, and between the two extremes for loam soils. The C:N ratios of the sandy loam soils were significantly lower than the other soil types for all depths, which suggests that the sandy loam soils are relatively more depleted in C than N.

Table 3. Cedar River Deep Soil Cores (sampled May 2008).
Data expressed as g of C or N per kg of dry soil.

Soil Type	TC	TN	C:N
0-15 cm depth			
Waukee (loam)	20.68 b†	1.89 b	10.93 b
Flager (sandy loam)	12.67 c	1.22 c	10.45 c
Spillville/Coland (clay loam)	22.65 a	2.02 a	11.23 a
15-30 cm depth	1.23	0.11	0.24
Waukee (loam)	18.27 a	1.67 a	10.93 b
Flager (sandy loam)	12.03 b	1.13 b	10.59 c
Spillville/Coland (clay loam)	19.77 a	1.76 a	11.23 a
30-60 cm depth			
Waukee (loam)	11.23 b	1.08 a	10.24 b
Flager (sandy loam)	7.83 c	0.77 c	9.89 b
Spillville/Coland (clay loam)	13.38 a	1.20 a	10.93 a
60-90 cm depth			

Waukee (loam)	5.57 b	0.67 a	8.89 b
Flager (sandy loam)	2.20 c	0.31 b	7.45 c
Spillville/Coland (clay loam)	6.80 a	0.68 a	10.17 a

†Means in the same column within each depth increment followed by the same lower case letter are not significantly different at p ≤ 0.05 (Tukey's HSD)

Table 4. Cedar River Surface Soil (sampled May 2009). Depth 0-15 cm. Data expressed as g of C or N per kg of dry soil.

Soil Type	**TC**	**TN**	**C:N**
Waukee (loam)	21.70 a†	2.00 b	10.84 a
Flager (sandy loam)	12.80 b	1.32 c	9.67 b
Spillville/Coland (clay loam)	22.95 a	2.13 a	10.74 a

†Means in the same column followed by the same lower case letter are not significantly different at p ≤ 0.05 (Tukey's HSD)

Comparisons of TC, TN and C:N for 0-15 cm depth increment sampled in May 2008 (Table 3) prior to the flood and in May 2009 (Table 4) suggest minimal net impact of flooding on soil TC and TN. However, C:N ratio of the sandy loam soils, which have the lowest concentrations of TC and TN among the three soil types, decreased more than 70% between May 2008 and May 2009, suggesting the flood may have had more subtle impacts on the quality of the soil organic matter in these soils.

Soil chemical properties varied significantly among the three soil types. Most macro- and micronutrient concentrations were greatest in clay loam, intermediate in loam, and lowest in sandy loam (Table 5). Exceptions were P and Mn (lower in loam than the other two soils) and K and Cu (similar in all soils). Sandy loam soil was more acidic in the top 15 cm compared to the other soils.

Table 5. Cedar River: Soil Chemical Properties

	Clay Loam	Loam	Sandy Loam
Phosphorus (mg kg^{-1})			
0 – 7.5 cm†	85.0a††	57.9b	99.4a
7.5 – 15 cm	41.0b	24.9c	53.0a
15 – 30 cm‡	18.0b	21.0b	36.7a
30 – 60 cm	14.6a	15.5a	18.8a
60 – 90 cm	13.4a	14.7a	12.6a
Potassium (mg kg^{-1})			

0 – 7.5 cm	154a	146a	153a
7.5 – 15 cm	106a	81a	117a
15 – 30 cm	88a	96a	58a
30 – 60 cm	64a	58a	44a
60 – 90 cm	67a	57a	38a
Magnesium (mg kg^{-1})			
0 – 7.5 cm	593a	554b	248c
7.5 – 15 cm	516a	471b	154c
15 – 30 cm	469a	463a	131b
30 – 60 cm	409a	407a	132b
60 – 90 cm	329a	302a	69b
Calcium (mg kg^{-1})			
0 – 7.5 cm	3710a	3155b	1331c
7.5 – 15 cm	3440a	2801b	885c
15 – 30 cm	3539a	3089b	1073c
30 – 60 cm	3075a	2713a	1105b
60 – 90 cm	2273a	1882a	494b
Sulfur (mg kg^{-1})			
0 – 7.5 cm	70.7a	64.9b	33.6c
7.5 – 15 cm	66.0a	58.2b	26.4c
15 – 30 cm	63.4a	62.4a	33.5b
30 – 60 cm	54.5a	53.3a	28.6b
60 – 90 cm	39.5a	35.2a	10.9b
Boron (mg kg^{-1})			
0 – 7.5 cm	1.09a	0.81b	0.49c
7.5 – 15 cm	0.87a	0.66b	0.44c
15 – 30 cm	0.60a	0.54a	0.22b
30 – 60 cm	0.43a	0.35a	0.13b
60 – 90 cm	0.31a	0.24a	0.03b
Copper (mg kg^{-1})			
0 – 7.5 cm	20.5a	15.8b	17.3ab
7.5 – 15 cm	21.4a	15.2b	13.6b
15 – 30 cm	11.5a	22.5a	2.6b
30 – 60 cm	17.2a	20.5a	1.9b
60 – 90 cm	21.3a	25.3a	1.0b
Iron (mg kg^{-1})			
0 – 7.5 cm	209a	171b	151c
7.5 – 15 cm	208a	176b	158c
15 – 30 cm	154a	152a	128b
30 – 60 cm	138a	126a	83b
60 – 90 cm	154a	125b	83c
Manganese (mg kg^{-1})			
0 – 7.5 cm	140a	104b	144a
7.5 – 15 cm	105a	73b	96a
15 – 30 cm	74a	51b	65ab
30 – 60 cm	30a	21a	26a
60 – 90 cm	50ab	29b	80a

Zinc (mg kg^{-1})			
0 – 7.5 cm	9.22a	6.22b	6.10b
7.5 – 15 cm	8.36a	5.24b	4.55b
15 – 30 cm	4.79a	5.34a	1.49b
30 – 60 cm	3.01a	3.75a	0.53b
60 – 90 cm	3.77a	4.33a	0.51b
pH			
0 – 7.5 cm	6.63a	6.59a	5.92b
7.5 – 15 cm	6.38a	6.19a	5.32b
15 – 30 cm	6.28a	5.85b	5.24c
30 – 60 cm	6.30a	5.91b	5.64c
60 – 90 cm	6.49a	6.01b	5.89b

† Samples collected in Spring 2009

‡ Samples collected in Spring 2008

†† Means in the same row within each depth increment followed by the same lower case letter are not significantly different at $p \leq 0.05$ (Tukey's HSD)

Vegetation Treatment Effects on Soil C and N (May 2014)

Overall, TC and TN concentrations in May 2014 were highest in the clay loam soil and lowest in the sandy loam soil similar to our results for May 2008 (Table 6 and 7 and May 2009 (Table 8 and 9). Nearly all of the effects of vegetation on TC and TN for all three soil types were observed in the top 15 cm of soil.

In May 2014, soil TC concentration in the surface (0-15 cm) soil was greatest under the prairie mix vegetation for all three soil types, although statistically significant only for the clay loam and loam soils (Table 6). Carbon enrichment in the near-

Table 6. Cedar River Biomass Experiment Total Soil Carbon Concentration (g TC kg^{-1}) to 90 cm for May 2008 and May 2014

Soil Type Depth Increment Year Vegetation Treatment	Clay loam	Loam (0-15 cm) 2008	Sandy Loam	Clay loam	Loam (0-15 cm) 2014	Sandy Loam
16-Biomass Mix (B)	20.91aB†	20.86aA	11.59bA	21.62aB‡	21.00aB	14.58bA*
5-Grass Mix (G)	20.89aB	19.97aA	12.69bA	23.14aB*	23.10aB*	14.76bA
32-Prairie Mix (P)	23.94aA	21.50bA	13.13cA	24.65aA	25.36aA*	16.22bA*
Switchgrass (SW)	25.42aA	20.35bA	13.36cA	22.45aB*	21.92aB	15.00bA
Soil Type Depth Increment Year Vegetation Treatment	Clay loam	Loam (15-30 cm) 2008	Sandy Loam	Clay loam	Loam (15-30 cm) 2014	Sandy Loam
15-Biomass Mix (B)	18.20aB	17.61aA	10.43bA	18.38aB	18.63aA	12.38bA
5-Grass Mix (G)	18.15aB	17.85aA	12.09bA	19.09aB	20.15aA	14.31bA
32-Prairie Mix (P)	20.37aA	18.95bA	12.54cA	21.39aA	19.43aA	14.52bA
Switchgrass (SW)	22.83aA	18.92bA	13.12cA	18.91aB*	19.11aA	14.88bA
Soil Type Depth Increment Year	Clay loam	Loam (30-60 cm) 2008	Sandy Loam	Clay loam	Loam (30-60 cm) 2014	Sandy Loam

Vegetation Treatment						
16-Biomass Mix (B)	13.58aA	10.26bA	6.60bA	12.23aB	11.33aB	9.32bA
5-Grass Mix (G)	12.42aA	12.47aA	6.64bA	13.51aB	15.13aA	9.67bA
32-Prairie Mix (P)	12.88aA	9.89abA	8.45bA	15.37aA	13.01aB	10.25bA
Switchgrass (SW)	15.16aA	12.19bA	9.71cA	13.65aB	12.63aB	11.12bA

Soil Type	Clay loam	Loam	Sandy Loam	Clay loam	Loam	Sandy Loam
Depth Increment		(60-90 cm)			(60-90 cm)	
Year		2008			2014	
Vegetation Treatment						
16-Biomass Mix (B)	6.78aA	5.25aA	1.61aB	8.29aA	5.16bB	2.72bA
5-Grass Mix (G)	7.85aA	5.36abA	2.05bB	8.23aA	8.15aA	2.82bA
32-Prairie Mix (P)	4.69aA	4.07aA	2.09aB	7.58aA	4.93aB	3.17bA
Switchgrass (SW)	7.76aA	7.58aA	3.02aA	7.42aA	8.81aA	3.89bA

† Means in the same row within each depth increment for each sampling year followed by the same lower case letter and means in the same column within each depth increment followed by the same upper case letter are not significantly different at p ≤ 0.05 (Tukey's honest significant difference test)
‡ Asterisk following means within each depth increment for the 2014 sampling year indicates a significant difference between years within each soil type/ vegetation treatment pair at p ≤ 0.05

Table 7. Cedar River Biomass Experiment Total Soil Nitrogen Concentration (g TN kg^{-1}) to 90 cm for May 2008 and May 2014

Soil Type	Clay loam	Loam	Sandy Loam	Clay loam	Loam	Sandy Loam
Depth Increment		(0-15 cm)			(0-15 cm)	
Year		2008			2014	
Vegetation Treatment						
15-Biomass Mix (B)	1.90aB†	1.88aBC	1.09bC	1.79aB*	1.69aC*	1.29bB*
5-Grass Mix (G)	1.87aB	1.80aC	1.23bBC	1.83aB	1.87aBC	1.33bAB*
32-Prairie Mix (P)	2.11aA	1.98aAB	1.30bAB	1.94aA*	2.08aA	1.43bA
Switchgrass (SW)	2.25aA	1.88bBC	1.25cBC	1.83aB*	1.88aBC	1.29bB
Soil Type	Clay loam	Loam	Sandy Loam	Clay loam	Loam	Sandy Loam
Depth Increment		(15-30 cm)			(15-30 cm)	
Year		2008			2014	
Vegetation Treatment						
16-Biomass Mix (B)	1.63aB	1.55aB	0.98bA	1.53aB	1.47aB	1.08bB
5-Grass Mix (G)	1.61aB	1.61aAB	1.16bA	1.54aB	1.61aAB	1.24bAB
32-Prairie Mix (P)	1.80aB	1.74aAB	1.21bA	1.68aA	1.63aAB	1.25bAB
Switchgrass (SW)	2.00aA	1.80bA	1.19cA	1.52aB*	1.65aA	1.26bA
Soil Type	Clay loam	Loam	Sandy Loam	Clay loam	Loam	Sandy Loam
Depth Increment		(30-60 cm)			(30-60 cm)	

Year	2008			2014		
Vegetation Treatment						
16-Biomass Mix (B)	1.17aA	0.96bA	0.66cA	1.04aB	0.96aB	0.87aA
5-Grass Mix (G)	1.12aA	1.18aA	0.71bA	1.13aAB	1.22aA	0.88bA
16-Prairie Mix (P)	1.20aA	1.01bA	0.86bA	1.23aA	1.18aAB	0.89bA
Switchgrass (SW)	1.35aA	1.19bA	0.86cA	1.17aAB	1.21aA	0.95bA

Soil Type	Clay loam	Loam	Sandy Loam	Clay loam	Loam	Sandy Loam
Depth Increment		(60-90 cm)			(60-90 cm)	
Year		2008			2014	
Vegetation Treatment						
16-Biomass Mix (B)	0.68aA	0.79aA	0.27bA	0.70aA	0.51abB*	0.39bA
5-Grass Mix (G)	0.72aA	0.58aB	0.29bA	0.78aA	0.74aA	0.41bA
32-Prairie Mix (P)	0.50aB	0.53aB	0.32aA	0.76aA*	0.54bcB	0.39cA
Switchgrass (SW)	0.80aA	0.85aA	0.34bA	0.74aA	0.90aA	0.45bA

† Means in the same row within each depth increment for each sampling year followed by the same lower case letter and means in the same column within each depth increment followed by the same upper case letter are not significantly different at $p \leq 0.05$ (Tukey's honest significant difference test)

‡ Asterisk following means within each depth increment for the 2014 sampling year indicates a significant difference between years within each soil type/ vegetation treatment pair at $p \leq 0.05$

Table 8. Cedar River Biomass Experiment Total Soil Carbon Concentration (g TC kg^{-1}) to 15 cm for May 2009 and May 2014

Soil Type	Clay loam	Loam	Sandy Loam	Clay loam	Loam	Sandy Loam
Depth Increment		(0-7.5 cm)			(0-7.5 cm)	
Year		2009			2014	
Vegetation Treatment						
16-Biomass Mix (B)	21.72aB†	20.06aB	14.07bA	26.55aB‡*	23.50bB	17.81cA*
5-Grass Mix (G)	23.65aB	24.94aA	13.00bA	27.01aB*	26.13aA	15.19bB
32-Prairie Mix (P)	26.80aA	24.44aA	15.40bA	29.62aA*	28.20aA*	18.40bA*
Switchgrass (SW)	28.54aA	24.98bA	14.74cA	29.45aA	24.45bB	16.69cA*
Soil Type	Clay loam	Loam	Sandy Loam	Clay loam	Loam	Sandy Loam
Depth Increment		(7.5-15 cm)			(7.5-15 cm)	
Year		2009			2014	
Vegetation Treatment						
16-Biomass Mix (B)	20.84aA	18.61bB	10.71cA	19.66aB	19.03aB*	11.54bA
5-Grass Mix (G)	19.79aA	21.25aA	11.25bA	19.98aB	20.77aB	11.14bA
32-Prairie Mix (P)	21.10aA	20.60aB	11.65bA	21.49aA	21.29aA	11.65bA
Switchgrass (SW)	22.70aA	19.95bB	11.85cA	22.79aA	19.70bB	12.61bA

† Means in the same row within each depth increment for each sampling year followed by the same lower case letter and means in the same column within each depth increment followed by the same upper case letter are not significantly different at $p \leq 0.05$ (Tukey's honest significant difference test)
‡ Asterisk following means within each depth increment for the 2014 sampling year indicates a significant difference between years within each soil type/ vegetation treatment pair at $p \leq 0.05$

Table 9. Cedar River Biomass Experiment Total Soil Nitrogen Concentration (g TN kg^{-1}) to 15 cm for May 2009 and May 2014

Soil Type	Clay loam	Loam	Sandy Loam	Clay loam	Loam	Sandy Loam
Depth Increment		(0-7.5 cm)			(0-7.5 cm)	
Year		2009			2014	
Vegetation Treatment						
16-Biomass Mix (B)	1.96aB†	1.81aB	1.30bA	2.08aA	1.93bB	1.44cA
5-Grass Mix (G)	2.30aA	2.23aA	1.21bA	2.08aA*	1.93aB*	1.19bB
32-Prairie Mix (P)	2.45aA	2.35aA	1.50bA	2.30aB	2.09bA	1.47cA
Switchgrass (SW)	2.58aA	2.18bA	1.41cA	2.25aB*	1.94bB*	1.31cA
Soil Type	Clay loam	Loam	Sandy Loam	Clay loam	Loam	Sandy Loam
Depth Increment		(7.5-15 cm)			(7.5-15 cm)	
Year		2009			2014	
Vegetation Treatment						
16-Biomass Mix (B)	1.83aB	1.58aB	1.08bB	1.59aB*	1.46aA*	0.95bA
5-Grass Mix (G)	1.98aAB	1.96aA	1.19bA	1.58aB*	1.54aA*	0.88bA*
32-Prairie Mix (P)	2.00aAB	2.05aA	1.20bA	1.68aB*	1.63aA*	1.00bA*
Switchgrass (SW)	2.18aA	1.80bAB	1.21cA	1.83aA*	1.48bA*	1.03cA

† Means in the same row within each depth increment for each sampling year followed by the same lower case letter and means in the same column within each depth increment followed by the same upper case letter are not significantly different at $p \leq 0.05$ (Tukey's honest significant difference)

‡ Asterisk following means within each depth increment for the 2014 sampling year indicates a significant difference between years within each soil type/ vegetation treatment pair at $p \leq 0.05$

surface (0-7.5 cm) soil was statistically significant for all three soil types and included the 7.5-15 cm depth interval for the clay loam and loam soils (Table 7). The relative enrichment of soil TC in the clay loam soil under prairie vegetation compared to the other plantings extended to a depth of 60 cm (Table 6).

Similar to results for TC, soil TN concentration in the surface (0-15cm) soil was significantly higher under prairie vegetation for all three soil types (Table 8). For the clay loam near-surface (0-7.5 cm) soil TN was higher under prairie mix vegetation and switchgrass compared to biomass and warm-season grass mix vegetation. For the sandy loam near-surface soil, soil TN was significantly lower under warm-season grass mix vegetation (Table 9).

Soil C and N Change from 2008-2014

Significant changes in soil profile C were observed primarily in the top 15 cm of soil (Table 6). Averaged across all vegetation treatments, surface (0-15 cm) soil C concentration was significantly higher in 2014 compared to 2008 for all three soil types.

Soil C change in the near-surface soil layer under prairie vegetation was 10.5, 15.4, and 19.5 % greater in 2014 for clay loam, loam, and sandy loam soil, respectively (Table 7). Near-surface soil C concentrations in the clay loam soil were also higher in 2014 under biomass mix vegetation (22.2%) and warm-season grass vegetation (12.4%). The sandy loam near-surface soil C was greater in 2014 for all vegetation treatments, ranging from 13.2% higher under the switchgrass monoculture to 26.6% higher for biomass mix vegetation.

Surface (0-15 cm) soil C was higher in 2014 for most of the soil/vegetation treatment combinations but was not statistically significant in all cases (Table 6). Observed increases in surface soil C concentration were entirely due to significant five-year increases in near-surface (0-7.5 cm) soil C, with no change occurring in soil C at the 7.5-15 cm depth interval (Table 8). The exception was for the loam soil under biomass mix vegetation, where total soil C increased slightly (2.3%) at 7.5-15 cm (Table 8). The greatest significant change in surface soil C occurred under prairie (23.5%) and biomass mix (20.5%) vegetation on sandy loam soil (Table 6). Significant increases in soil C were also found under warm season grass (15.9%) and prairie (15.2%) vegetation for the loam soil and for clay loam soil under warm season grass (10.7%). However, the apparent soil C increase in the top 15 cm from 2008 to 2014 under warm season grass for loam soil is due to the flooding that occurred in June 2008, because soil C concentration in May 2009 (23.10 g kg^{-1}; Table 7) is not different than the measured value in May 2014 (23.10 g kg^{-1}; Table 6) for this soil type/treatment combination. For clay loam soil to a depth of 30 cm under switchgrass vegetation, soil C concentrations were significantly lower in 2014 than in 2008 (Table 6).

Similar to soil C, nearly all changes in total soil N occurred in the top 15 cm of soil (Table 8). In contrast to soil C change, total soil N was lower in 2014, averaged across all vegetation treatments. Additionally, decreases in total soil N in the top 15 cm were nearly all due to significant losses of soil N from the 7.5-15 cm increment (Table 9). Loss of total soil N in the 7.5-15 cm depth increment for clay loam soil ranged from 13.1% under biomass mix vegetation to 20.2% under warm season grass. The loam soil lost 11.4-21.4% and the sandy loam soil lost 12.0-26.1% of the N present in May 2008 in this depth increment.

Observed changes in surface (0-15 cm) soil total N from 2008-2014 (Table 7) were less consistent than the near-surface soil N changes (Table 8). In fact, total soil N in the 0-15 cm depth increment significantly increased in sandy loam soil under biomass mix (18.4%) and warm season grass (8.1%) vegetation.

Conclusions and Recommendations

Nearly all of the changes in soil C concentration that we observed in this experiment occurred primarily in the top 7.5 cm of soil. In a few instances, we also observed positive increases in soil C to a depth of 15 cm. Looking strictly at the main effect of vegetation treatment within each soil type on soil C concentration in 2014, soil C under the 32-

species prairie mix vegetation is higher than the other vegetation treatments for all three soil types in the near-surface soil (0-7.5 cm). Increases in soil C concentration in surface soil over the 5-yr period were consistent for all three soil types only under the prairie mix vegetation. However, because the plots in clay loam soil planted to prairie mix vegetation had significantly higher soil C concentration at the beginning of the experiment in May 2008, it became necessary to normalize the C data relative to the initial values in order to observe the complete picture. The normalized data show that the biomass mix vegetation increased soil C concentration in the near-surface soil to a greater extent than the prairie mix vegetation (Table 10). The magnitude of the increase in soil C due to planting the biomass mix was equally great in the clay loam soil compared to the less C-enriched sandy loam soil.

Table 10. Percent change in soil C concentration for the 0.7.5 cm soil later

Vegetation	Clay loam	Loam	Sandy Loam
16-Biomass mix	22.2	17.2	26.6
5-Grass mix	12.4	N/C	N/C
32-Prairie mix	10.5	15.4	19.5
Switchgrass	N/C	N/C	13.2

In contrast to soil C change, we observed consistently lower total soil N concentrations in the 7.5-15 cm soil layer in 2014 (Table 11) that were mirrored by lower soil N to a depth of 15 cm in the clay loam and loam soil. On average, decreases in soil N concentration were not as large under the biomass mix vegetation compared to the other vegetation treatments. For the switchgrass monoculture, total soil C concentrations were significantly lower in 2014 to a depth of 30 cm (Table 6) in addition to reduced soil N concentrations in the surface layers. The exceptions to the pattern of N loss were in the sandy loam soil under biomass mix (18.4% increase) and grass vegetation (8.1% increase) (Table 8).

Table 11. Percent change in soil N concentration for the 7.5- 15cm soil layer

Vegetation	Clay loam	Loam	Sandy Loam
16-Biomass mix	-13.1	-11.4	-12.0
5-Grass mix	-20.2	-21.4	-26.1
32-Prairie mix	-16.0	-20.5	-16.7
Switchgrass	-16.1	-17.8	-14.9

Biomass mix and prairie mix vegetation clearly fostered increased soil C concentrations in the near-surface soil of all three soil types to a greater extent than the warm season grass mix and the switchgrass monoculture. All vegetation treatments reduced soil N concentration, however the biomass mix reduced N the least.

Implications for Soil Carbon Sequestration

In order to determine if the observed changes in surface soil total C concentrations correspond to increased potential for C sequestration, soil inorganic C concentration (data not shown) and bulk density (data not shown) must be taken into consideration. Carbon sequestration potential was evaluated for the three vegetation mixes and the switchgrass monoculture planted in the sandy loam soil because increases in surface soil total soil C concentrations were most pronounced for this soil type. Soil organic C concentrations were calculated as the difference between total soil C and soil inorganic C concentration. Soil organic C (SOC) content (MgC ha^{-1}) was calculated using the bulk density for surface soil (0-15 cm) (Table 12). Surface soil organic C content increased from 2008 to 2014 under all of the vegetation treatments, ranging from an 8-17% increase for the sandy loam soils. The results demonstrate a strong potential for these unfertilized perennial grass systems to enhance C sequestration in the 5 year period following grass planting.

Table 12. Carbon sequestration potential for sandy loam surface soil 2008-2014

Vegetation	**SOC 2008, MgC ha^{-1} to 15 cm**	**SOC 2014, MgC ha^{-1} to 15 cm**	**SOC Change, MgC ha^{-1} to 15 cm**	**% Change in SOC to 15 cm**
Biomass mix	2.93	3.32	0.39	13
Grass mix	2.95	3.46	0.51	17
Prairie mix	3.13	3.51	0.38	12
Switchgrass	2.96	3.19	0.23	8

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SECTION G

Prairie Power Biomass Test Burn Report

Testing to Determine Optimal Densification

One hectare of a biomass mix plot was harvested in early November 2011 to obtain 10 large bales (~565 lbs/bale) to provide material for densifying studies of mixed prairie species. Four of the bales were shipped to the Idaho National Laboratory of the U. S. Department of Energy in Idaho Falls, Idaho. They tested the densifying characteristics and determined that 1/4-inch pellets can successfully be produced from the material.

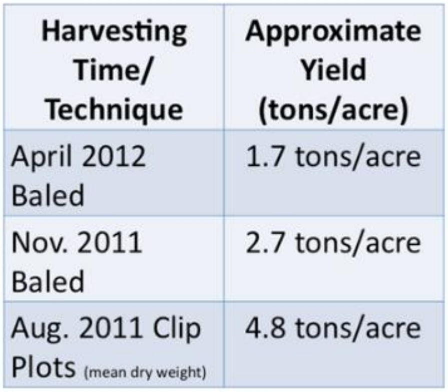
Preparation for Densification

The densifying process was successful and sample pellets were returned to the Tallgrass Prairie Center. In March 2012 the Tallgrass Prairie Center held a meeting with the Cedar Falls Utilities to plan for the test burn. Plans were developed to harvest the prairie biomass in early April 2012 and store the large bales until arrangements could be made for pelletizing. At the time, the only available equipment capable of densifying the material to the specifications recommended by the Idaho National Laboratory was in Idaho Falls, Idaho. In lieu of transporting the harvested material to Idaho to be densified with this equipment, Cedar Falls Utilities attempted, to no avail, to locate other users for the equipment in Iowa so that the Department of Energy could justify transporting the equipment to Iowa. Cedar Falls Utilities then began to search for a company closer to northeast Iowa that could densify the material into a shape and size that would be an acceptable compromise to the specifications suggested by the Idaho National Laboratory.

Approximately 165 tons of prairie biomass at CRERS was harvested and baled on April 1, 2012. The bales were stacked for storage on the site until ready to grind to prepare for densification. Also, an additional 24 tons of prairie biomass was harvested and baled from the Greenhill Road Site and stacked for storage. During the storage process, project staff were concerned about their ability to keep the hay stacks dry as the wind tore off any covers that were applied.

The following table provides a rough estimate of biomass yields based on harvest time and technique. The April 2012 and November 2011 yields are approximated from the average weight per bale and the August 2011 clip plot yield is derived from direct weighing of dried plant material.

Table 1. Yield from various harvesting times and techniques



Harvesting Time/ Technique	Approximate Yield (tons/acre)
April 2012 Baled	1.7 tons/acre
Nov. 2011 Baled	2.7 tons/acre
Aug. 2011 Clip Plots (mean dry weight)	4.8 tons/acre

Note that yield measured during harvest in November 2011 was almost half that of yield derived from clipped plot sampling in August 2011. This indicates that biomass yields derived from sampling may not be a good estimate of actual yields obtained during harvesting. Also note that the yield dropped dramatically from the fall harvest in 2011 to the spring harvest in 2012. This is most likely due to loss of standing plant material during the winter months.

Preparation for Test Burn of Biomass Material

It was anticipated that the biomass material would be densified and a test burn conducted at Cedar Falls Utilities in August of 2012. However, difficulties were encountered in locating a company to do the densification. Some of the difficulties in securing a pelletizing company were due to the fact that Cedar Falls Utilities wanted to conduct the test burn with 5/8-inch diameter pellets rather than the more common one-quarter-inch diameter pellets. Pellet Technology in Gretna, Nebraska agreed to do the 5/8-inch pelletizing. Vermeer Corporation of Pella, Iowa wanted to test a new grinder and agreed to do the grinding on site at CRERS. 51 tons of material were ground and then transported to Gretna in three 17-ton truckloads by Green Products of Janesville, IA.

Pellet Technology over-estimated their pelletizing capability as they had to grind the material to a finer state and were still unable to provide a firm, durable 5/8-inch pellet. As a compromise, Cedar Falls Utilities agreed to use the ¼-inch pellets that Pellet Technology could reliably produce and do a sequential test burn of the pelletized prairie biomass followed by a test burn of pelletized corn stover so that there would be enough biomass material for the test burn to produce valid emissions stack test results. The test burn was then scheduled for the week of Nov. 12, 2012. However, delays with Pellet Technology continued. Apparently, there are two different types of pelletizers and one type may be better designed to handle problem material. Pellet Technology did not have that type. They were able to complete pelletizing the prairie biomass material in October of 2012, but were only able to return 40.13 tons of pellets from the 51 tons of prairie biomass supplied to them. The balance of the biomass material was lost in the pelletizing process. They attribute the loss to the challenges they faced in grinding and pelletizing, especially due to problems related to a stem material of a specific plant (possibly *Heliopsis helianthoides*) that is shown in the following photograph that was taken by Pellet Technology:

Figure 1. Photograph of stem material

Tallgrass Prairie Center project staff along with Cedar Falls Utilities asked the Idaho National Laboratory of the U.S. Department of Energy in Idaho Falls, Idaho to review their test results from the fall of 2011 to determine if they noted any problems. They did the review and found no problems with the process. However, the Idaho National

Laboratory only does ¼-inch pellets so they are unable to test pelletizing the 5/8-inch size.

When the pellets were returned to Cedar Falls in October of 2012, Cedar Falls Utilities decided to transfer the pellets from the delivery trucks to railcars for storage until the test burn was conducted. In order to transfer the pellets from the trucks to the railcars for storage, Cedar Falls Utilities staff developed a system to do the transfer as there was no system in place to handle this type of material in this way. The pellets were first unloaded from the trucks the same way that coal is unloaded, but then the material was loaded into the railcars from the plant's radial telescopic stacker through a chute that Cedar Falls Utilities fabricated specifically for this purpose.

The test burn was then delayed until December of 2012 as Cedar Falls Utilities waited for completion of the pelletizing of the corn stover by Pellet Technology. Because of the delay, Cedar Falls Utilities had to request an extension on their test burn permit from the Department of Natural Resources which delayed the test burn even further. When the permit extension was granted, the test burn was scheduled for and conducted on February 27 and 28, 2013. Although these delays were unintended, one positive outcome was that project staff were able to observe the effects of storing the pellets over the winter. Cedar Falls Utilities stated that the pellets were in virtually the same physical condition at the time of the test burn as they were when they were delivered.

Cedar Falls Utilities Background

Cedar Falls Utilities (CFU) is a municipal utility providing electricity, natural gas, water and communication services to the City of Cedar Falls, Iowa. The electric utility owns generation, transmission and distribution assets, and services the electric needs of the city and the rural area to the north and west of the city. The generation resources of the electric utility are fractional shares of baseload steam generation units in western Iowa, two steam generation units at Streeter Station and two turbine generation units at the Gas Turbine site, both in Cedar Falls, and wind generation resources at two wind farms in Iowa. Streeter Station was the primary electric generation site for electricity for the City of Cedar Falls until 1978, when the electric utility bought fractional shares of large remote generation units and transported the electricity to Cedar Falls by way of the transmission system. At that time, Streeter Station transitioned to a peak generation facility instead of a baseload generation facility.

There are two electric generation units at Streeter Station. Unit #7, built in 1973, is rated at 35 megawatts and burns pulverized coal. Unit #6, built in 1963, is a stoker fed coal fired steam electric generation unit with an output rating of 16 megawatts. Stoker units scatter solid fuel onto a grate, where the fuel is burned and the released heat is transformed into steam to drive the turbine and generator. Stokers units are designed for stoker grade coal, but have the capability to handle any solid fuel. Cedar Falls Utilities has been test firing manufactured solid fuels using renewable biomass based raw materials as an alternative to fossil fuel combustion. In a mutually beneficial collaboration, CFU partnered with the Tallgrass Prairie Center at the University of Northern Iowa on the Prairie Power Project to perform a test burn of densified prairie biomass in Streeter Station Unit #6.

Prairie Biomass Fuel Analysis and Test Burn Data

Fuel Analysis (proximate, ultimate, & mineral analyses) of test burn material using Ogden, et al.

Laboratory analysis results for five different materials are shown in the following tables. The five materials included are: 1) the sample of prairie biomass taken in the fall of 2011 that was used for the densification study by the Idaho National Laboratory, 2) the prairie biomass harvested in the spring of 2012 that was used in the February 2013 Cedar Falls Utilities test burn, 3) the corn stover that was used in the February 2013 Cedar Falls Utilities test burn, 4) Knight Hawk Red Hawk 6BC Stoker Coal which is one of the fuels that Cedar Falls Utilities regularly burns in its Streeter Generation Station facility, and 5) Knight Hawk Prairie Eagle Washed Stoker Coal which Cedar Falls Utilities also regularly burns in its Streeter Generation Station facility. Data on the prairie biomass that was used in the Cedar Falls Utilities test burn is highlighted.

Table 2. Proximate Analysis

	Moisture (wt. %, as rec'd)	Ash (wt. %, as rec'd)	Gross Calorific Value (btu/lb)
Prairie Power 2011 Fall Harvest Sample	12.14	5.49	6963
Prairie Power 2012 Spring Harvest Test Burn Biomass	12.04	7.97	6561
Corn Stover used in Test Burn	13.67	18.57	5466
Knight Hawk Red Hawk 6BC Stoker Coal	10.86	9.09	11458
Knight Hawk Prairie Eagle Washed Stoker Coal	11.13	8.56	11401

Moisture content was comparable to that of coal and ash content was lower than coal. As moisture and ash are the non-combustible components of fuels, these figures represent desirable fuel qualities. The calorific value of the prairie biomass used in the Cedar Falls Utilities test burn was about 57% of the calorific value of the types of coal that Cedar Falls Utilities uses, but it was 20% higher than the calorific value of the corn stover used in the test burn. A higher calorific value means more energy is stored per unit weight of the material. This equates to lower costs for transportation, processing, storage, and handling of the material because fewer pounds are needed to produce the same energy as a material with a lower calorific value such as corn stover.

Table 3. Fuel calorific values of biomass mixes and corn stover

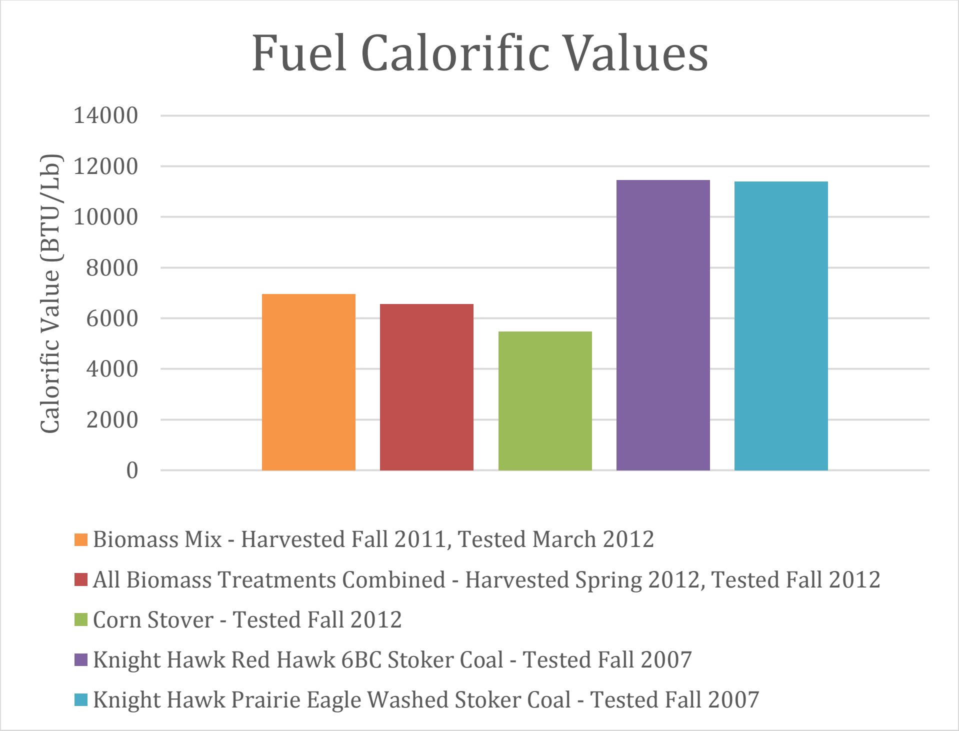


Table 4. Ultimate Analysis (weight %, as received)

	Carbon	Hydrogen	Nitrogen	Oxygen	Sulfur	Mercury	Chlorine
Prairie Power 2011 Fall Harvest Sample	43.70	4.39	0.53	33.68	0.07	0.000003	0.03
Prairie Power 2012 Spring Harvest Test Burn Biomass	36.64	4.94	0.16	38.21	0.04	0.000002	0.03
Corn Stover used in Test Burn	31.77	4.33	0.52	31.09	0.05	0.000002	0.16
Knight Hawk Red Hawk 6BC Stoker Coal	63.86	4.48	1.29	7.96	2.44	0.000007	.02
Knight Hawk Prairie Eagle Washed Stoker Coal	63.12	4.58	1.19	8.22	3.15	0.000007	.05

Prairie biomass contained significantly less sulfur and mercury than coal. Sulfur and mercury are both undesirable elements in power plant boiler feedstocks. Chlorine levels in prairie biomass were similar to that of the types of coal burned in the Cedar Falls Utilities power plant. Chlorine is linked to fouling issues in power plants.

Table 5. Elemental Ash Composition (% of ash)

	Prairie Power 2011 Fall Harvest Sample	Prairie Power 2012 Spring Harvest Test Burn Biomass	Corn Stover used in Test Burn	Knight Hawk Red Hawk 6BC Stoker Coal	Knight Hawk Prairie Eagle Washed Stoker Coal
SiO_2	54.56	78.65	71.11	51.78	52.88
Al_2O_3	2.23	3.53	9.19	22.24	20.31
TiO_2	0.25	0.13	0.67	1.09	1.00
Fe_2O_3	1.72	1.09	3.11	18.42	17.29
CaO	20.08	8.46	4.14	1.39	2.48
MgO	4.84	1.98	2.84	0.95	0.91
K_2O	7.78	3.39	5.74	2.20	2.16
Na_2O	0.36	0.64	1.26	0.23	0.84
SO_3	1.27	0.60	0.60	0.99	1.52
P_2O_5	4.00	1.32	1.07	2.20	2.16
SrO	0.07	0.03	0.03	0.02	0.03
BaO	0.13	0.07	0.09	0.04	0.03
MnO_2	0.22	0.11	0.15	0.03	0.04
Undetermined	2.49	0.00	0.00	0.55	0.44

Using these elemental ash composition data, the following formulas were used to calculate slagging and fouling indices:

- B/A Ratio = B/A where B = Fe_2O_3 + CaO + MgO + K_2O + Na_2O and A = SiO_2 + TiO_2 + Al_2O_3 (Winegartner 1974)
- Fouling Index = (B/A) x Na_2O (Huppa and Backman 1983)
  Classification of fouling potential (Bryers 1996):

Fouling Index < 0.2 – Low Fouling
0.2 < Fouling Index < 0.5 – Medium Fouling
0.5 < Fouling Index < 1.0 – High Fouling
1.0 < Fouling Index – Severe Fouling

- Slagging Index = (B/A) x S (Attig and Duzy 1969)

Classification of slagging potential (Bryers 1996):

Slagging Index < 0.6 – Low Slagging
0.6 < Slagging Index < 2.0 – Medium Slagging
2.0 < Slagging Index < 2.6 – High Slagging
2.6 < Slagging Index – Severe Slagging

T_{250} (the sample's temperature at which the slag viscosity is 250 poises) and silica value (the percentage of silica in the sample that aids in the formation of low-melting compounds) were provided in laboratory reports. Higher T_{250} values signify lower slag viscosities which generally equate to better flow (i.e. less slagging). Silica is a low-melting point element which potentially reduces the melting point of ash. Higher silica values signify a greater potential for slagging. T_{250} and silica value are presented for comparison purposes between the different fuels that were analyzed.

Table 6. Fuel Analysis

	B/A Ratio	Fouling Index	Fouling Potential	Slagging Index	Slagging Potential	T_{250}	Silica Value
Prairie Power 2011 Fall Harvest Sample	0.6097	0.2195	Medium	0.0549	Low	2242	67.19
Prairie Power 2012 Spring Harvest Test Burn Biomass	0.1890	0.1210	Low	0.0076	Low	2900	87.21
Corn Stover used in Test Burn	0.1210	0.2659	Medium	0.0127	Low	2825	87.57
Knight Hawk	0.3087	0.0710	Low	0.8460	Medium	2534	71.38

Red Hawk 6BC Stoker Coal							
Knight Hawk Prairie Eagle Washed Stoker Coal	0.3192	0.2681	Medium	1.1331	Medium	2519	71.89

Using these formulas, the calculated fouling and slagging indices indicated low potential for fouling and slagging. Additionally, T_{250} for the prairie biomass used in the Cedar Falls Utilities test burn was the highest of the five materials analyzed which indicates that it has a lesser potential for slagging. Interestingly, the prairie biomass and corn stover used in the Cedar Falls Utilities test burn had almost the same silica value. Both amounts were considerably higher than the two types of coal or the prairie biomass sample that was harvested in the fall of 2011. These higher silica values indicate a greater potential for slagging.

Test Burn and Emissions Stack Test

The test burn was performed at Cedar Falls Utilities Streeter Station Unit #6 on February 28, 2013 with approximately 40 tons of ¼” pelletized material. Prairie biomass was burned from approximately 9:45am until 3:30pm at a rate of approximately 10 KPPH at a generating output of approximately 5 MW. During this time period, prairie biomass was the sole fuel that was burned in the boiler.

Table 7. Emission Stack Test Data

	Prairie Biomass	Corn Stover	Coal
Particulate Matter (Lb/MMBtu)	0.007*	0.01*	0.562**
No_x (Lb/MMBtu)	0.42	0.514	0.589
CO (Lb/MMBtu)	0.373	0.264	0.095
HCl (Lb/MMBtu)	0.0773	0.1483	0.057
Mercury (Lb/MMBtu)	1.86×10^{-7}	5.99×10^{-7}	4.09×10^{-6}

*Tested after baghouse air filtration system**Tested before baghouse air filtration system

Emissions stack test data for Particulate Matter, NO_x, and CO are the average of three test runs, and for HCl and Mercury are the average of two test runs. Please note that particulate matter emissions data for prairie biomass and corn stover cannot be compared directly to particulate matter emissions for coal because prairie biomass and corn stover particulate matter emissions were tested after the baghouse air filtration system and coal particulate matter emissions were tested before the baghouse air filtration system. Sulfur (SO_2) emissions were not tested in this burn. We can infer that SO_2 emissions would be lower than that of coal because sulfur content in laboratory analysis of prairie biomass is much lower than that of coal. The only issue of concern in the emissions stack test data is CO. Cedar Falls Utilities states that this can be addressed by tuning the boiler to more fully combust the biomass. The boiler is currently tuned for coal and would need to be adjusted for biomass if biomass were to be used regularly as a fuel. Cedar Falls Utilities thinks that CO level could be reduced to approximately the level that coal produces right now by tuning the boiler for biomass.

Opacity was also measured throughout the test burn by an instrument called a balometer which is located before the baghouse air filtration system. Average opacity for prairie biomass during this test burn was 0.82%. The current regulation limit for opacity is 40%. Prairie biomass performs much better than coal by this measure. In lay terms, this means that the prairie biomass produces much less soot than coal.

Literature Cited

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Huppa M, Backman R. 1983. Slagging and fouling during combined burning of bark and oil, gas or peat. Fouling of Heat Exchanger Surfaces. Engineering Foundation. New York. 419432 p.

Olthoff E. 2009. Testimony to U.S. Senate Ag, Nutrition, and Forestry Committee. September 1, 2009.

Winegartner E. (Ed.) 1974. Coal Fouling and Slagging Parameters. American Society of Mechanical Engineers (ASME) Research Committee on Corrosion and Deposits from Combustion Gases. ASME Publication.

SECTION H

Additional Studies Conducted at CRERS 2010 - 2014

The following section of the report describes additional experiments conducted at CRERS from 2009-2014 and major results of the research during the 5-year grant period.

Study 1: Soil type and species diversity influence selection on physiology in *Panicum virgatum*

In summer 2012, we tested whether diversity influences natural selection on the physiology of switchgrass (*Panicum virgatum*), using the four diversity treatments of native vegetation established at the site. In each diversity treatment, we measured photosynthetic rate, chlorophyll content, specific leaf area, aboveground biomass, and glume number on 100 systematically sampled individuals. We replicated this experiment on the loam and clay loam soils (total n = 800). We estimated selection as the relationship between each physiological trait and fitness (glume number and aboveground biomass). When significant, selection favored increased photosynthesis, increased chlorophyll concentration, and decreased specific leaf area. Selection for these attributes was stronger in the faster-draining loam soil than the slower-draining clay soil. Selection rarely differed significantly between diversity treatments; however, most instances in which selection differed between soil types occurred in the high-diversity mixes (16- and 32-species) suggesting that species diversity alters the impact of soil type as an agent of selection. Selection may have been stronger in the loam soil because of differences in water availability. There was a lengthy summer drought in 2012, and under these conditions, plants with high photosynthetic function would have more resources to invest in their root system for water uptake. This mechanism would account for the greater adaptive significance of these attributes in the faster-draining loam soil. Our results suggest that species diversity is a weak agent of selection and only influences the evolution of physiology by modifying the pressures exerted by other environmental factors. This work was published in the journal *Evolutionary Ecology* (Section J).

Study 2: Nitrogen use in Prairie Biomass Feedstocks

Biomass feedstocks composed of low diversity assemblages without legumes should deplete soil nitrogen at a faster rate than high diversity assemblages with legumes (Section F). To compare nitrogen depletion in high-diversity and low-diversity perennial grassland assemblages, we tested whether switchgrass (*Panicum virgatum*) plants grown in high-diversity assemblages have higher nitrogen content and produce more biomass than switchgrass plants grown in low-diversity assemblages. If soil nitrogen depletion has occurred at a faster rate in the low-diversity assemblages than the high-diversity assemblages, then plants within those low-diversity treatments should display lower tissue nitrogen and produce less biomass. This result would support the conclusion that high-diversity prairie assemblages reduce the need for fertilizer input and increase their appeal as a long-term biomass feedstock.

For this study, we measured photosynthesis, leaf N, chlorophyll content, FvFm, and SLA on 800 plants in the sandy soil at CRERS. This experiment was replicated over two growing seasons (2014 and 2015). We have processed all the biomass from the summer 2014 harvest for combustion analysis. We sent this tissue to a collaborator for analysis and we are currently awaiting the results. Preliminary results suggest that nitrogen depletion has been higher in the 5 species grass mix than the high diversity mixtures; however, the switchgrass monocultures do not show evidence of nitrogen depletion (Figure 2). This result could be due to the greater nitrogen uptake of the 4 other grasses (Indian grass, big bluestem, little bluestem, and side oats grana) in the 5 grass mix, relative to switchgrass.

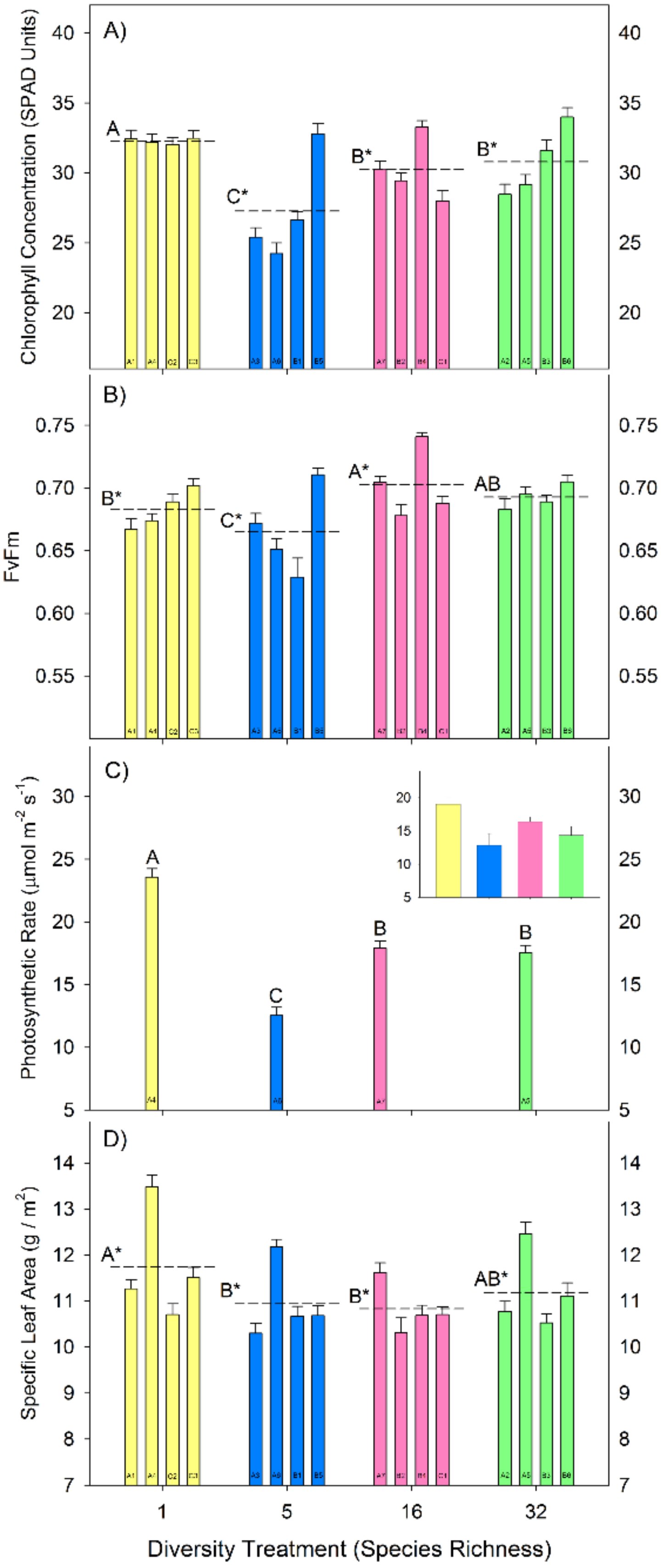
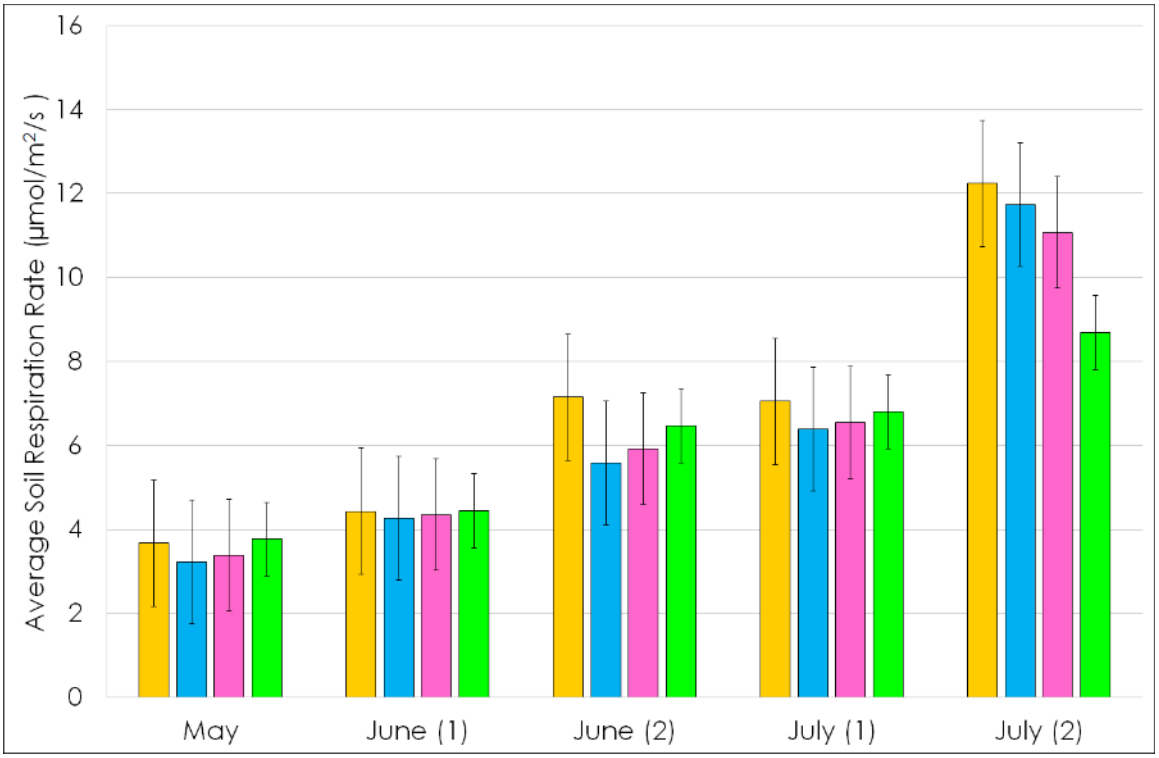


Figure 1. Switchgrass physiology in the four diversity treatments switchgrass monoculture (yellow), 5-grass species mix (blue), 16-species mix (pink), 32-species mix (green). Letters represent significant differences based on Tukey post hoc test. * represent significant differences between plots within treatments. Panel C inset: photosynthesis of 10 randomly selected plants per treatment measured on the same day.

Study 3: Soil Carbon Cycling and Rates of Litter Decomposition

Net ecosystem exchange (the net input or output of carbon) is largely dominated by soil respiration rather than productivity. To understand how much carbon is being sequestered in these biofuel feedstocks, we are measuring soil respiration bi-weekly throughout the growing season and monthly outside of the growing season. From this we will be able to estimate the net carbon (C) loss from soils and determine whether that differs among feedstocks. Initial results show that during the height of the growing season, higher diversity plots respire less C (and presumably therefore sequester more C) than lower diversity plots, but these differences exist only in the peak of the growing season when soil respiration is highest (Figure 2).

Figure 2. CO_2 efflux from soil at five dates during the 2015 early to mid growing season. Average efflux is shown for switchgrass monoculture (gold bars), 5-grass mix (blue), 16-species mix (pink), and 32-species mix (green).



In addition to measuring soil respiration, we are measuring the rate of decomposition of the stubble that is left behind in the field after harvest. Since this stubble represents potential soil C, differences in the rate of decomposition can influence the amount of C sequestered. We are also measuring root production and root turnover in the top meter of soil using clear plastic tubes installed in the ground and a specialized camera that can be used to track root growth and death. Both of these projects (litter decomposition and root growth) are in the initial stages and do not yet have results.

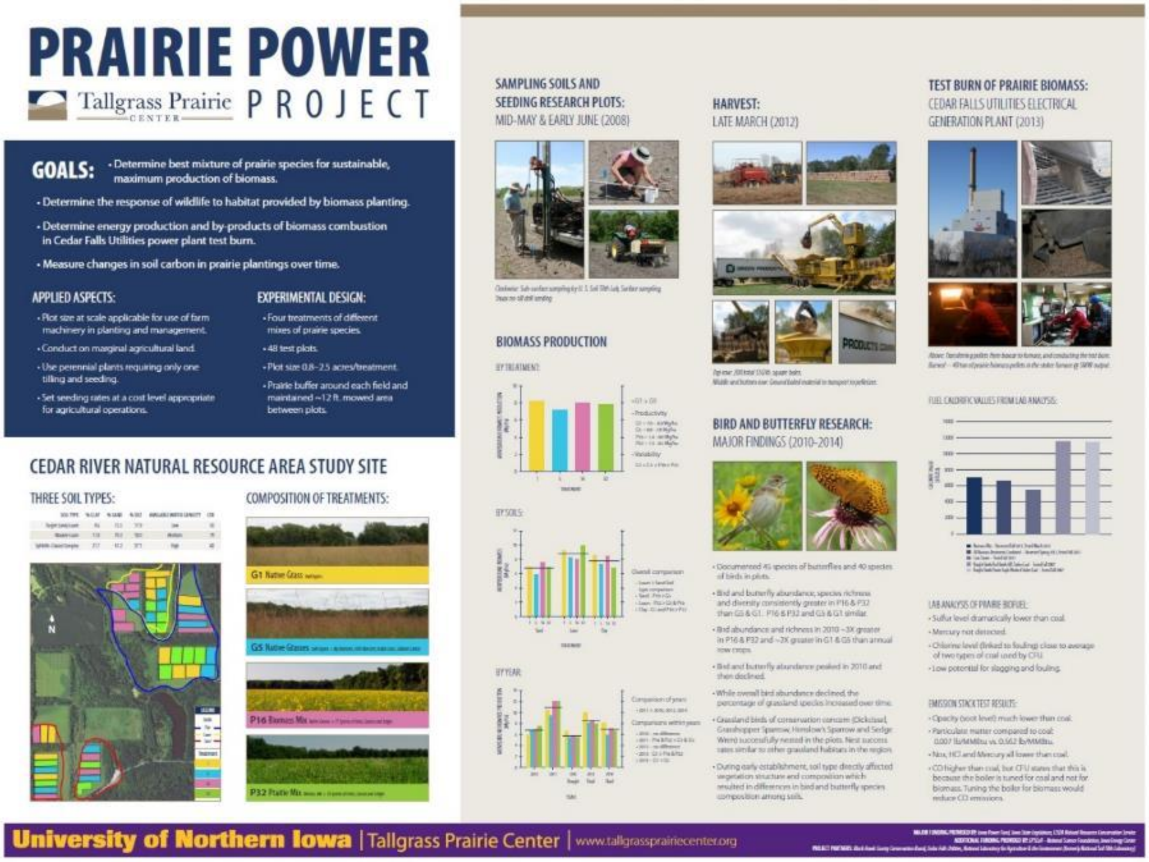
SECTION I

Promotion of Prairie Power Project and Dissemination of Results

Prairie Power Project results have been and are being disseminated in a number of ways. A section of the Tallgrass Prairie Center's website was created for the Prairie Power Project. This contains a general description of the project, information on the seed mixes used in the project, the economic benefits of planting prairie biomass, preliminary investigations from the project, and links to digital copies of all research posters, Masters theses, and journal articles produced from the project. All Masters theses associated with the Prairie Power Project are publicly posted and available for download on the University of Northern Iowa Rod Library's UNI ScholarWorks website.

The initial and ongoing effort to increase public awareness of the project includes a newspaper article in the Waterloo/Cedar Falls Courier on September 2, 2007 entitled *Center Researches Grass as Fuel*, an article on the Biopact website that was also posted on September 2, 2007 entitled *Tallgrass Prairie Center to implement Tilman's Mixed Grass Findings*, and an interview of Tallgrass Prairie Center Director Daryl Smith, Program Manager Dave Williams, and Cedar Falls Utilities' Environmental Coordinator Ed Olthoff on Iowa Public Radio's The Exchange on March 26, 2008. The Fall 2007 Tallgrass Prairie Center Newsletter also featured an article entitled *Researching the Use of Prairie Hay to Generate Electricity*. Prairie Power Project activities were also featured in the Tallgrass Prairie Center's Spring 2012 Newsletter (*Burning Prairie Hay to Generate Electricity*) and the Spring 2015 Newsletter (*Prairie Power Project*).

Prairie Power staff of the Tallgrass Prairie Center hosted field days at CRERS during the North American Prairie Conference in 2010 (560 in attendance) and the Iowa Prairie Conference in 2015 (180 in attendance). Following orientation by project staff, participants had an opportunity to tour and observe the response of the treatments on various soil types. A poster summarizing the results of the Prairie Power Project was also presented at the Iowa Prairie Conference (see image below, Figure 1).



PRAIRIE POWER
Tallgrass Prairie CENTER PROJECT

GOALS:
- Determine best mixture of prairie species for sustainable, maximum production of biomass.
- Determine the response of wildlife to habitat provided by biomass planting.
- Determine energy production and by-products of biomass combustion in Cedar Falls Utilities power plant test burn.
- Measure changes in soil carbon in prairie plantings over time.

APPLIED ASPECTS:
- Plot size at scale applicable for use of farm machinery in planting and management.
- Conduct on marginal agricultural land.
- Use perennial plants requiring only one tilling and seeding.
- Set seeding rates at a cost level appropriate for agricultural operations.

EXPERIMENTAL DESIGN:
- Four treatments of different mixes of prairie species.
- 48 test plots.
- Plot size 0.8–2.5 acres/treatment.
- Prairie buffer around each field and maintained ~12 ft. mowed area between plots.

CEDAR RIVER NATURAL RESOURCE AREA STUDY SITE

THREE SOIL TYPES:

COMPOSITION OF TREATMENTS:

G1 Native Grass

G5 Native Grasses

P16 Biomass Mix

P32 Prairie Mix

SAMPLING SOILS AND SEEDING RESEARCH PLOTS:
MID-MAY & EARLY JUNE (2008)

BIOMASS PRODUCTION

BY TREATMENT:

BY SOILS:

BY YEAR:

HARVEST:
LATE MARCH (2012)

BIRD AND BUTTERFLY RESEARCH:
MAJOR FINDINGS (2010-2014)

- Documented 45 species of butterflies and 40 species of birds in plots.
- Bird and butterfly abundance, species richness and diversity consistently greater in P16 & P32 than G5 & G1. P16 & P32 and G5 & G1 similar.
- Bird abundance and richness in 2010 ~3X greater in P16 & P32 and ~2X greater in G1 & G5 than annual row crops.
- Bird and butterfly abundance peaked in 2010 and then declined.
- While overall bird abundance declined, the percentage of grassland species increased over time.
- Grassland birds of conservation concern (Dickcissel, Grasshopper Sparrow, Henslow's Sparrow and Sedge Wren) successfully nested in the plots. Nest success rates similar to other grassland habitats in the region.
- During early establishment, soil type directly affected vegetation structure and composition which resulted in differences in bird and butterfly species composition among soils.

TEST BURN OF PRAIRIE BIOMASS:
CEDAR FALLS UTILITIES ELECTRICAL GENERATION PLANT (2013)

FUEL CALORIFIC VALUES FROM LAB ANALYSIS:

LAB ANALYSIS OF PRAIRIE BIOFUEL:
- Sulfur level dramatically lower than coal.
- Mercury not detected.
- Chlorine level (linked to fouling) close to average of two types of coal used by CFU.
- Low potential for slagging and fouling.

EMISSION STACK TEST RESULTS:
- Opacity (soot level) much lower than coal.
- Particulate matter compared to coal: 0.007 lb/MMBtu vs. 0.562 lb/MMBtu.
- Nox, HCl and Mercury all lower than coal.
- CO higher than coal, but CFU states that this is because the boiler is tuned for coal and not for biomass. Tuning the boiler for biomass would reduce CO emissions.

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Figure 1. Poster presentation of the Prairie Power Project

Upon approval, the final report will be disseminated in a number of ways. It will be posted on the Tallgrass Prairie Center and UNI ScholarWorks websites, and will then be shared through various regional and national organizations' e-newsletters including the Tallgrass Prairie Center, CenUSA Bioenergy, Green Lands Blue Waters, the Illinois Biomass Working Group, the Biomass Thermal Energy Council, the Environmental and Energy Study Institute, and Biomass Magazine. The final results of the project will also be presented at the Green Lands Blue Waters Conference November 3 and 4, 2015. Additionally, prairie as a biomass energy feedstock is being promoted through the Tallgrass Prairie Center's new Prairie on Farms program. Connections were made at Prairie on Farms field days in June and September of 2015 with producers who may be interested in harvesting planted prairie vegetation for biomass energy. Prairie on Farms field days in 2016 will include presentations on the use of harvested prairie vegetation as a biomass energy feedstock that can be integrated with their nutrient reduction and soil quality enhancement practices.

Educational materials to increase awareness and understanding of the use and benefits of prairie biomass are being developed for these field days and other outreach activities. These materials also indicate how to become involved in producing prairie biomass.

Next steps

In order to expand the use of native prairie for biomass energy, and reap the environmental benefits, we need to invest in infrastructure for harvest, processing, transport and energy conversion that is well-matched to energy end-use. Successful examples of burning mixed native prairie for heating exist in several other states but have yet to be widely replicated. Agrecol Native Seed Nursery in Evansville, Wisconsin pelletizes the biomass by-products of their native seed production process and burns them in specialized boilers that heat their greenhouses and office space. Pork and Plants, a pasture raised meat and greenhouse produce business in Altura, Minnesota, pelletizes and burns native prairie biomass from their own property to heat their greenhouses. And Show Me Energy Cooperative in Centerview, Missouri, processes native prairie biomass and other dedicated energy crops into customer specified finely ground or pelletized forms that are suitable for heating, electricity generation, liquid fuels research, or cattle feed. The resulting new value chain around home-grown energy will reduce the dependence on LP gas, create economic opportunities and keep more energy dollars circulating in our communities.

Additional work is needed to develop the value chain that will ultimately give producers the incentive to grow prairie vegetation for biomass energy. One major hurdle is that proper processing equipment must be accessible within reasonable proximity of the source and end-use of the prairie biomass so that more energy is extracted from the biomass during combustion than what is expended on harvesting, processing, and transportation. Iowa currently has very little infrastructure that is suitable for processing prairie biomass into a form that is usable in biomass energy conversion equipment. If conversion equipment requires pelletized biomass, the closest facility that can process prairie biomass into pellets is in Gretna, Nebraska. As an alternative to pelletizing prior to burning for electricity generation, the feasibility of chopping and grinding prairie biomass and possibly mixing with coal needs additional investigation.

Barriers like this and others will need to be bridged in order for the production of prairie vegetation as bioenergy feedstock to become a viable enterprise. To that end, the Tallgrass Prairie Center is now beginning a study (funded by Iowa Nutrient Research Center) which will summarize the following: 1) the timing and quantity of thermal energy demand and supply capacity for representative farms in eastern Iowa that are either currently engaged in restoration of perennial vegetation for nutrient reduction purposes or are considering such a move; 2) the equipment requirements optimized for this scale of demand and supply; and 3) the estimated payback time for the model biomass production and thermal energy systems. Our goal is to use this study as the basis for a pilot prairie biomass energy system that could be replicated throughout the state and the region. Ultimately, the development of a prairie biomass energy value chain will give producers more of an in incentive to plant prairie on the landscape.

Section J

Academic Outcomes & Products

Project outcomes during the 5-year grant period include 2 publications in peer-reviewed ecological research journals, 1 paper accepted for publication, 21 presentations at state or national scientific meetings, 5 Master's theses, 8 Summer Undergraduate Research Program projects, as well as 1 Undergraduate Honor's Thesis and 4 Master's theses which are ongoing.

Publications

Myers, M.C., J.T. Mason**, B.J. Hoksch**, C.A. Cambardella, J.D. Pfrimmer**. 2015. Birds and butterflies respond to soil-induced habitat heterogeneity in experimental plantings of tallgrass prairie species managed as agroenergy crops in Iowa, USA. *Journal of Applied Ecology*. DOI: 10.1111/1365-2664.12503

Myers, M.C., B.J. Hoksch*, and J.T. Mason**. 2012. Butterfly response to floral resources at a heterogeneous prairie biomass production site in Iowa, USA. *Journal of Insect Conservation* 16(3):457-472. DOI: 10.1007/s10841-011-9433-4

Sherrard, M.E. L.C. Joers**, C.M. Carr, and C.A. Cambardella. 2015. Soil type and species diversity influence selection on physiology in *Panicum virgatum*. *Evolutionary Ecology* 29(5):679-702

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Abernathy, J.E., D.R.J. Graham, M.E. Sherrard, and D.D. Smith. Productivity and resistance to weed invasion in four perennial bioenergy feedstocks with different diversity. *Global Changes in Biology: Bioenergy*

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Conference Presentations

Young, J**, J. Abernathy**, and KJ Elgersma (2015). Above- and belowground biomass and soil respiration in a low-input perennial biofuel production system. Ecological Society of America Annual Meeting, Baltimore, MD, 8/10/2015.

Ridgway, A**, KJ Elgersma, S Hendrix, M Myers, B Hoksch**, and A Wen (2015). Density and diversity of bees in the Midwestern agricultural landscape: comparing vegetable and biofuel production to native remnant prairies. Ecological Society of America Annual Meeting, Baltimore, MD, 8/12/2015.

Abernathy, J. and M. Sherrard. 2015. The Utility of Tallgrass Prairie Reconstructions as Bioenergy Feedstocks. (Poster). Iowa Prairie Conference, University of Northern Iowa, Cedar Falls, Iowa, July16-18, 2015.

Abernathy, J. and M. Sherrard. 2015. The Utility of Tallgrass Prairie Reconstructions as Bioenergy Feedstocks. (Poster). Iowa Academy of Science, University of Iowa, Iowa City, Iowa. April 17-18, 2015.

Abernathy, J. and M. Sherrard. 2015. The Utility of Tallgrass Prairie Reconstructions as Bioenergy Feedstocks. (Poster). Society of Ecological Restoration-Midwest Chapter Conference. Chicago, Illinois, March 27-29, 2015.

Elgersma, K.J., M Myers, and M Sherrard. 2014. Biofuels Research at the Cedar River Natural Resource Area. Iowa EPSCoR SEB Bioenergy Platform Site Review, Iowa City, IA, 10/16/2015.

Abernathy, J and M. Sherrard. 2014. The Utility of Tallgrass Prairie Reconstructions as Bioenergy Feedstocks. Iowa Experimental Program to Stimulate Competitive. (Poster Research (**EPSCoR**) Meeting, Iowa State University, Ames, Iowa. July 21, 2014.

Graham, D. Species Rich Tallgrass Plantings for Biomass Production. Iowa Academy of Science, Iowa Central Community College, Fort Dodge, Iowa. April 18-19.

Pfrimmer, J.D.**, M.C. Myers, and J.T. Mason**. 2014. Interannual shifts in avian community composition in heterogeneous native prairie biofuel feedstocks. 74th Midwest Fish & Wildlife Conference, Kansas City, Missouri, January 26-29, 2014.

Hoksch, B.J.**, M.C. Myers, J.T. Mason**, J.D. Pfrimmer**, A.J. Ridgway*. 2013. Birds and butterflies respond to soil-induced habitat heterogeneity in experimental plantings of native tallgrass prairie species in Iowa, USA. Society for Ecological Restoration, Madison, Wisconsin, October 6-11, 2013.

Graham, D. 2013. Species Rich Tallgrass Plantings for Biomass Production. (Poster). Iowa Prairie Conference. Luther College. July 18-20, 2013.

Myers, M.C., J. Mason**, B. Hoksch*, J. Pfrimmer**, and D. Miller*. 2012. Birds and butterflies respond to soil-induced habitat heterogeneity in experimental plantings of native tallgrass prairie species. Iowa Academy of Science, North Iowa Area Community College, Mason City, Iowa. April 20-21, 2012

Pfrimmer, J.**, Myers, M.C., J. Mason**, B. Hoksch*, and D. Miller*. 2012. Bird use of heterogeneous prairie biomass production plots. Iowa Academy of Science, North Iowa Area Community College, Mason City, Iowa. April 20-21, 2012

Myers, M.C., B. Hoksch*, and J. Mason**. 2011. Butterfly response to floral resources during early establishment at a heterogeneous prairie biomass production site. Iowa Academy of Science, Wartburg College, Waverly, Iowa. April 29-30, 2011

Mason, J.** and M.C. Myers. 2011. Avian colonization during early establishment in a prairie biofuel project. Iowa Academy of Science, Wartburg College, Waverly, Iowa. April 29-30, 2011

Mason, J.** and M.C. Myers. 2010. Bird, butterfly, and small mammal colonization during early establishment in a prairie biofuel project. North American Prairie Conference, University of Northern Iowa, Cedar Falls, Iowa. August 1-5, 2010

Schlumbohm, M., D.• Williams, and D. Smith. The Effect of Tallgrass Prairie Species Composition on Above-Ground Biomass Production. Iowa Academy of Science, Wartburg College, Waverly, Iowa April 29-30.

Hoksch, B.* and M.C. Myers. 2010. Butterfly response to floral resources in a heterogeneous prairie biomass production site (Poster). North American Prairie Conference, University of Northern Iowa, Cedar Falls, Iowa. August 1-5, 2010

Schlumbohm, M., D.* Williams, D. Smith. 2010. The Effect of Tallgrass Prairie Species Composition on Above-Ground Biomass Production. North American Prairie Conference, University of Northern Iowa, Cedar Falls, Iowa, August 1-5, 2010.

Mason, J.** and M.C. Myers. 2010. Small mammal, bird, and butterfly colonization during early establishment in a prairie biofuel project. Iowa Academy of Science, Graceland College, Lamoni, Iowa. April 16-17, 2010

Schlumbohm, M.D.* and D. Smith 2010 Maximizing Biomass Production of Prairie Vegetation as an Alternative Energy Source. Iowa Academy of Science, Graceland College, Lamoni, Iowa. April 16-17, 2010

*indicates UNI undergraduate student co-author, ** indicates UNI graduate student co-author

Master of Science Students
Jessica Abernathy. M.S. in Biology, University of Northern Iowa (2013-15)
The Utility of High-Diversity Prairie Mixtures as Bioenergy Feedstocks.

Dustin Graham. M.S. in Biology, University of Northern Iowa (2012-14)
Biodiversity and Ecosystem Function and the Design of Tallgrass Restorations for Biomass Production.

Ben Hoksch. M.S. in Biology, University of Northern Iowa (2013-2015)
Project title: *Plant and butterfly community dynamics in experimental plantings of tallgrass prairie species managed as agroenergy crops.*

Jarrett Pfrimmer. M.S. in Biology, University of Northern Iowa (2011-2013)
Project title: *Bird use of heterogeneous native prairie biofuel production plots.*

James Mason. M.S. in Biology, University of Northern Iowa (2008-2012)
Project title: *Early avian colonization in a prairie biofuel project.*

Summer Undergraduate Research Program (SURP) students

Sarah Huebner. Summer Undergraduate Research Program, University of Northern Iowa (2015)
Project title: *Soil respiration and belowground biomass in restored native prairies*.

Ben Nettleton. Summer Undergraduate Research Program, University of Northern Iowa (2015)
Project title: *Comparing bee diversity and abundance in candidate biomass crops*.

Libby Torresani. Summer Undergraduate Research Program, University of Northern Iowa (2014)
Project title: *Grassland bird nest survival in perennial agroenergy crops*.

Stephanie Paape. Summer Undergraduate Research Program, University of Northern Iowa (2014)
Project title: *Ground arthropod abundance in switchgrass and diverse prairie agroenergy crops*.

Andrew Ridgeway. Summer Undergraduate Research Program, University of Northern Iowa (2013)
Project title: *Effects of flooding on the flora and fauna of a reconstructed tallgrass prairie*. Included Honor's thesis)

Nick Tebockhorst. Summer Undergraduate Research Program, University of Northern Iowa (2012)
Project title: *Butterfly response to floral resources in a heterogeneous prairie biomass production site*.

Drew Miller. Summer Undergraduate Research Program, University of Northern Iowa (2011)
Project title: *Butterfly and plant community characteristics following fire management at a prairie biofuel production site*.

Ben Hoksch. Summer Undergraduate Research Program, University of Northern Iowa (2010)
Project title: *Butterfly response to floral resources in a heterogeneous prairie biomass production site*.

Ongoing Student Research

Jordan Young. M.S. in Biology, University of Northern Iowa (2014-) *Soil respiration and litter decomposition in a low-input high-diversity perennial biofuel cropping system.* Expected completion in Spring 2016.

Andrew Ridgway. M.S. in Biology, University of Northern Iowa (2014-) *Native bee abundance and diversity in grassland biofuel and vegetable cropping farms.* Expected completion in Spring 2016.

Molly Schlumbohm. M.S. in Environmental Science. University of Northern Iowa (2010-) *Comparison of productivity of prairie biomass mixtures during establishment.* Expected completion in Summer 2016.

Richard Knar. M.S. in Biology. University of Northern Iowa (2015-) *Biomass Production in Perennial Agroenergy Feedstocks.* Expected completion in Spring of 2017.

Sara Judickas. Floyd Undergraduate Research Assistanship, University of Northern Iowa (2015-). *Butterfly community dynamics at a heterogeneous tallgrass prairie bioenergy production site in Black Hawk County, Iowa.*

Section K

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