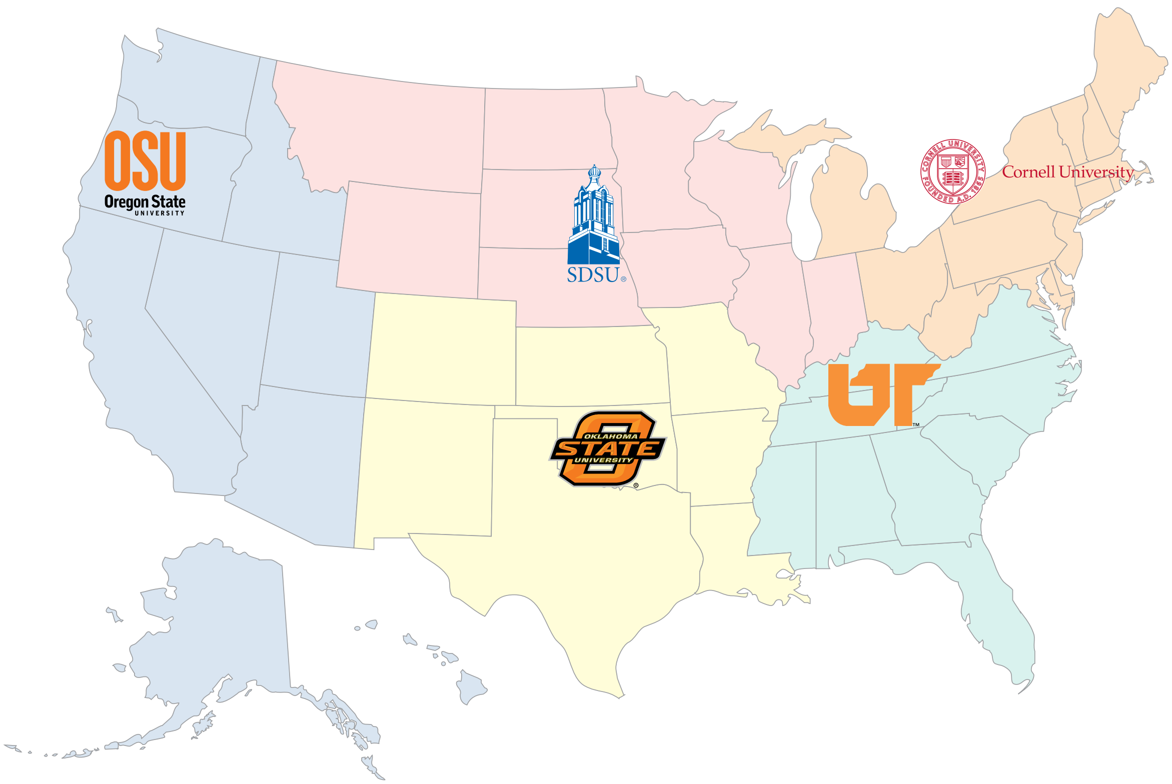
Sun Grant/Department of Energy-
Office of Biomass Programs



Regional Biomass Feedstock Partnership
Status Report

February 2011

SunGrant Initiative

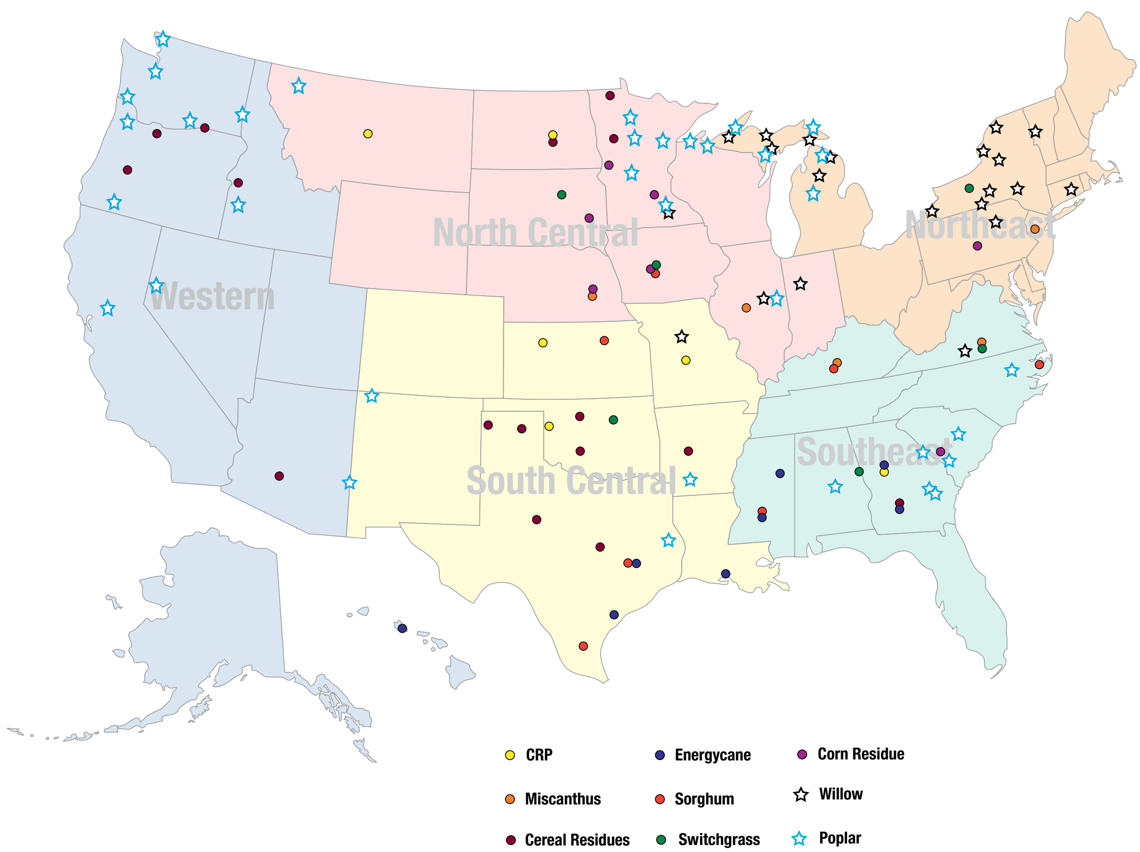
U.S. Department of Energy

TABLE OF CONTENTS

Introduction

The Sun Grant/DOE Regional Biomass Feedstock Partnership developed from the USDA/DOE publication *Biomass as a Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply*. This publication projected that approximately 1.3 billion tons of cellulosic biomass could be available annually in the United States for the production of liquid fuels, chemicals, and power. To explore this possibility, the Department of Energy and the Sun Grant Initiative formed the Regional Biomass Feedstock Partnership. Each of the five Sun Grant Regions conducted workshops with experts from academia, national laboratories, federal and state governments, the private sector and public interest groups. In each region, the potential production of diverse biomass feedstocks was evaluated, obstacles and knowledge gaps were considered, and research needs were identified. Teams of the nation's leading scientists were then formed to further assess biomass feedstock potentials, initiate field trials of the most promising options at the regional and national levels, and estimate and enhance the nation's bioenergy production potential from research and other data.

This report summarizes the mid-term findings and lessons learned by the 96 university and USDA-ARS scientists directly involved in this six year project. One hundred and ten (110) field trials have been established in 39 states in addition to the crop modeling and education/outreach efforts (see the map below). Two-thirds of the crop species under investigation are perennial and are just beginning to move from the establishment phase into the highly productive years of their life cycle. Baseline samples have been collected so that an assessment of the environmental impacts and sustainability of the crop management systems in this project can be performed after five or more years of harvesting. The midterm progress of this project presents valuable results and an excellent preliminary data set. The continued progress of the Regional Biomass Feedstock Partnership will provide a more comprehensive suite of data and information for a better understanding of our potential biomass feedstock supply chain.



BIOMASS ASSESSMENT

Geospatial Analysis of Bioenergy Options for the Northeastern Sun Grant Region

Dr. Peter B. Woodbury, Regional Coordinator, Northeast Sun Grant Center

Executive Summary

A bibliographic database of references on selected biomass feedstocks throughout the 14-state Northeast Sun Grant Region (Michigan to West Virginia to Maine) was developed. Additionally, a comprehensive inventory of existing biomass crop yield data was conducted, and a database on spatial attributes, weather, management, composition information, and yield was compiled. The land availability and potential feedstock production throughout the region was quantified. The land currently in non-forest cover that could be available for bioenergy feedstock production without competing with current agricultural production was analyzed. Then the production potential of bioenergy feedstocks on these lands based on soil and climate characteristics and historical yields of selected crops was modeled. Based on historical trends of increasing yield of individual crops, the projection is that in 10 of the 14 states, 3 to 20% of cropland could become available for feedstock production in 2020 while maintaining current crop production at 2007 levels. Alternately, this land could be used for increased crop production or other uses. Based on regression models representing future feedstock production, the projection total potential for feedstock production is 40 million dry tons for low intensity production or 63 million dry tons for high intensity production on potentially available cropland and herbaceous land. However, not all owners of potentially available land will be interested in producing bioenergy feedstocks, so these estimates are upper limits for this land base. Additionally, the estimate of potentially available herbaceous land does include lands that may not be available for feedstock production such as state and county parks. Achieving the projected high-intensity yield with perennial feedstocks will require substantial field research, some of which is being conducted by collaborators in this overall research program. Forests are very important sources for potential feedstocks, but are not included in this analysis to date.

Introduction

Development of a large bioenergy economy in the United States will require dramatically increasing sustainable biomass feedstock production. The potential for increased biomass production has been analyzed at the national scale (Perlack et al. 2005). However, there is a need for more detailed analyses at regional, state, and local scales. The land availability and potential feedstock production for the 14-state Northeast Sun Grant region was quantified. The land currently in non-forest cover that could be available for bioenergy feedstock production without competing with current agricultural production was analyzed. Then the production potential of bioenergy feedstocks were modeled on these lands based on soil and climate characteristics and historical yields of selected crops.

The overall goal of this project is to conduct a geospatial analysis of bioenergy options for the Northeastern Sun Grant Region as part of a national effort jointly conducted by the Sun Grant Initiative and the Department of Energy-Office of Biomass Programs. The Northeast Sun Grant Region includes Connecticut, District of Columbia, Delaware, Maine, Maryland, Massachusetts, Michigan, New Hampshire, New Jersey, New York, Ohio, Pennsylvania, Rhode Island, Vermont, and West Virginia. This report contains a summary of results to date, as well as anticipated results for 2011. This report focuses on results to date for two primary analysis tasks.

Conduct an inventory of existing biomass crop yield data

In order to understand the factors controlling the yield of biomass energy crops and to predict the yield potential at the regional scale, the existing data should be analyzed and new feedstock yield trials throughout the region must be conducted. A comprehensive inventory of existing biomass crop yield data was conducted including compiling available data on spatial attributes, weather, management, and composition information. Searches included peer-reviewed scientific and technical publications, the U.S. Department of Agriculture's Cooperative State Research, Education and Extension Service

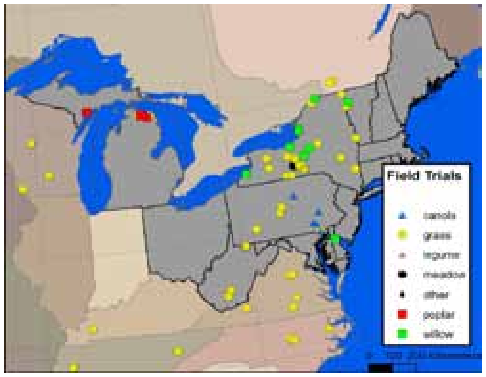


Figure 1. Location of selected field trials of potential bioenergy feedstocks in the Northeast Sun Grant region and nearby States and Provinces.

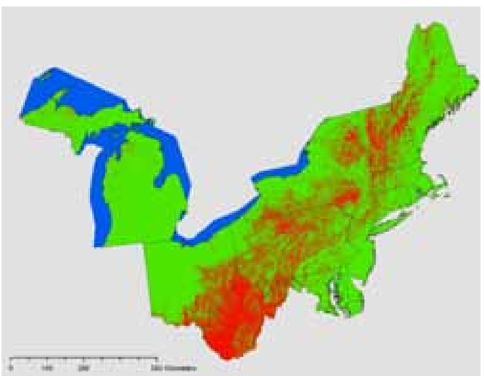


Figure 2. Land in the Northeast Sun Grant Region with slope exceeding 15%. This criterion and others were used to determine suitability for biomass production.

Figure 3. Cropland that could become available by year 2020 for bioenergy feedstock production due to increases in crop yield. Note that this land could alternately be used to increase total crop production above 2007 levels.

(CSREES) – Current Research Information System (CRIS) database, and results from experiment stations. A bibliographic database on both herbaceous and woody bioenergy crops was developed. This database focuses on the Northeast Sun Grant Region but also contains records from other locations. At present, this database includes 592 references on grasses, including 242 references on switchgrass, and 215 references on short rotation woody crops. A database of yield data from field trials within the Northeast Sun Grant Region and adjacent states and Canadian provinces was also developed. These data have been uploaded to the Department of Energy for inclusion in the Knowledge Discovery Framework. A subset of these data that contains the most detailed yield data and comprehensive location data are shown as an example in Figure 1.

Develop a Regional Feedstock GIS Atlas Database

A Geographic Information System (GIS) Atlas database (geodatabase) for the Northeast Sun Grant region was developed. This geodatabase includes data on feedstock yield as described above, as well as estimates of lands that are suitable and potentially available for feedstocks production and the production potential of these lands, as described below.

Trends in yield of major crops in each of the 14 states in the Northeast Sun Grant Region were quantified. For each state, these trends were projected to the year 2020 to analyze the amount of land that could be available in coming years for either increased crop production or increased bioenergy feedstock production. Additionally, idle and suitable agricultural land that is currently in herbaceous cover but is not harvested was quantified based on geospatial analysis of land cover data from the National Land Cover Database, Federal land ownership, and a digital elevation model. Land with slopes greater than or equal to 15% was considered not to be suitable for production of herbaceous or short-rotation woody feedstocks (Figure 2).

Based on historical trends of increasing yield of individual crops, the projection is that in 10 of the 14 states in the region, 3 to 20% of cropland could become available for feedstock production by year 2020 while maintaining current crop production at 2007 levels (Figure 3). Alternately, this land could be used for increased crop production or other uses. Also observed is that for most states, much more land currently in herbaceous cover but not producing crops is available compared to cropland that could become available due to increases in crop yield (Figure 4).

Geospatial soils data from the Natural Resource Conservation Service (NRCS) throughout the region is being used. Regression models have been developed to predict the yield of selected crops in the region, including maize and grass hay using county-level yield data from the National Agricultural Statistical Service. Models to project the potential yields of perennial biomass feedstocks such as switchgrass and short-rotation willow throughout the region based on soil and climatic characteristics have also been developed. Using these models, the projected total potential feedstock production is 40 million dry tons for low intensity or 63 million dry tons for high intensity production on potentially available cropland and herbaceous land (Fig. 5). However, not all owners of potentially available land will be interested in producing bioenergy feedstocks, so these estimates are in the upper limits. Based on surveys of landowners and on detailed analysis for New York State, only half of landowners might be interested in harvesting biomass from their lands. However, further research is required to better understand landowners' values and interest in producing biomass feedstocks, and attitudes may change as more opportunities to sell feedstocks become available throughout the region.

A geospatial data set containing estimates of potential production of feedstocks on both cropland and non-crop land using both low intensity and high intensity management was developed. These data were uploaded to the Department of Energy's Knowledge Discovery Framework site during 2010. Since that time, improved geospatial data sets are being developed on land use and soil properties to refine the yield estimates.

Anticipated Accomplishments for 2011

During 2011, the range of biomass feedstocks that are being modeled throughout the region will be expanded. The estimates of potentially available land for feedstock production will also be improved. Additionally, the analysis of potentially available land and potential feedstock production to the entire conterminous United States will be expanded, in collaboration with colleagues including regional GIS leads from other regions and those conducting research on specific feedstock crops.

Literature Cited

Perlack, R., L. Wright, A. Turhollow, R. Graham, B. Stokes, and E. D. 2005. Biomass as Feedstock for a Bioenergy and Bioproducts Industry: Technical Feasibility of a Billion-Ton Annual Supply. (ORNL/TM-2005/66). Oak Ridge National Laboratory Oak Ridge, TN.

Figure 4. Land currently in herbaceous cover that is suitable and potentially available for bioenergy feedstock production (not used for current agricultural production of hay, pasture, etc.).

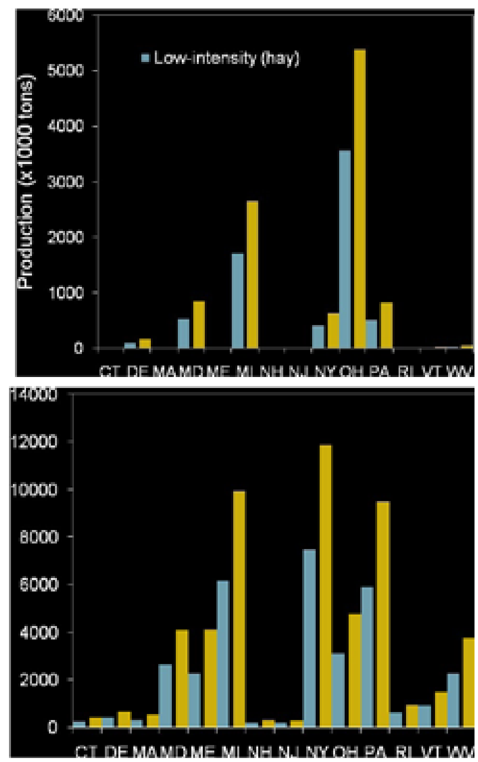


Figure 5. Predicted production (dry tons) of low and high-intensity feedstocks. The upper panel shows results for cropland that could become available due to increases in crop yield, and the lower panel shows results for land currently in herbaceous cover that is not producing agricultural crops.

Geospatial Analysis of Bioenergy Options for the North Central Sun Grant Region

Michael C. Wimberly, Regional Coordinator, North Central Sun Grant Center
Mirela Tulbure
Rajesh Chintala

Introduction

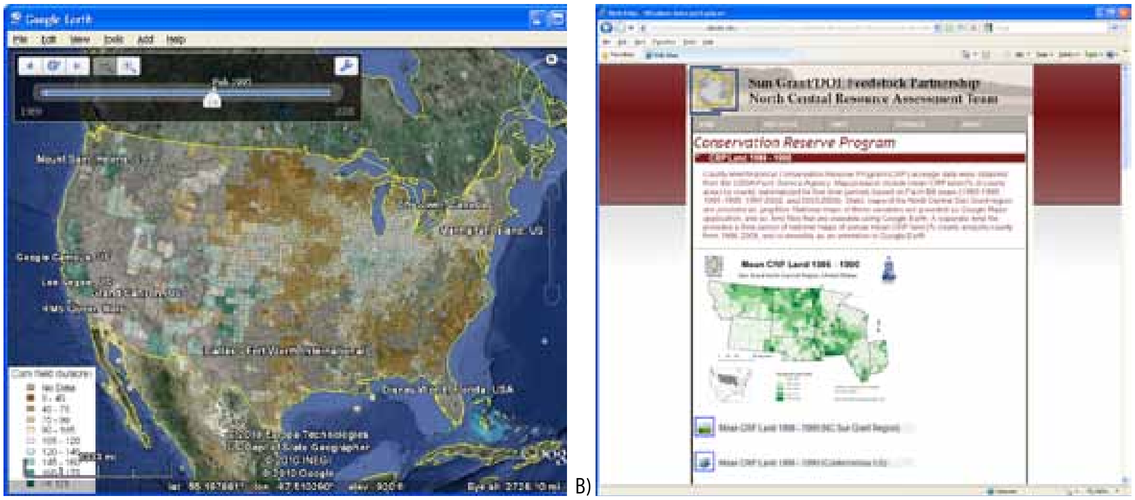
The recent U.S. Renewable Fuel Standard calls for 36 billion gallons of ethanol production by 2022 with over half produced from plant biomass. To achieve this goal, new systems for sustainable feedstock production must be developed. Potential novel biofuels feedstocks include annual crops such as sorghum, perennial grasses such as switchgrass and prairie cordgrass, crop residues, fast-growing trees, and wood residues. Given the vast range of climate and soils in the North Central Region of the United States, multiple production systems must be developed and adapted for different environments, and these systems need to be both commercially viable and environmentally sustainable. There is enormous potential for applying geospatial technologies to support these efforts. The overarching goal of the North Central Region's resource assessment team is to provide an estimate of the potential bioenergy feedstock supplies that are available for conversion into cellulosic ethanol. In the North Central Region, the research focus to date has been on the influences of climatic variability in space and time on the potential yields of biomass feedstocks.

Data Compilation

As outlined in the Regional Feedstock Modeling and GIS (Geographic Information System) Task Statement of Work, an extensive library of data from a variety of sources was compiled. Information on bioenergy crop yield was collected from the published literature along with accompanying data on spatial locations, management practices, and environmental factors. Yield points were collected for key bioenergy crops, including corn stover, sorghum, CRP grasslands, energy cane, Miscanthus, switchgrass, poplar and willow. A historical county-level database of National Agricultural Statistics Service (NASS) cropped areas, productivity, and yields from 1970-present for more common agricultural crops (e.g., corn, soybeans, wheat) was compiled. In addition, a geodatabase that includes regional GIS data sets characterizing climate, land cover/land use, land ownership and conservation status, and soils was assembled. A regional database of remotely-sensed environmental metrics from 2000-present, including Moderate Resolution Imaging Spectrometer (MODIS) surface temperature and vegetation indices derived from the Bidirectional Reflectance Distribution Function (BRDF)-corrected reflectance product was also developed. These data were used to model regional patterns of evapotranspiration (ETa) using the simplified surface energy balance (SSEB) method. These data form the basis for the subsequent geovisualization and data analyses outlined below.

Geovisualization and Data Dissemination

To make these data more accessible to a variety of end users, including policy makers, biomass growers, bioenergy producers, and the general public, emerging web-GIS technologies such as digital globes (e.g., Google Earth, Figure 1) have been applied. These technologies allow for the development of geovisualization products that facilitate user interaction with spatial data and permit dynamic space-time visualization, but do not require a technical background in GIS. Work to date has involved the distillation of a large volume of geospatial data relevant to biofuels feedstock production into a set of informative digital map products. A novel web atlas framework was developed to facilitate the dissemination of these products (Liu et al. 2010). This atlas includes a variety of digital map products relevant to feedstock production, including historical cropped area and crop yield, land cover/land use, climate, and soils (http://globalmonitoring.sdstate.edu/sungrant/).



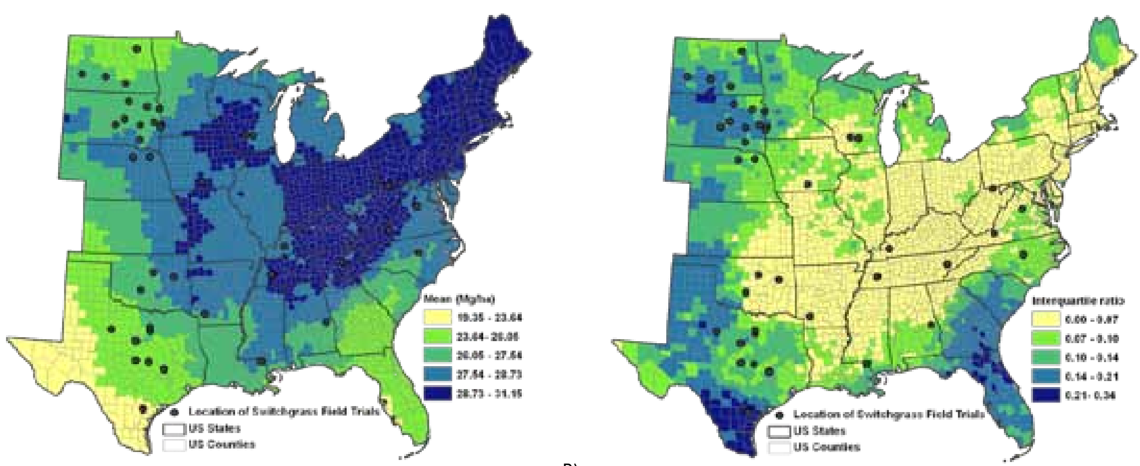
A) B)

Figure 1: A) Geovisualization of the spatio-temporal dynamics of corn yield from 1970-present using Google Earth. B) Project website and web atlas.

Climatic and Genetic Controls of Switchgrass Yield, a Model Bioenergy Species

The recent U.S. Renewable Fuel Standard calls for 36 billion gallons of ethanol production by 2022 with over half produced from plant biomass. Switchgrass (*Panicum virgatum* L.), a warm-season perennial grass native to North America, has emerged as the leading candidate among herbaceous species to be developed as a bioenergy feedstock. To reach biofuels production goals, more information is needed to characterize potential production rates of switchgrass in relation to soil, climate, and cultivation practices. A meta-analysis of existing studies was conducted (1,167 observations associated with 45 field trial locations across 16 states) to investigate: (1) the main drivers of switchgrass yields (e.g., climate, environmental variables, genetic factors) across a broad geographic region; (2) whether lowland cultivars have a distinctive climatic niche compared to upland cultivars; and (3) interannual variability in switchgrass yields due to climate.

Nitrogen fertilizer was the most important explanatory variable followed by cultivar, highlighting the importance of agronomic practices and genetic variability. Based on these results, the data was further split by ecotypes (upland and lowland) and modeled switchgrass yield as a function of 10 environmental variables (% silt, % clay, April-May precipitation, June-Sept precipitation, average growing season temperature, nitrogen fertilizer, stand age, cultivar, origin of cultivar, and month of harvest). While similar variables were important in explaining variability of switchgrass yields of both cultivars,



A) B)

Figure 2: A) Mean switchgrass yield (Mg/ha) from 1970 to 2008 for lowland cultivars, B) Switchgrass yield variability expressed as interquartile range/ median for lowland cultivars

the relationships differed (e.g., April-May precipitation increased yields up to an optimum of 100 mm for lowland cultivars, whereas for upland cultivars the relationship was close to linear, yields increasing up to 200 mm). Using yearly historical PRISM climate data from 1970 to 2008, the year to year variability in switchgrass yields resulting from climatic variability was quantified. This result highlights the importance of accounting for interannual variability in biomass yields for the future production and use of switchgrass as feedstock, and provides an approach for highlighting areas with high and low yield variability (Figure 2). These results have been documented in a manuscript that is in preparation for submission to Environmental Research Letters (Tulbure et al., In Prep).

Residues

Crop residues are another important source of cellulosic feedstocks for bioenergy production. However, the geographic patterns and interannual variability of crop residue production in relation to climatic variables such as precipitation and temperature are not well understood. To study the spatial and interannual variability of crop residue yield potential across the North Central region of the United States, a time series analysis was used. NASS crop yield data from 1970 -2008 were used to model potential crop residue harvests. Spatial and temporal variability in potential crop residue production was quantified by mapping the coefficient of variation for each county. PRISM temperature and precipitation data were used to model the relationships between climatic variability and potential residue production. Counties in the southeastern part of North Central region were observed to have a relatively high mean crop residue yield potential and the lowest interannual variability in crop residue yield potential (Figure 3). Portions of Wyoming, the eastern Dakotas, and northern Minnesota had the highest variability in crop residue yield potential. Statistical analyses identified relationships between crop residue yield potential and growing season temperature and annual precipitation. In general, counties with higher average temperature and annual precipitation exhibited higher crop residue yield potential. These exploratory analyses have been documented in a manuscript submitted to *Biomass and Bioenergy* (Chintala et al. , *Under Review*).

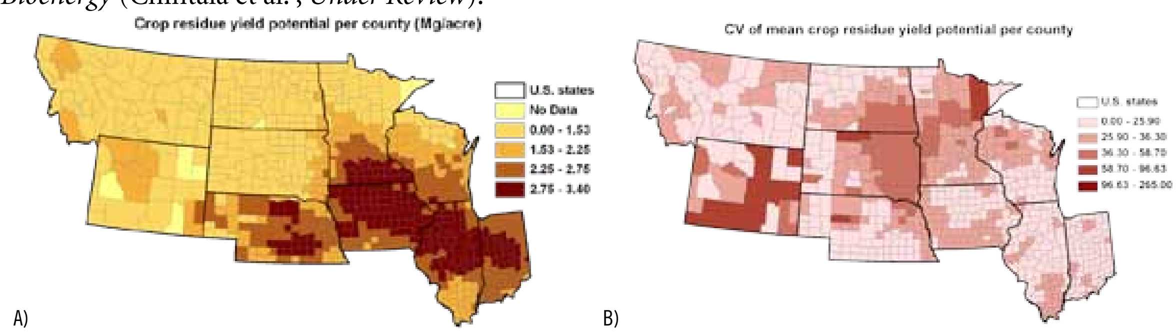


Figure 3: A) Mean crop residue yield potential for 1970-2008 in Mg/Acre[1], B) Coefficient of variation (CV) of crop residue yield potential from 1970-2008.

Anticipated Results for 2011

A major update to our website and web atlas is planned for January 31, 2011. This revised website will include new web atlas functionality and an online survey to gather feedback from end users. New geovisualization products will continue to be produced and added to the web atlas throughout 2011. The switchgrass modeling paper will be expanded by using downscaled general circulation models (GCM) to forecast potential switchgrass yield under various climate change scenarios. Additional modeling studies will be conducted to assess the influences of interannual climatic variability on the spatial and temporal patterns of crop yield and potential crop residue harvests. During the past year, a pilot study of methods was conducted to map "marginal lands" that could be potentially used for biofuels production in South Dakota. In the upcoming year, the plan is to map these marginal lands across to the entire North Central Region. These future efforts will increase understanding of the environmental drivers of biofuels production in the northern Great Plains and provide access to a variety of new maps and geovisualization products.

[1] Mg/Acre (megagram per acre) = 2204.62 pounds (lbs) per acre

Geospatial Analysis of Bioenergy Options for the South Central Sun Grant Region

Michael R. Dicks, Regional Coordinator, South Central Sun Grant Center
Arjun Basnet
Theophilus A. Depona

Accomplishments

A bibliographic database has been developed and is under continuous development on potential biomass crops including corn stover, small grain residue, energycane, sweet sorghum, CRP grasses, miscanthus, switchgrass, short-rotation willow, and short-rotation poplar. Yield data from the NRCS web resources have been collected for primary and secondary biomass crops regarding soil types that support crop production (soil class 1 to soil class 4). Records are available for all the yield data of primary and secondary biomass crops available in the NRCS web resources for counties in Oklahoma, Colorado, Kansas, Missouri, Arkansas, Louisiana, Texas, and New Mexico.

Switchgrass yields have been estimated for the top five soils for all counties in Oklahoma. The estimate of yields was performed using the switchgrass yield data collected from the research stations and comparing these yields with the yields of other crops obtained from the NRCS online sources for that particular soil type. The current estimate of the total potential switchgrass supply for Oklahoma from the top five soils of each county is 49.5 million tons. Estimated switchgrass yields were compared to those from earlier estimates by the Oakridge National Laboratory (ORNL) and these estimates were roughly half of the estimates by ORNL. A modeling system was developed to re-estimate all the soil based yields as new data becomes available from research trials. A paper entitled "Potential Biomass Yields in the South Central US" was presented at the Southern Agricultural Economics Association's Annual meetings in Corpus Christi, Texas on February 7, 2011.

Results

The following switchgrass supplies have been estimated using the yield data collected from different experiment stations across Oklahoma, published literature, and the NRCS online web resources. The table below shows the estimated total supply of switchgrass in tons for nine agricultural districts in Oklahoma. The total supply has been estimated only for the top five most productive and predominant soils for each county in Oklahoma.

Table 1: Oklahoma agricultural districts - Total supply of Switchgrass

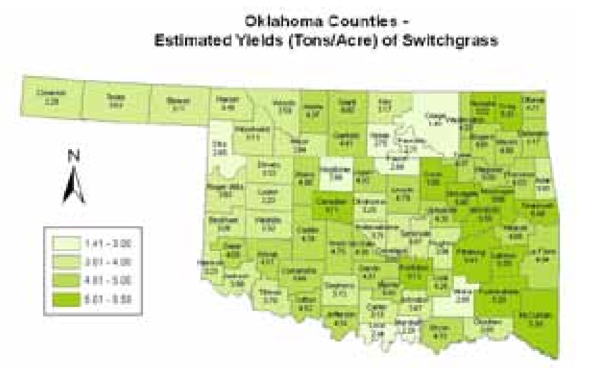
Oklahoma Districts	Total Supply (Tons)	Top Five (Total Acres)	No. of Counties	Total Farm Land (Acres)	% of Farmland
Northeast	7,410,473	1,888,175	10	3,888,067	48.56%
Central	6,641,226	1,574,831	13	5,090,829	30.93%
Panhandle	6,292,770	1,862,584	5	4,714,382	39.51%
North Central	6,236,352	1,703,395	9	5,049,869	33.73%
Southwest	5,643,748	1,380,778	8	3,814,777	36.20%
South Central	5,561,676	1,435,346	12	4,513,767	31.80%
East Central	5,290,790	1,041,258	9	2,987,821	34.85%
West Central	3,517,203	999,656	6	3,573,477	27.97%
Southeast	2,999,421	597,872	5	1,454,280	41.11%
Total	49,593,659	12,483,895		35,087,269	35.58%

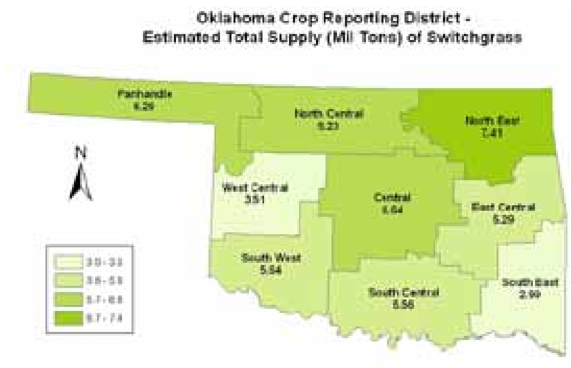
Economic Analysis

The total potential supply of switchgrass from Oklahoma was estimated to be 49.5 million tons. The Northeast region in Oklahoma was found to be the dominant supplier of switchgrass with 7.4 million tons and the Southeast region to be the lowest supplier with 2.99 million tons (see map below). The ton per acre calculation of switchgrass gives a different result. The Southeast and East Central districts were found to supply the maximum quantity of switchgrass per acre as compared to other districts. Therefore, economically future plant locations can be established and can be viable in these districts as the soils in these districts can produce approximately 5 tons/acre and can supply about 3-5 million tons of switchgrass.

GIS Atlas Database

The estimated switchgrass yield for each county in Oklahoma and the total supply of switchgrass (mil tons) for the Oklahoma Crop Reporting District has been mapped using Arc GIS 9.2. The map is based on the estimated mean yield of switchgrass for each county in Oklahoma. A draft GIS Atlas database (geo-database) is being developed for the South Central Sun Grant region. Every effort is being made to expand and update the existing resources.





Anticipated Results for 2011

- Continue search for data on yields from literature and experiment stations.
- Upload revised yield data for the region to the DOE SharePoint website.
- Upload bibliographic data for the region to the DOE SharePoint website for use in the KDF.
- Continue expanding the geo-database.
- Continue to map the estimated total supply of switchgrass in Oklahoma on a county basis and perform economic analysis.
- Upload to DOE estimates of land that is potentially available throughout the region.
- Upload to DOE estimates of yield potential of selected feedstocks throughout the region.
- Work with DOE and other regional GIS leads to develop protocols for integrating geospatial databases and predictions of yield potential at the national level.
- Continue developing an appropriate procedure to estimate missing yield data.
- Continue estimating switchgrass yields for each county in Colorado, Kansas, Missouri, Arkansas, Louisiana, Texas, and New Mexico.
- Work with other regions in the development of the national border to border estimates of yields for all potential feedstocks.

Peer-Reviewed Publication

Dicks, Michael R., Jody Campiche, Daniel De La Torre Ugarte, Chad Hellwinckel. 2009. Land Use Implications of Expanding Biofuel Demand, Journal of Agricultural and Applied Economics 41 (2): 1-19.

Geospatial Analysis of Bioenergy Options for the Southeastern Sun Grant Region

Sam Jackson, Regional Coordinator, Southeast Sun Grant Center
Daniel De La Torre Ugarte
Bradley Wilson

Over the past two years, the primary efforts under this project have focused on developing tools to address issues related to the emerging biofuels industry. Specifically, questions often arise when selecting sites for biomass using facilities. These questions may relate to feedstock availability, land conversion or availability, feedstock costs, transportation costs, and other issues. This research has developed a method for using the Geographic Information System (GIS) to model feedstock availability and ideal biorefinery locations in an economically feasible manner.

The software developed as part of this study is referred to as BIOFLAME (Biofuels Facility Location Analysis Modeling Endeavor). Expanding on similar efforts that came before it, the model allows the user to perform an analysis on any combination of counties within a 16 state region in the southeast United States given parameters such as biorefinery capacity, crop prices, transport cost rate, feedstock yield adjustments, hay land availability, driving distance limit, required profit, and more.

BIOFLAME is a comprehensive GIS modeling system for assessing potential feedstock across a region and identifying ideal locations for biorefineries and preprocessing facilities. The software attempts to site these facilities in a way that minimizes feedstock procurement and transportation costs while satisfying industrial requirements. Remote sensing data are incorporated to analyze feedstock availability at the sub county level and street level network analysis estimates transportation costs of hauled cellulosic material from field to facility. A flexible suitability analysis allows for sites to be situated near or away from a variety of geographic features that may be important to a particular scenario.

Using a break-even analysis, the model determines the price point at which it becomes profitable for farmers to start growing switchgrass instead of traditional crops. This analysis incorporates switchgrass yield and cost of production data that is adjusted for dry matter loss and equipment usage respectively according to the harvesting and storage options specified for a scenario. The resulting farm gate price, along with all of the other data utilized by the model resides at the sub county "crop zone" level which is comprised of five mile area hexagons that cover a 16 state area of the southeastern United States. The model determines an ideal facility location by analyzing candidate facility nodes and selecting low cost feedstock until a given capacity is met. The candidate facility with the overall lowest total feedstock cost (farm gate + transport costs) is chosen and output maps are generated showing the facility location as well as the location of the feedstock that would supply the facility. A detailed report is also generated that shows a breakdown of the annual costs involved as well as the impact on regional agriculture in terms of converted cropland.

A number of significant improvements and additions have been made to BIOFLAME in 2010, the most important being the ability to site multiple facilities and multiple facility types. The model can now site up to 8 biorefineries or combinations of biorefineries and preprocessing facilities for a given scenario. Supported preprocessing facility types include compacting, pelletizing, and cubing along with a wider range of harvesting methods such as chopping, round baling, and square baling. The transportation system has also been expanded to evaluate the hauling of these new material types from the fields to the facilities. Another new feature for 2010 is the ability to use existing industrial parks for site selection. While initially limited to east Tennessee, these industrial park sites can be evaluated based on such properties as sale or lease price, proximity to rail, building type, lot size, and distance to interstate.

A number of improvements were also made to the user interface that allow for a better graphical representation of model output. Hexagon crop zones are now shaded with colors that indicate where feedstock that supplies a given facility resides at the sub county level. Higher resolution base maps now provide a better backdrop for output at all zoom levels. Scenario input parameters and tabular output data have also been streamlined into a neater spreadsheet form to make setting up scenarios and evaluating output easier. In the interest of providing a way to evaluate a large number of scenarios at once, at batch capable version of BIOFLAME was created that allows multiple instances of the model to run simultaneously. While still under development, this feature will eventually enable users to evaluate hundreds of variations of scenarios at once.

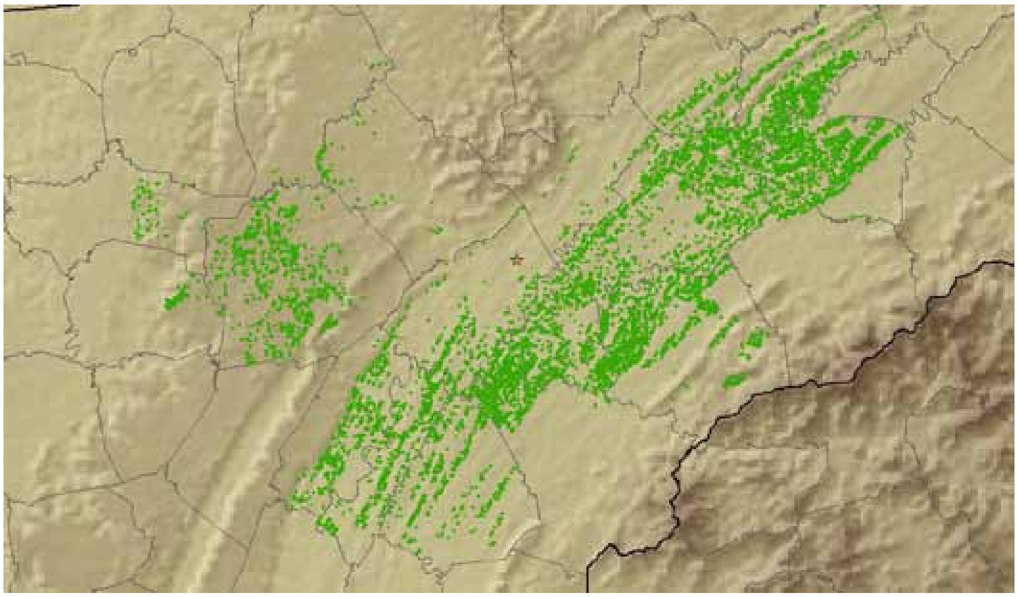


Figure 1: Example Output of Feedstock Supply Region for Hypothetical Biorefinery Location Generated by BioFlame

BioRefinery Siting Report

Feedstock Summary

Total Feedstock Cost	$9,268,298
Total Farmgate Cost	$4,095,532
Total Transportation Cost	$5,172,770
Total Switchgrass Supply	187,508
Marginal Cost	$42.95
Average Feedstock Cost Per Ton	$49.43
Average Farmgate Cost Per Ton	$21.84
Average Transportation Cost Per Ton	$27.59

Cropland Converted To Switchgrass

Barley Acres	
Corn Acres	1,750
Cotton Acres	
Hay Acres	16,694
Oats Acres	
Rice Acres	
Sorghum Acres	
Soybeans Acres	1,000
Wheat Acres	1,571

Figure 2: Hypothetical Switchgrass Feedstock Supply Analysis for a Potential Biorefinery Location Generated by BioFlame

Geospatial Analysis of Bioenergy Options for the Western Sun Grant Region

Christopher Daly, Regional Coordinator, Western Sun Grant Center
Michael Halbleib
Russ Karow
Jan Auyong
Bill Boggess

Oregon State University

The work of the Sun Grant Western Regional Geographic Information System (GIS) Center has focused on three main areas: (1) preparing a geospatial inventory of existing biomass in the Western Region; (2) estimating the geospatial distribution of biomass for cereal crops nationally, in support of the Sun Grant cereals lead (Russ Karow); and (3) developing national, "wall-to-wall" crop suitability maps for important feedstocks. Accomplishments in each focus area are summarized below.

Geospatial Biomass Inventory for the Western Region

An inventory of existing biomass crop yield data, including data on spatial attributes, weather, management, and composition is being prepared. To date, nearly 3,900 data points from peer reviewed journal articles, experiment station reports, general publications, and other suitable data sources have been collected. Figure 1 shows the counties for which data have been collected, and Figure 2 breaks down the database by crop across the region. Most of the data collected have been for wheat; however, information on relatively obscure crops in the region has also been collected. Some of these crops might have a fit as a rotation crop, or in areas that have lower rainfall or lack irrigation, they may serve as a means of capturing additional biomass that is not currently available. Data points in western Washington and Oregon are notably absent; most of the agriculture in these areas has historically been in high-value crops with little biomass production.

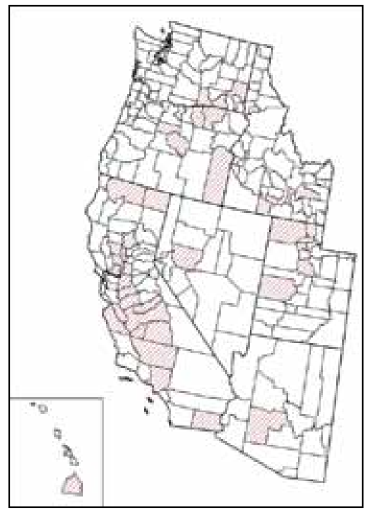


Figure 1. Western region map showing counties for which biomass data have been collected (no data were collected in Alaska).

National Geospatial Biomass Estimates for Cereals

In support of the Sun Grant cereals program, USDA National Agricultural Statistics Service (NASS) geospatial data on yields for important cereal crops were processed to provide a national picture of the historical distribution of grain yield and the potential for biomass (straw) production. For example, Figure 3 shows the reported wheat grain production per acre over the period 1999-2008, averaged by county. Important assumptions were made in preparing this map. The NASS survey is voluntary, and as such there are undoubtedly unreported yield data. As a metric for the consistent production needed to support a processing facility, a county was included in our map as having a valid average yield only if it had non-zero production reported in all ten years.

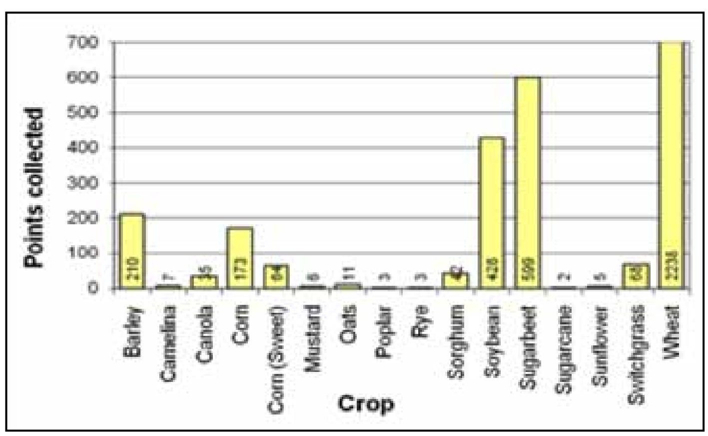


Figure 2. Total number of locations for which biomass data have been collected, broken out by crop.

A harvest index (ratio of wheat straw to grain) of 0.4 was applied to the yield estimates in Figure

3 to estimate the number of tons of available wheat biomass in each county. The resulting map (Figure 4) provides a general overview of straw biomass production that could have been expected throughout the country based on the ten year period 1999-2008.

A much more complete yield database has been recently acquired from the USDA Risk Management Agency (RMA), and that database has begun to be processed to produce similar maps. Given that the RMA database is the most comprehensive and accurate available, it is anticipated that a more complete picture of historical production across the country can be developed.

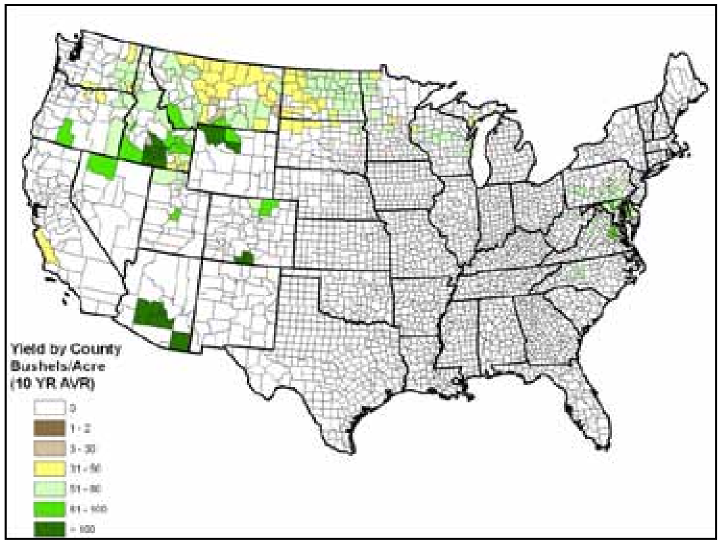


Figure 3. NASS average wheat grain yield by county in bushels per acre based for the period 1999-2008.

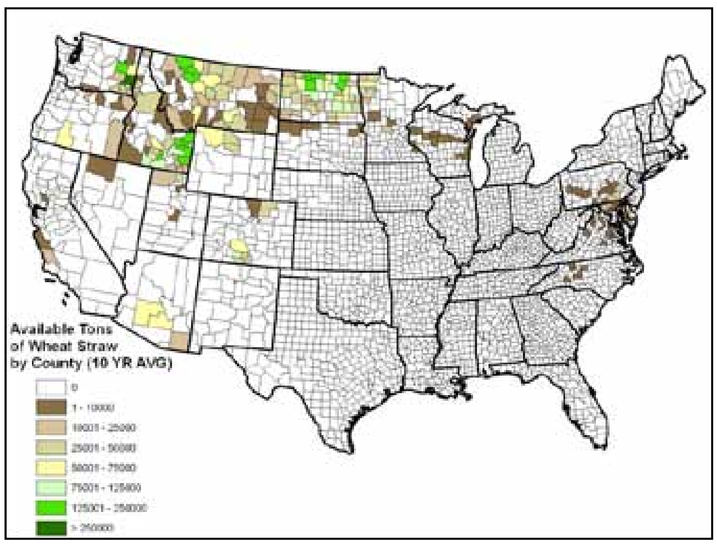


Figure 4. Estimated available tons of wheat straw by county for the period 1999-2008 (based on NASS data).

National Suitability Mapping

An overall goal of the Sun Grant GIS program is to create national maps showing potential biomass productivity across the United States. Unfortunately, it is unlikely that there will ever be data points of sufficient number, placement, and consistency to directly represent the actual variations in productivity. In addition, this approach has limited capability to determine the potential for new crops, or play "what if" games for future climates. Finally, there is a need to coordinate priorities for biomass data collection across regions.

To address these issues, the Western Region has taken the lead on developing a simple suitability/yield model that incorporates the important environmental constraints on biomass production, namely climate and soils. The result is high-resolution, gridded "first-guess" potential biomass maps for the conterminous United States. The maps serve as a starting point for more refined mapping of current and future potential biomass resources with the aid of field data, management and economic analysis, land use/land cover, and other spatial datasets that help define lands suitable for bio-energy crops. In addition, these first-guess maps, in concert with point maps showing what yield data have been collected and where, will inform the regional centers where additional data would be helpful to validate the maps.

The intent is to provide a unifying modeling framework for the assessment of feedstock resources, and in the process, clarify requirements for field trial and literature-based yield information, as well as other spatial datasets.

The suitability mapping system currently consists of the following components: (1) PRISM spatial climate grids; (2) SSURGO GIS soils information; (3) Internet map server; (4) basic suitability model; and (5) field validation (Figure 5).

The PRISM (Parameter-elevation Regressions on Independent Slopes Model) knowledge-based system has been used to create climate grids (precipitation and minimum and maximum temperatures) for the United States and other parts of the world. PRISM is a state-of-the-science climate mapping technology that has been used in several major climate mapping efforts in the United States, including official maps for the U.S. Department of Agriculture. An 800-m resolution, PRISM monthly time series data set for minimum and maximum temperature and precipitation for the entire conterminous United States that spans the period 1895-2009 has been developed.

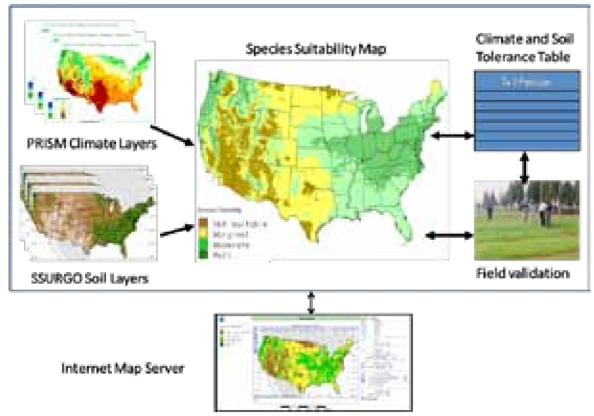


Figure 5. Overview of the current crop suitability mapping system.

The GIS-based soil information used for creating crop suitability maps (pH, drainage, and salinity) was obtained for the United States from the USDA-NRCS SSURGO spatial data set. Mean pH, salinity, drainage, and available water layers, at a resolution of 1:1,000,000 (1:1M), are used to compare with crop species' quantitative tolerances for these factors.

Internet map server technology is a means of creating and displaying geospatial maps, allowing users to display or hide individual map layers, pan or zoom into specific regions, and query map elements for more specific information through a web browser such as Internet Explorer or Firefox. The initial version of the internet map server application called "Species Suitability Modeling" (http://prismmap.nacse.org/forages/) was created by the PRISM Climate Group for forage program activities related to marketing Oregon-grown seed in China.

The six elements that make up the basic suitability model are: mean July maximum temperature, mean January minimum temperature, annual precipitation, soil pH, soil salinity, and soil drainage. Users can select one, some, or all of the elements to be included and can adjust the threshold values of each. The model is presented as a fillable form on the map server (Figure 6).

Species Suitability Model

Version Name: Tall Fescue

Include?	☑		☑		☑		☐		☐		☐	☐ >>>
	July Max Temp (C)		Jan Min Temp (C)		Annual Precip (mm)		Soil pH		Soil Drainage (categories)		Soil Salinity (mmhos/cm)	Water Balance Yield(%)
	Low	High	Low	High	Low	High	Low	High	Low	High	High	Low
Well Adapted	5.98	28.32	-12	9999	625	9999	5.38	7.98	SPD	WD	5.99	0.75
Moderate	9.20	31.12	-15	9999	450	9999	4.78	8.58	PD	ED	9.89	0.5
Marginal	13.07	33.2	-18	9999	300	9999	4.06	9.3	VPD	ED	13.15	0.25

Figure 6. Example of a basic suitability model for tall fescue, to be modified and enhanced for Sun Grant applications.

Agronomic field trials have been the standard evaluation technique for selecting species and cultivars, but extrapolation of information from one site to another for these types of trials has always been a problem. By developing suitability maps first, based on our best knowledge of species characteristics, field-based evaluation makes more efficient the use of available testing resources. Thus, field trials are used to validate and inform the modeling process and refine estimates contained in the quantitative tolerances table for each species.

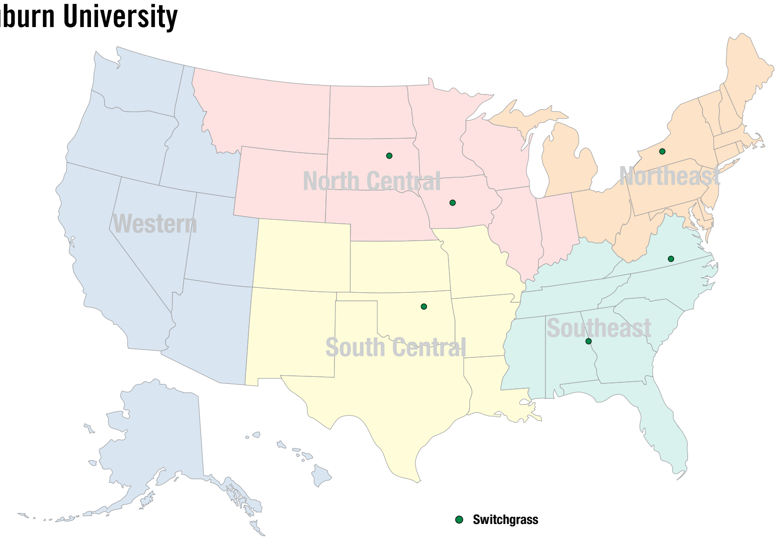
An enhanced suitability mapping system is being developed for Sun Grant that incorporates continuous climate and soils response function that will allow the estimation of yield, not just suitability categories. Tall fescue (*Lolium arundinaceum* (Schreb.) Darbysh.) is the demonstration species. Tolerance information is being collected and rough suitability maps are being produced for corn, cereals (wheat, barley, oats), energycane, tall fescue, annual ryegrass, miscanthus, sorghum, switchgrass (upland and lowland), willow, and poplar, and possibly one or two other tree species. The aforementioned USDA RMA yield database will be useful in validating and adjusting the first-guess maps produced by the environmental model.

BIOMASS RESOURCE DEVELOPMENT
Herbaceous Energy Crops

Vance Owens, Team Lead
South Dakota State University

Switchgrass

V.N. Owens, Switchgrass Coordinator, South Dakota State University
Chang Hong, South Dakota State University
Emily Heaton, Iowa State University
John Fike, Virginia Tech
Don Viands, Cornell University
Rodney Farris, Oklahoma State University
Rob Mitchell, USDA-ARS
David Bransby, Auburn University



Introduction

Switchgrass has been identified as a model herbaceous perennial feedstock because it is broadly adapted and has high yield potential on marginal croplands (Vogel, 2004). The Regional Feedstock Partnership selected switchgrass as one of four herbaceous species for which replicated field trials should be established across the United States. Switchgrass is well adapted to marginally-productive crop land and has been planted on millions of acres of land enrolled in the Conservation Reserve Program (CRP). Although switchgrass tolerates low fertility soils, optimizing biomass and maintaining quality stands requires nitrogen (N) fertilizer inputs and proper harvest management (Mitchell et al. 2010).

Field Trial PI	Institution	State	Planted
V. Owens	SDSU	SD	2008
D. Viands	Cornell	NY	2008
E. Heaton	ISU	IA	2009
J. Fike	Virginia Tech	VA	2008
R. Farris	OSU	OK	2008
D. Bransby	Auburn	AL	2010

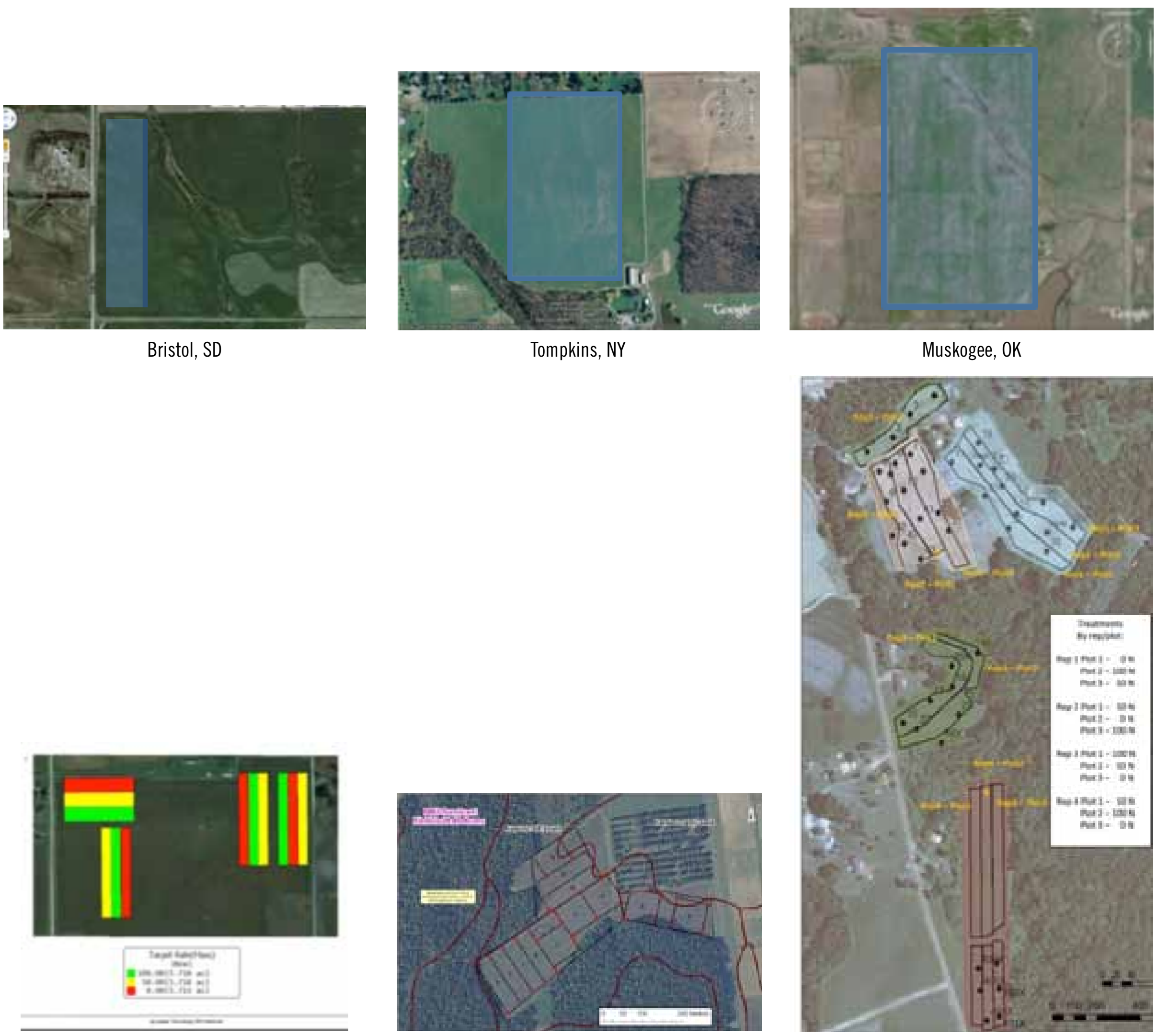
Fig. 1. Field locations for switchgrass. Research sites are labeled on the map with their corresponding site information shown in the table to the right.

While there is significant information in the literature relative to nitrogen fertilizer management at the small-plot scale, there is little field-scale data available, particularly on land that may be classified as marginal for crop production. Therefore, two key objectives of this research are to determine: 1) switchgrass production on land that may be marginal for traditional agricultural crops in different regions of the United States, and 2) the influence of nitrogen fertilizer on switchgrass production on field-scale plots using conventional agricultural equipment.

Five field trials were initiated in 2008 and a sixth was added in 2009 (Fig. 1). The Alabama location was replanted in 2009 and 2010 due to drought. Another site in Nebraska (Rob Mitchell with USDA-ARS) was added in 2009 but does not have the common nitrogen treatments.

Management information

Sites were identified for switchgrass field trials in six states on land with slopes ranging from 0-20% (Fig. 2). Switchgrass establishment can be difficult; therefore, no nitrogen treatments were imposed during the seeding year since application of this fertilizer tends to encourage weedy growth



Bristol, SD | Tompkins, NY | Muskogee, OK

Story, IA | Auburn, AL | Pittsylvania, VA

Fig. 2. Overhead view of replicated switchgrass field trials in six states.

more than switchgrass. In subsequent years, three levels of nitrogen fertilizer (0, 50, and 100 lbs N A^{-1} [2]) were applied at each location during the spring. Individual plot sizes ranged from 1-2 acres allowing for use of field-scale agricultural equipment. The use of this type of equipment is critical in order to demonstrate switchgrass management and production to potential producers. Furthermore, field-scale research permits evaluation of switchgrass across undulating terrain and in areas that may be less suitable for traditional agricultural crops. Soil information was collected at each location to help ascertain suitability for switchgrass or other crops.

Based on the fact that trials are located throughout the eastern half of the United States, some locations may have better soil or environmental conditions for switchgrass than others and the type of equipment used at each location will vary. For this reason, selection of switchgrass cultivar and type of agricultural equipment used at each location was made based on standard recommendations and practices for the region. For example, in South Dakota a 14-foot no-till drill was used to plant switchgrass into soybean stubble, a 70-ft spray applicator was used for fertilizer and herbicide application, a 16-foot swather was used for harvesting, and a large round baler was used for baling. On the other hand, switchgrass was planted with corn as a nurse crop in Iowa.

Results to Date

Biomass Production: Yield data were gathered for trials in New York, Oklahoma, South Dakota, and Virginia in 2009 and for trials in Iowa, New York, Oklahoma, South Dakota, and Virginia in 2010. Switchgrass was planted one year later in Iowa than in other states, and the trial in Alabama was successfully replanted and established in 2010. Therefore, only one year of data are shown for Iowa and none for Alabama. Harvested yields are not yet available for Virginia from 2010 due to early December snow; plots will be harvested during late December 2010 or early January 2011.

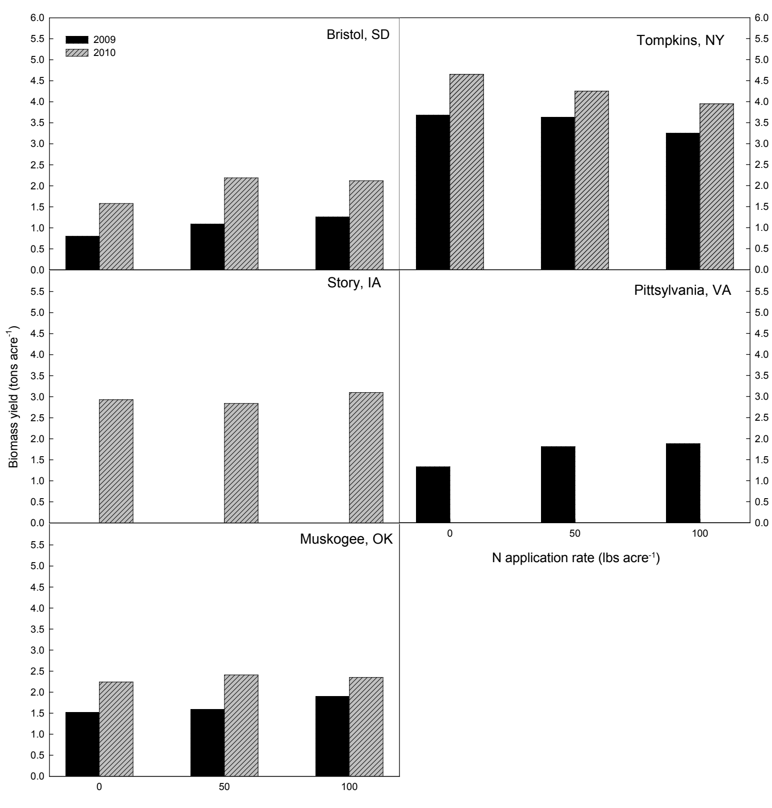


Fig. 3. Switchgrass yield response to N fertilizer at five locations in the eastern half of the United States in 2009 and 2010.

Biomass production varied by location, ranging from 0.80 to 4.65 tons/acre[3] (Fig. 3). Yields were higher during the second harvest year (2010) for all sites established in 2008. Yields of well-established stands are expected to reach peak production in the second to fourth year after establishment. In six of eight harvest year x location combinations, yields increased with 50 or 100 lbs N/acre, although not always significantly. This is of critical importance since nitrogen fertilizer represents a significant expense in the production system and is potentially a source of environmental contamination. The nitrogen content of harvested switchgrass is being determined in order to calculate the nitrogen

[2] lbs N A^{-1} = pounds nitrogen per acre

[3] ton/acre = 2204.62 pounds (lbs) per acre

removal rate from the field. Investigators at Cornell saw no real difference in nitrogen removal regardless of nitrogen application rate; however, biomass yields were similar across nitrogen treatments. Harvesting later in the season allows some of the N to be redistributed from above- to below-ground biomass, thus improving the efficiency of N utilization (Mulkey et al., 2006).

Sustainability: To estimate sustainability of switchgrass production, nitrogen losses through leaching of nitrate-nitrogen (NO_3-N) and emission of nitrous oxide (N_2O), a greenhouse gas, were determined at Bristol, SD beginning in 2009. Application of 100 lbs N/acre resulted in nearly three times as much leaching of NO_3-N compared to the 0 and 50 lbs/acre treatments in 2010 (Fig. 4). Nitrate loss was similar under the 0 and 50 lbs N/acre application rates and is likely related to the yield differences between these two treatments.

Nitrogen removed with biomass was determined at all sites (data for South Dakota and New York shown in Fig. 5). Yields at New York were double that of South Dakota, thus the much higher nitrogen removal rate. Nitrogen removal increased with nitrogen rate in South Dakota but not in New York. This explains the differential removal of nitrogen in South Dakota (Fig. 5). Based on these preliminary data, it is clear that nitrogen application rates and losses must be carefully evaluated in order to minimize adverse environmental effects.

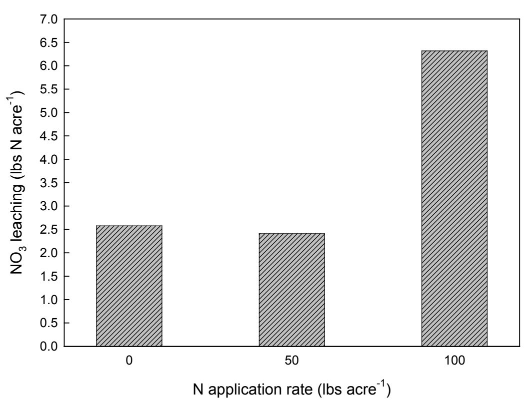


Fig 4. Leaching NO_3-N loss at the different rate of N application near Bristol, SD in 2010.

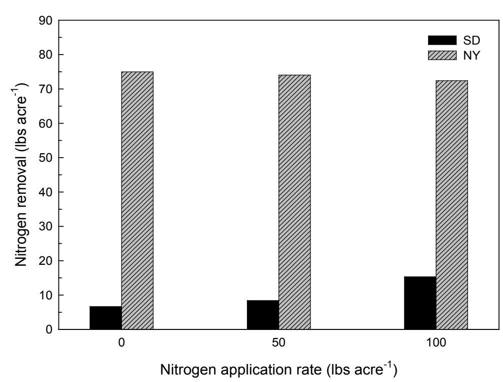


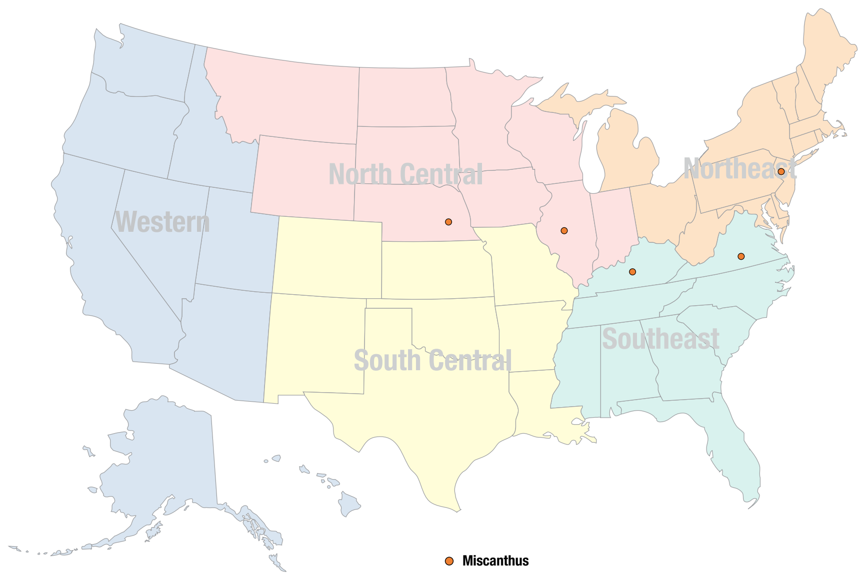
Fig 5. Nitrogen removal at the different rate of N application at Bristol, SD and Tompkins, NY in 2010.

Anticipated Results for 2011

Switchgrass from all seven locations is expected to be harvested in 2011. This will be the second or third production year for each location; therefore, it is anticipated that yields will be higher. Extensive sustainability data will be obtained at the South Dakota location. One manuscript regarding economics of establishment is currently being prepared and another will be written regarding initial sustainability measurements.

Miscanthus x *giganteus* Bioenergy Field Trials

Tom Voigt, Miscanthus Coordinator, University of Illinois
Stacy Bonos, Rutgers
James Murphy, Rutgers
John Fike, Virginia Tech
Roch Gaussoin, University of Nebraska
David Williams, University of Kentucky



Miscanthus x *giganteus* is a warm-season, perennial grass native to Japan. Originally brought to the United States as a landscape ornamental, Miscanthus has become the subject of renewable energy research in Europe and the United States due to great biomass production compared to other crops suited to temperate regions. Being sterile, it is propagated asexually by dividing the clumps of below-ground rhizomes. While it is expensive to establish, plantings are expected to be productive for 10 - 15 years.

During the winter and spring 2008, *M.* x *giganteus* plants were propagated in University of Illinois, Urbana-Champaign greenhouses and later shipped to the study sites. By the end of June 2008, 12 plots of 100 plants each had been established in Lexington, Kentucky; West Lafayette, Indiana; Mead, Nebraska; and Adelphia, New Jersey, while the Urbana, Illinois, plots were planted in July 2008 (Table 1). At each site, 3 nitrogen (N) fertility levels (0, 53, and 107 pounds of N per acre per year) are applied using urea or ammonium nitrate as the nitrogen source. Soil samples were collected in the 2008 growing season to establish baselines for comparisons at the conclusion of the five-year study. The objectives of this study are to determine *M.* x *giganteus* survivability, growth, development, and biomass yields in five environments when grown under three nitrogen regimes and to determine the amount of greenhouse gasses given off from the soil and carbon accumulated in the soil at the Illinois site.

Survivability during the first winter (2008-09) was variable (Table 1) ranging from 17% survival in Illinois to 100% survival in New Jersey. *M.* x *giganteus* death was attributed to wet conditions followed by a precipitous drop in temperature during the late fall in Illinois and Indiana. Where necessary, replanting occurred in 2009. In spring 2009, the Indiana site dropped out of the study due to poor winter survival and a personnel change. In June 2010, a site near Gretna, VA, was established to replace the Indiana site (Figure 1).

Yield data were collected at the Kentucky, Nebraska, and New Jersey sites in 2009; data were not collected at the Illinois site due to the mixture of first- and second-year plants in the trial. *M.* x *giganteus* biomass yields at these sites ranged from a high of 7.7 tons per acre in Kentucky in the plots receiving 53 pounds of nitrogen per acre per year to a low of 4.8 tons per acre in New Jersey in the plots receiving 0 pounds of nitrogen per acre per year (Table 2). There were significant differences in biomass yields only at the New Jersey site where the plots receiving 0 pounds of nitrogen per acre per year had significantly lower yields than the plots receiving 53 or 107 pounds of nitrogen per acre per year (Table 2). These yield differences likely relate to the differences in soil texture, organic matter, and natural fertility; the New Jersey site soil is mostly a sandy loam with less organic matter and lower natural fertility than the silt loam at the Kentucky site or the silty clay loam at the Nebraska site.

Table 1. Sites, dates planted, and first-winter survival in the DOE/ North Central Sun Grant Center Herbaceous Feedstock Partnership *Miscanthus* x *giganteus* Study.

Location	Planted	First-Winter Survival (%)
Urbana, IL	July 2008	17
West Lafayette, IN	June 2008	33
Lexington, KY	June 2008	99
Mead, NE	June 2008	79
Adelphia, NJ	June 2008	100
Gretna, VA	June 2010	NA

Figure 1. Locations of the DOE/ North Central Sun Grant Center Herbaceous Feedstock Partnership *Miscanthus* x *giganteus* Study in 2010.

In the literature, it is often stated that on good soils, *M.* x *giganteus* biomass production reaches plateau yields in the third year. The Nebraska biomass yields were quite impressive with each treatment averaging more than 12 tons per acre, and given that there were many second-year plants interspersed in the Illinois trial, yields of 6.6-to-7.2 tons per acre were also acceptable and expected (Table 3). Yields in New Jersey and Kentucky were less than anticipated and less than in 2009 (Tables 2 and 3), which can be attributed to dry summer months in 2010. June and July precipitation in New Jersey was 4.37 inches versus an average of 7.87 inches and in Kentucky, precipitation totaled 1.19 inches in August and September versus a normal average of 6.82 inches. In 2010, nitrogen fertilization had no significant effects on *M.* x *giganteus* biomass yields (Table 3).

Table 2. Second-year (2009) *M.* x *giganteus* biomass yields (tons/acre).

Fertilizer	Lexington, KY	Mead, NE	Adelphia, NJ
0 lbs. N/A	7.3	7.0	4.8 a
53 lbs. N/A	7.7	6.8	6.5 b
107 lbs. N/A	7.4	6.4	6.3 b

Table 3. Third-year (2010) *M.* x *giganteus* biomass yields (tons/acre).

Fertilizer	Urbana, IL*	Lexington, KY	Mead, NE	Adelphia, NJ
0 lbs. N/A	6.6	5.5	12	5.5
53 lbs. N/A	7.2	5.2	12.6	5.2
107 lbs. N/A	7.1	6.7	12.5	4.4

* A combination of many second-year plants with few third-year plants (see Table 1).

Also beginning in 2010, extensive *M.* x *giganteus* growth data were collected. The data includes: (1) average emergence date; (2) percent survival/coverage; (3) noticeable pests; (4) monthly stem heights; (5) dates of closed canopy and flowering; (6) harvest date and yields; (7) number of shoots per plant; (8) stem diameter; (9) harvested stem length; (10) number of green leaves per stem; and (11) number of nodes per stem.

Soils - Soil analyses have been completed for the samples collected in Illinois, Kentucky, Nebraska, and New Jersey in 2008 and have been used to develop baseline data for texture (% sand, silt, and clay), pH (water pH), cation exchange capacity (CEC), soil organic matter (SOM), extractable sulfur (S), phosphorous (P), calcium (Ca), magnesium (Mg), potassium (K), sodium (Na), boron (B), iron (Fe), manganese (Mn), copper (Cu), zinc (Zn), and aluminum (Al), total soil carbon (C), nitrogen (N), and C:N, exchangeable calcium, magnesium, potassium, sodium, and hydrogen (H), and bulk density (BD). Analysis of the soils collected from Virginia is currently ongoing.

Generally, the Illinois and New Jersey soils contain large amounts of sand, contain less organic matter, and are less naturally fertile than the soils at the Kentucky and Nebraska sites. The Illinois site is classified as a sandy loam or sandy clay loam, the New Jersey site is mostly a sandy loam, the Kentucky site is a silt loam, and the Nebraska site is a silty-clay loam.

As expected, analyses has shown that a notable relationship exists between soil organic matter, carbon, and nitrogen at all four locations and suggests that high levels of total carbon are associated with high levels of soil organic matter and that when high levels of total nitrogen are present there are typically high levels of total carbon and soil organic matter also present. Our baseline data and analyses (not presented) also suggest that of the four sites, the highest amounts of carbon are in Nebraska and Kentucky. The usefulness of these data will be more relevant in a few years once more soil cores are taken after the fifth year of *M.* x *giganteus* growth. This will allow us to see how much carbon has been captured in the soil by growing a perennial crop like *M.* x *giganteus*.

Greenhouse gas emissions from production of *M.* x *giganteus* - Substituting plant biomass for fossil fuels can have beneficial effects on the environment; however, the effects of biofuel production would be dramatically reduced if the plants also emit large amounts of the greenhouse gases, N_2O (nitrous oxide) and CO_2 (carbon dioxide). Agricultural practices, such as fertilization, could lead to emissions of N_2O and reduce the positive impacts of using biofuels. This portion of our research intends to determine if fertilization of *M. x giganteus* has an effect on the emissions of CO_2 and N_2O under field conditions in Illinois. In addition, the study looks to relate those N_2O and CO_2 emissions to other field parameters, such as soil moisture and temperature, as well as inorganic N concentrations.

In 2009, mean N_2O emissions from the 107 lbs. N A^{-1} and 53 lbs. N A^{-1} fertilizer treatment plots were significantly greater than from the 0 lbs. N ac^{-1} plot. In 2010, however, the 107 lbs. N A^{-1} was significantly greater than the 53 lbs. N A^{-1} and the 0 lbs. N A^{-1} (Table 4). Peak fluxes in N_2O emission followed fertilization and precipitation events as expected. The 107 lbs. N A^{-1} treatment consistently had the highest fluxes compared to the 53 lbs. N A^{-1} and the 0 lbs. N A^{-1}.

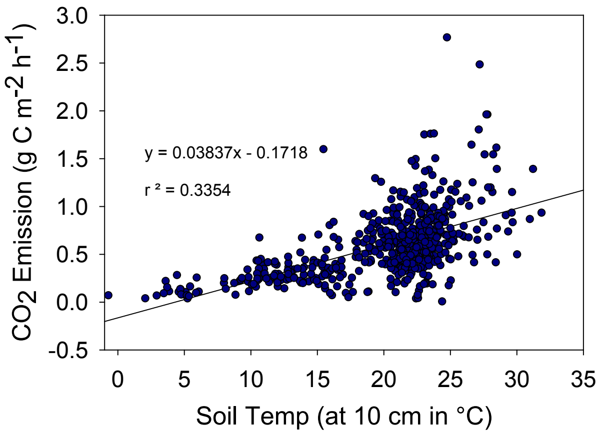


Figure 2. Relationship between soil temperature and CO_2 emission.

Table 4. N_2O Fluxes in 2009 and 2010.

N_2O Flux (μg N_2O–N m^{-2} hr^{-1}) [4]

Fertilizer	2009	2010
0 lbs. N/A	20	9
53 lbs. N/A	37*	16
107 lbs. N/A	41*	76*

* Significant difference at the 0.05 level.

CO_2 ranged from 0.06 to 1.47 g C m^{-2} h^{-1} [5] during the study. Mean CO_2 emissions did not significantly vary among fertilizer treatments. However, directly after the plots were fertilized, CO_2 emissions did increase. The peak CO_2 emissions generally followed temperature patterns; the warmer the soil, the greater CO_2 emission. Figure 2 shows the relationship between CO_2 and temperature at 10 cm.

Our results show an increased risk for N_2O emissions when fertilizer is used for production of *M.* x *giganteus*. Likewise, total inorganic soil N is significantly related to fertilizer treatment. In addition, directly following urea applications, CO_2 emissions did increase, due to NH_4 volatilization, which can occur when urea is used as a fertilizer for production of *M.* x *giganteus*. Overall however, season-long CO_2 emissions did not respond to fertilizer treatments, and were strongly related to temperature.

[4] μg N_2O–N m^{-2} h^{-1} = micrograms nitrous oxide - nitrogen per square meter per hour
[5] g C m^{-2} h^{-1} = grams carbon per square meter per hour

Anticipated 2011 Results

In 2011, it is anticipated that *M.* x *giganteus* biomass yields in Illinois, Kentucky, and New Jersey will increase provided more normal weather patterns return and Nebraska yields will remain the same as in 2010 or drop slightly. The first harvest will occur at the Virginia site. *M.* x *giganteus* growth and development will continue to be measured in order to better understand the interactions among *M.* x *giganteus* growth and development, biomass yields, nitrogen fertilization practices, and different growing environments.

Publications

Ahonsi, M.O., B.O. Agindotan, D.W. Williams, R. Arundale, M.E. Gray, T.B. Voigt, and C.A. Bradley. 2010. First report of *Pithomyces chartarum* causing a leaf blight of *Miscanthus* x *giganteus* in Kentucky. Plant Disease. 94(4):480.

Anderson, E., R. Arundale, M. Maughan, A. Oladeinde, A. Wycislo, T. Voigt. (In Press) Growth and agronomy of *Miscanthus* x *giganteus* for biomass production. Biofuels.

Anderson, E.K., S.K., T.B. Voigt, G.A. Bollero, and A.G. Hager. 2010. *Miscanthus* x *giganteus* response to preemergence and postemergence herbicides. Weed Technology. (24)4: 453-460.

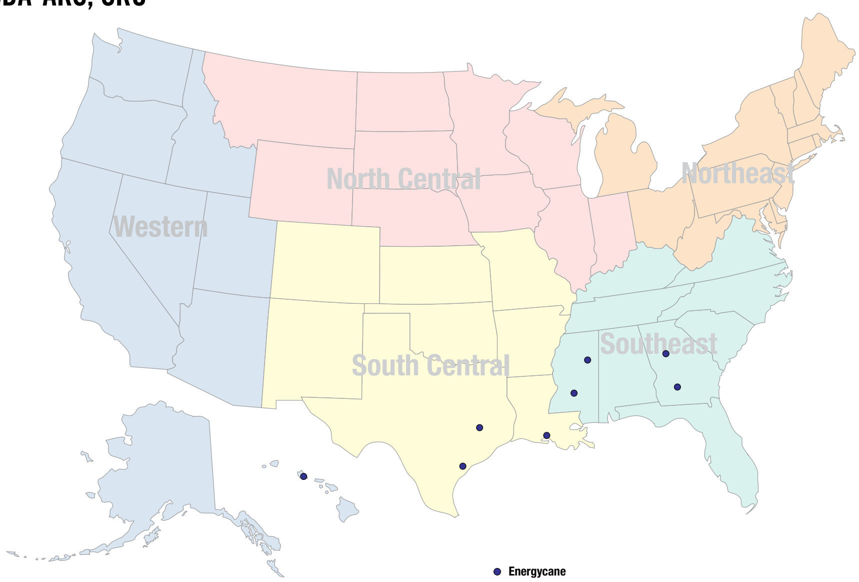
Heaton, E.A., F.G. Dohleman, F. Miguez, J.A. Juvik, V. Lozovaya, J. Widholm, O.A. Zabotina, G.F. McIsaac, M.B. David, T.B. Voigt, N.N. Boersma, and S.P. Long. 2010. Miscanthus: a promising biomass crop. Advances in Botanical Research. 56:75-135.

Heaton, E.A., N. Boersma, J.D. Caveny, T.B. Voigt and F.G. Dohleman. 2010. Miscanthus for biofuel production. eXtension Bioenergy Feedstock Community of Practice.

Pyter, R.J., F.G. Dohleman, T.B. Voigt. 2010. Effects of rhizome size, depth of planting and cold storage on *Miscanthus* x *giganteus* establishment in the Midwestern USA. Biomass and Bioenergy. 34 (10):1466-1470.

Energycane

Brian Baldwin, Energycane Coordinator, Mississippi State University
Bill Anderson, USDA-ARS/UGA
Wayne Hanna, USDA-ARS/UGA
Charles Brummer, University of Georgia
Ken Gravois, Louisiana State University
Jürg Blumenthal, Texas A&M University
Jimmy Ray Parish, Raymond, MS
Ted Wilson, Texas A&M University
Goro Uehara, University of Hawaii
Anna Hale, USDA-ARS, SRC
Ed Richard, USDA-ARS, SRC



Sugarcane has tremendous potential to yield biomass. Once in full production, average yields of sugarcane range from 22 (in LA) to 34 (in FL) tons/acre of dry material on mainland United States. To put this in perspective, other perennial biomass crops such as switchgrass, yields 5-8 tons/acre and giant miscanthus yields 10-18 tons/acre in the South. Five varieties of cold-hardy sugarcane (called energycane) are being tested at eight locations around the United States to determine the limits of their ability to grow and yield at these locations. Three locations (Starkville, and Raymond, Mississippi and Athens, Georgia) are 100 to 250 miles north of the northern sugarcane growing regions. These varieties are also being increased at Waimanalo, Hawaii for planting at higher (cooler) elevations of the Hawaiian Islands.

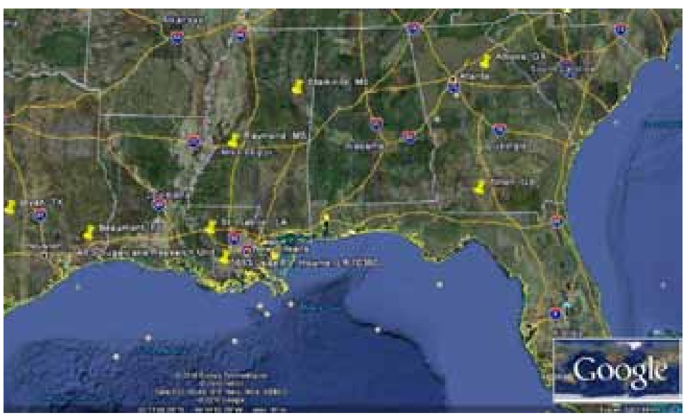
Pedigree of energycane varieties common to all Herbaceous Feedstock Partnership testing sites.

Variety Name	Pedigree	Genetic Makeup
Ho 02-147	F1 hybrid	50% sugarcane/50% wild cold hardy parent
Ho 02-144	F1 hybrid	50% sugarcane/50% wild cold hardy parent
Ho 72-114	backcrossed with sugarcane	75% sugarcane/25% cold hardy parent
Ho 06-9001	backcrossed with wild cane	25% sugarcane /75% cold hardy parent
Ho 06-9002	backcrossed with wild cane	25% sugarcane /75% cold hardy parent

Testing of energycane in Hawaii was delayed for two years because of state law which prohibited the importation of sugarcane and its relatives into Hawaii. That law was changed in 2009, and material was shipped directly from the USDA, Sugarcane Research Center in Houma, Louisiana to the Experiment Station at the University of Hawaii.

Herbaceous Feedstocks Partnership energycane research participants, location and affiliation:

Contact	Location	Affiliation	Yr added
Bill Anderson/Wayne Hanna	Tifton, GA	USDA-ARS/UGA Tifton	2008
Brian Baldwin	Starkville, MS	Mississippi State Univ.	2008
Charles Brummer	Athens, GA	Univ. Georgia	2008 late
Ken Gravois	St.Gabriel, LA	Louisiana State Univ.	2008
Jürg Blumenthal	Bryan, TX	Texas A&M Univ	2008 late
Jimmy Ray Parish	Raymond, MS	Mississippi State Univ	2008
Ted Wilson	Beaumont, TX	Texas A&M Univ	2008
Goro Uehara	Waimanalo, HI	University of Hawaii	2009
Anna Hale/ Ed Richard	Houma LA	USDA-ARS, SRC	source



Map locations of Herbaceous Feedstocks Partnership energycane research participants.

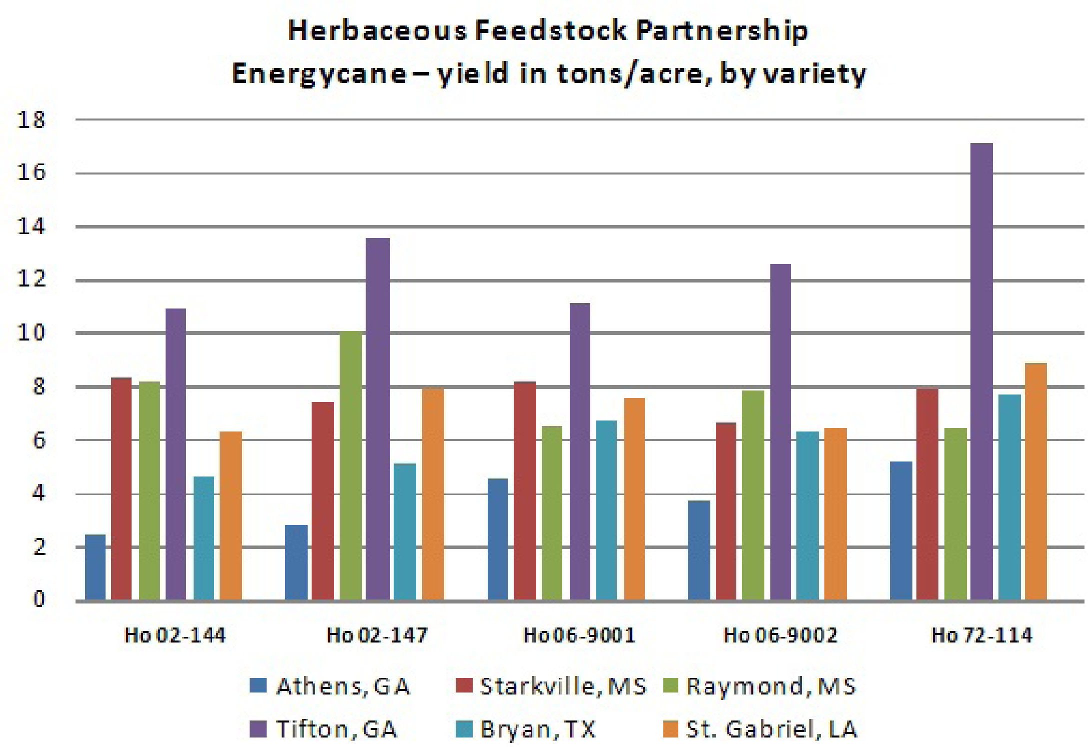
The material used for these tests originated from the breeding program of USDA-ARS Sugarcane Research Unit (Houma, LA). Drs. Ed Richard, Thomas Tew and Anna Hale developed hybrids of domestic sugarcane with a cold-hardy low sugar sugarcane relative. From these crosses, it is possible to make the offspring more cold tolerant. But in doing so, you give up some sugar production. While crossing with the wild parent decreases the sugar in the offspring, there is still a significant amount of sugar produced. This sugar is useful in preserving the crop when it is harvested. The sugars ferment into ethanol and produce natural acids that preserve the wet harvested material in a process known as ensiling. Silage, the product of ensiling, has been known to dairy farmers for hundreds of years as a way to store moist plant material.

The objective of this breeding work was to get the biomass production of sugarcane, coupled with the cold hardiness of the wild parent while capitalizing on hybrid vigor conveyed by the cross. The varieties listed in the table below have compositions that vary in the percentage domestic and wild parent. Initial testing for cold hardiness was conducted on nine varieties at Starkville, Mississippi, during fall and winter of 2006. Plant material was propagated and transplanted to a second test field in 2007. Of the nine varieties, the five listed below proved high yielding and tolerant to cold at Starkville, Mississippi.

Initial distribution of propagated material for the Herbaceous Feedstock Partnership testing started in late summer and fall of 2008, except for Athens, Georgia (added as a replacement for Auburn, Alabama) and Hawaii. Energycane, like sugarcane, is fall planted by laying mature stalks on their side in deep furrows and covering them with soil. The stalks sprout from "eyes" about 2-3 weeks after planting. This growth is killed back during the winter, but the developed root system remains intact for rapid spring regrowth. Once planted, energycane can be harvested and grows back the next year (called a ratoon). Three to five ratoon crops are typical for sugarcane.

Because sugarcane/energycane is tropical in origin, it doesn't stop growth in the fall. It stops only when cold temperatures kill back the leaves, but the stalks remain green well into the winter even at the northern-most locations. Information being gathered from all locations included: sugar accumulation and content over the course of the growing season, height over the growing season, stalk count and diameter of individual varieties, extractable sap, and stalk dry yield at the end of the season. No data was collected from the Beaumont, Texas, location in 2009 because tornadoes spawned from Hurricane Rita leveled the crop.

Initial planting of energycane took place in the fall of 2008, the first yield data available was from the fall harvest 2009 and winter 2010. Most sites harvest when they are sure the crop has been forced into dormancy by cold weather that is usually January or February.



Total dry matter yield in tons/acre of each energycane variety at each reporting location. (Beaumont, TX, and Waimanalo, HI, not reporting)

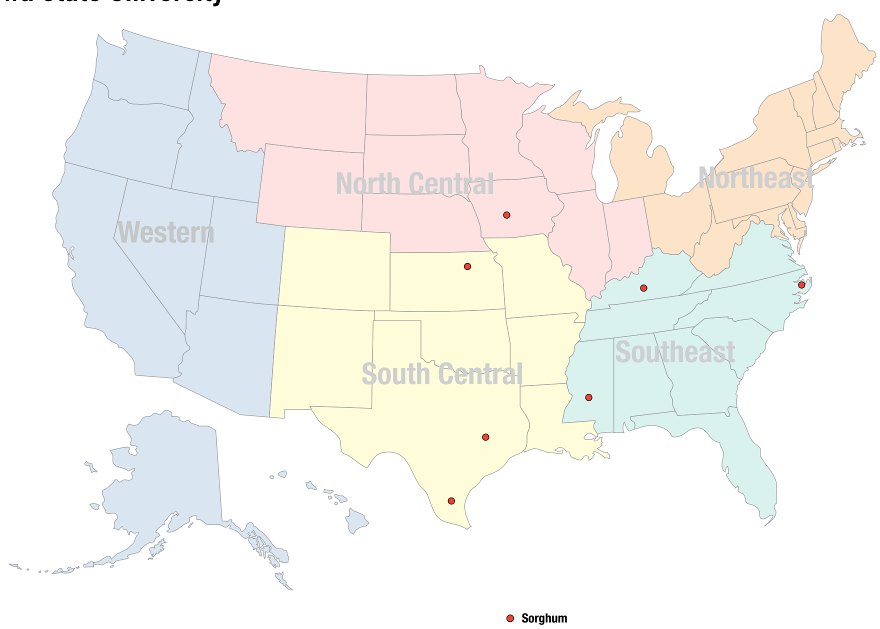
Yields for first year fields were excellent at all sites given their geographic location. With the exception of Athens, Georgia, all sites had at least one variety with an eight ton yield. Lowest yields were found at Athens, the most northern location in the program. It is more likely yields were less because propagation material was brought from Tifton, Georgia, very late in the season, preventing a good late summer establishment before the onset of winter. Highest yields (for every variety) were observed at Tifton, Georgia. Tifton is a southern location, but not the most southern. Bryan, Texas, suffered drought conditions so severe, winter irrigation was necessary to keep planted canes alive. Spring growth reflected the winter drought.

Regarding other information collected.

- All varieties continued to grow until local average temperatures dropped to 85 or below.
- Sugar accumulation, as expected, is 2-4% less than sugarcane varieties and is location dependent. Rainfall events just before harvest lower sugar levels while drought limits energycane yield but raises sugar levels.
- Peak sugar accumulation is location dependent and occurs at the time of fall frost. It is important to note that sugar does not degrade/dissipate rapidly after the frost. Noticeable decreases in sugar are observed about one to one and a half months after frost.
- Percent moisture in the stalk is variety dependent with Ho 9001 and 9002 having the lowest moisture and those higher in sugar retaining moisture. Overall, moisture declines after frost, but very slowly, taking more than two months in most cases. Therefore, delaying harvest isn't going to make harvest easier.
- Early onset growth is detrimental to varieties at northern locations because they are damaged by late spring frosts. It is beneficial to the same variety at southern locations.

Sorghum

W.L. Rooney, Sorghum Coordinator, Texas A&M University
G.N. Odvody, Texas A&M University
Scott Staggenborg, Kansas State University
Michael Barrett, University of Kentucky
Ron Heiniger, North Carolina State University
Bissondat Macoon, Mississippi State University
Ken Moore, Iowa State University



Test Locations

Location	Affiliation	Contact	History
Burleson County, Texas (near College Station, Texas)	Texas A&M Agronomy Farm	Dr. W.L. Rooney	Commercial/Experimental Farm Production since at least the 1930s
Nueces County, Texas (near Corpus Christi, Texas)	Texas AgriLife Research & Extension Center	Dr. G.N. Odvody	Commercial/Experimental Farm Production since at least the 1930s
Riley County, Kansas (in Manhattan, Kansas)	KSU Agronomy Farm	Dr. Scott Staggenborg	Commercial/Experimental Farm Production since at least the 1950s
Lexington, Kentucky	University of Kentucky Research Farm	Dr. Michael Barrett	Agricultural Production – Corn, Wheat & Soybeans for at least 25 years
Plymouth, North Carolina	North Carolina State University	Dr. Ron Heiniger	Agricultural Research Farm
Raymond, Mississippi	Mississippi State University	Dr. Bissondat Macoon	Agricultural Research Farm
Boone County, Iowa (near Ames, IA)	Iowa State University Sorenson Research Farm	Ken J. Moore	Agricultural Production

General Background and Considerations

Of the crops being tested in the regional project overview, sorghum is unique for several reasons. First, this crop has a very established history of production for both grain and forage production. While the goal of this project is biomass for bioenergy, this history provides an excellent starting point to access varieties and germplasm for testing and immediate application. Second, the crop is an annual; meaning that it is planted and harvested within the same production year and that it will be planted again in the next year. For this project and from a testing and evaluation perspective, this results in several significantly different approaches for testing. For example, rotation is a critical component to productivity of annual crops; hence, the exact field location of these trials varies each year within the farm based on rotational needs of the farm. In addition, as new hybrids are developed, they are included in the test; hence, hybrids are not consistent throughout the whole testing time.

Table 1. List of entries included for testing in the sorghum trials of the Regional Biomass Feedstock trials.

Entry	Type	Source	2008	2009	2010
Pioneer 84G62	Grain Sorghum	Pioneer Hi-Bred	X		
Graze-All	Forage Sorghum	Garrison & Townsend	X	X	X
Graze-n-Bale	Forage Sorghum	Garrison & Townsend	X	X	X
22053	Forage Sorghum (bmr)	Garrison & Townsend	X	X	X
Sugar-T	Forage Sorghum	Garrison & Townsend	X	X	X
M81-E	Sweet Sorghum	Traditional	x	X	X
TAMX8001	Bioenergy Sorghum	Texas Agrilife Research		X	X

Trials have been established annually since 2008 in the locations previously listed. Included in these trials are a total of six sorghum hybrids or varieties. While the entries have remained similar, there have been some changes; ie, the grain sorghum hybrid was replaced starting in 2009 with an energy hybrid (Table 1). In each location, agronomic practices (including fertilization and pesticide applications) standard to sorghum production were used; all trials were conducted as rainfed; there was no supplemental irrigation supplied at any location. Harvest schedules varied; in 2008 all plots were harvested in the fall just prior to or after a killing frost. Because this did not optimize yield in all entries, multiple harvests and variable harvest times were used to optimize productivity. For each location, standard yield data was collected, included but not limited to biomass yield, height, lodging and maturity. In addition, biomass samples have been collected for each entry at each location; composition analysis will be completed using NIR calibration curves developed through research collaboration between Texas AgriLife Research, National Sorghum Producers, and the National Renewable Energy Lab.

Summary of Results

Over three years, the results indicate that sorghum can be highly productive as a biomass crop and that the productivity begins in the year that the crop is planted (i.e., there is no establishment year). Like any crop, the yield potential is highly dependent on the environment. In 2008, measurable yields were harvested in six of the seven locations. The Iowa location was lost due to excessive moisture in the spring which precluded a timely planting. By the time it dried, it was too late to plant. In 2009, measurable yields were again harvested in six of the seven locations. The Corpus Christi location was lost to excessive drought which precluded timely emergence and growth. Again, by the time that the rains came, it was too late in the season for productive growth. These examples document that productivity of this crop and any other crop will be influenced by environmental conditions in a region in a given year.

Table 2. Average (and range) biomass yields and moisture content from sorghum yield trials in 2009 grown in six locations throughout the U.S.

Entry	Fresh Weight MT/hectare	Moisture %	Dry Weight MT/hectare
Grazeall 3	64.7 (19, 110)	74 (63-80)	16.8 (7-23)
Graze-n-Bale	73.4 (40, 108)	76 (67-81)	17.6 (9-27)
22053	52.2 (31, 70)	73.5 (70-75)	13.8 (9-18)
TAMX8001	60.0 (39, 104)	68 (63-72)	19.2 (13-34)
M81-E	65.9 (40, 111)	75.5 (72-82)	16.1 (9-31)
Sugar-T	61.5 (34, 98)	73.5 (66-77)	16.3 (12-24)
AVERAGE	63.0	73.4	16.6

Table 3. Average (and range) biomass yields and moisture content from sorghum yield trials grown in North Carolina in 2009.

Entry	Fresh Weight MT/hectare	Moisture %	Dry Weight MT/hectare
Grazeall 3	110	80	19
Graze-n-Bale	101	80	15
22053	70	74	18
TAMX8001	104	67	34
M81-E	111	72	31
Sugar-T	98	76	24

As demonstrated, biomass yields vary based on entry, location and year. While yield data from 2010 has not yet been compiled, yield data from 2009 clearly demonstrates the variation. Average fresh biomass was 63 MT/ha [6] and dry biomass was 16.6 MT/ha with a significant range in productivity across these tests (Table 2). Specific genotypes were better adapted to specific locations; for example, the forage sorghum hybrids performed better in more northern climates and under multiple cuts than the bioenergy hybrid (Tables 3, 4 and 5). In addition, yield variation across locations is strongly influenced by moisture availability; yields were significantly lower in College Station primarily due to significant drought during the growing season (Table 3-5). Total dry biomass yields are ultimately the primary consideration and as seen in Tables 2-5, moisture content in sorghum varies by entry. The biomass sorghum has the lowest moisture content and sweet sorghum has the highest, but all are higher than other biomass crops.

Table 4. Average (and range) biomass yields and moisture content from sorghum yield trials grown in Iowa in 2009.

Entry (no. harvests)	Fresh Weight MT/hectare	Moisture %	Dry Weight MT/hectare
Grazeall 3 (2)	99	76	23
Graze-n-Bale (2)	107	76	27
22053 (2)	70	75	16
TAMX8001 (1)	47	72	13
M81-E (1)	67	76	16
Sugar-T (2)	58	75	14

Table 5. Average (and range) biomass yields and moisture content from sorghum yield trials grown in College Station Texas in 2009.

Entry (no. harvests)	Fresh Weight MT/hectare	Moisture %	Dry Weight MT/hectare
Grazeall 3 (2)	31	77	7
Graze-n-Bale (2)	45	81	9
22053 (2)	38	75	9
TAMX8001 (1)	48	70	15
M81-E (1)	45	82	9
Sugar-T (2)	56	77	13

Yield in these crops is influenced by several factors including maturity, height and lodging. We have discovered that non-flowering entries have consistently higher yields than sorghums that flower. The increased yield in these hybrids is likely due to full use of the growing season for biomass accumulation and enhanced drought tolerance which allows the plant to go into periods of dormancy until moisture is available and then it will resume growth.

Management of sorghum for maximum productivity is important. As shown here, certain hybrids are more productive when harvested twice (a primary and a regrowth crop) while others are productive in a single cut system. Actually both systems are useful; a multiple cut allows greater distribution of the biomass over time (longer harvest seasons) while a single harvest reduces harvest costs with single pass collection.

Finally composition is an important component to the use of the biomass in a conversion system. While information on these hybrids and data are not yet complete, initial information from other related studies clearly indicate that both genotype and environment influence the composition of sorghum biomass. This means that management and genetics must be used to optimize the composition of these bioenergy sorghums for a conversion process. The environmental variation also means that processors must be ready to accept biomass with some variation in composition.

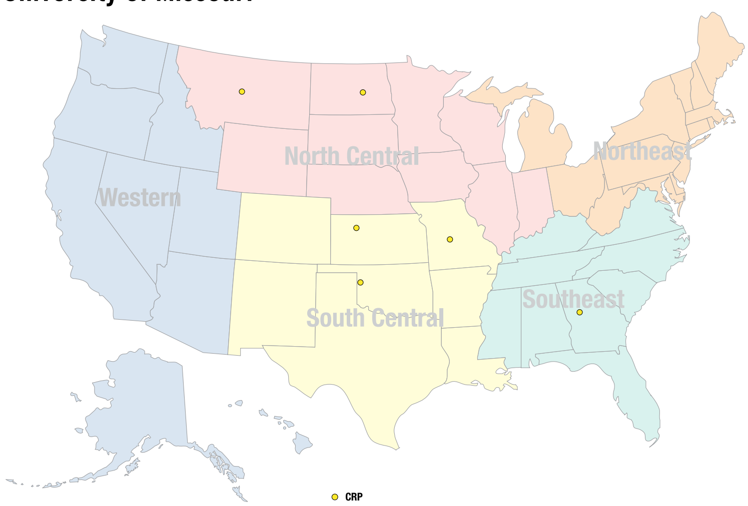
Activities in 2011

Field trials will continue at the locations already engaged in this project. Entries are expected to remain similar although some changes could occur based on the 2010 data and seed availability. To assess soil carbon and nutrient use in sorghum, collaborative research with Dr. Jim Heilman (Texas Agrilife Research) is being conducted on a specific location with established rotation history. This allows rotation and similar locations to be employed to assay those factors (which is difficult to do in the standard testing when various crops are rotated). In addition, economic analysis of sorghum as a bioenergy crop has been initiated using some of this data with ORNL and the Texas A&M Ag and Food Policy Group.

[6] 1MT/ha (metric ton per hectare) = 893 pounds (lbs) per acre

Conservation Reserve Program (CRP) Land

D.K. Lee, CRP Coordinator, University of Illinois
Ezra Aberle, North Dakota State University
Chengci Chen, Montana State University
Keith Harmoney, Kansas State University
Carl Jordan, University of Georgia
Gopal Kakani, Oklahoma State University
Robert Kallenbach, University of Missouri



Conservation Reserve Program (CRP) enrollment currently (October 2010) stands at approximately 30.6 million acres, most of which is dedicated to grasses. In its report on the technical feasibility of a billion-ton annual biomass feedstock supply, the Department of Energy (DOE) estimates that between 17 and 28 million dry tons of biomass to be available for bioenergy production from current CRP land. A successful feedstock production system requires reliable management practices for sustainable biomass production and persistence. Accordingly, realizing the full potential of CRP land requires data related to harvest and nitrogen (N) management. The objective of this project is to assess the yield potential and suitability of CRP grassland as a bioenergy feedstock source across logical regions of adaptation using agricultural practices that are standard for each region. This report summarizes the results of a 3-year farm scale field study that focuses on the effects of harvest timing and N-rate on yield and species composition and persistence in established stands at six different previously established CRP sites: North Dakota (ND), Kansas (KS), Oklahoma, (OK), Montana (MT), Missouri (MO)

Table 1. CRP Management Field Research Site Locations

State	Principal Investigator	Predominant Species*
ND	Ezra Aberle	BB, SW, SB
KS	Keith Harmoney	SW, LB,
OK	Gopal Kakani	SO, SW, LB, YS
MT	Chengci Chen	A, PW
MO	Robert Kallenbach	RC, TF
GA	Carl Jordan	TF, OR

*BB-big bluestem, SW-switchgrass, SB-smooth brome grass, LB-little bluestem, YS-yellow sweet clover, A-alfalfa, RC-red clover, TF-tall fescue, OR-orchard grass

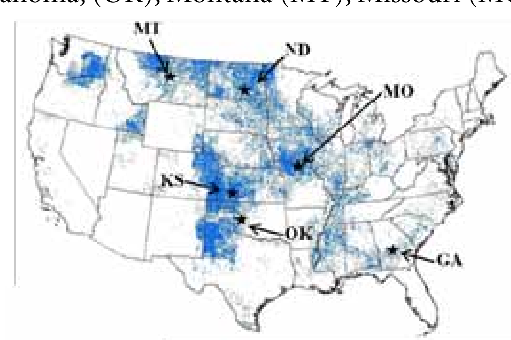


Figure 1. U.S. Map of 2009 CRP Enrollment

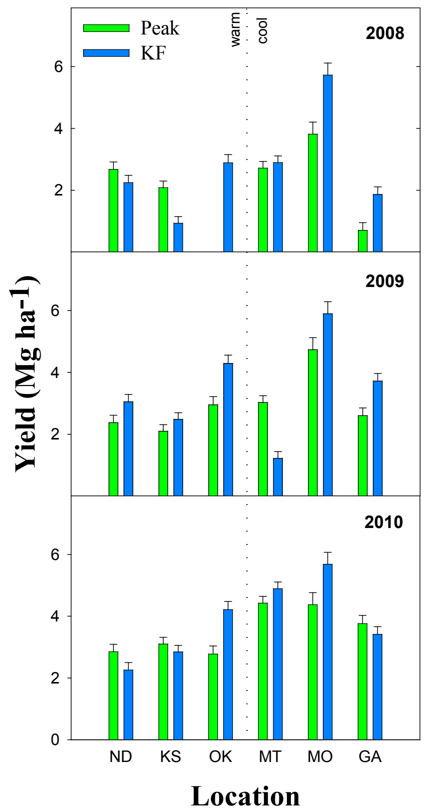


Figure 2. The effect of harvest timing on yield for each location during 2008-2010.

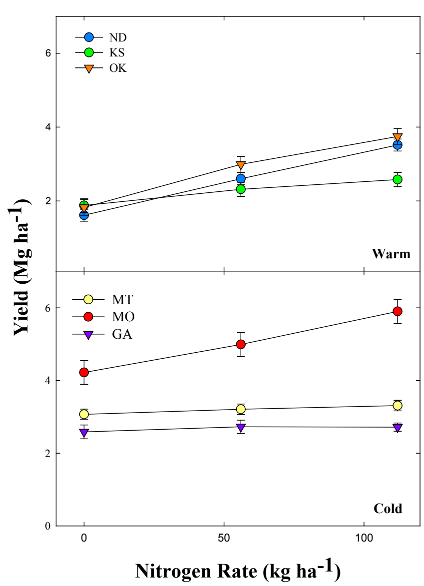


Figure 3. The effect of nitrogen rate on the yield of warm- and cool-season grasses when averaged across 2008-2010.

[7] 1kg ha^{-1} (kilogram per hectare) = 2.204 pounds (lbs)

and Georgia (GA). The locations of the six sites are shown in Figure 1. The six sites were divided between warm and cool season grasses. Warm-season grasses, or C4 grasses, predominated in North Dakota, Kansas, and Oklahoma, while cool-season grasses, or C3 grasses, predominated in Montana, Missouri, and Georgia. At each site plots were fertilized with 0, 56, or 112 kg ha^{-1} [7] and harvested at either peak standing (peak) or at the end of the growing season (EGS).

The effect of harvest timing on yield is shown in Figure 2. In general, yield was greatest when plots were harvested at the end of the growing season. This response was generally consistent among all sites; however, this did vary, depending on the site and during specific years. For example, in Montana in 2009 and in Kansas in 2008, yield was greatest when harvested at peak standing; however, this response was not seen in other years. Additionally, in 2010, in both North Dakota and Georgia, yields were lower when harvested at the end of the growing season; however, these differences were not significant. This yield pattern decrease was related to below normal precipitation during the latter part of the growing season. The greatest yield was measured with a cool-season mixture in Missouri at the end of the growing season.

The yield response to nitrogen fertilization is shown in Figure 3. At most of the warm-season grass sites yield was enhanced with the addition of nitrogen; however, in Kansas this response was minimal. Of all the cool-season grass sites, Missouri was the only location to show a response to nitrogen fertilization. Interestingly, the greatest yields were found at this site under the highest-level fertilization regimen. These results indicate a location dependent fertilization response of cool-season grasses.

The species composition results of the sites with predominant cool-season grass composition are shown in Table 2. In Montana, alfalfa (A) and pubescent wheatgrass (PW) competition was affected by both HT and nitrogen rate. When harvested at peak standing, alfalfa yields were higher, whereas at the end of the growing season, pubescent wheatgrass was more predominant. As the nitrogen rate increased composition favored pubescent wheatgrass; however, this increase was not enhanced much above an nitrogen rate of 56 kg ha^{-1}. In Missouri, the competition between red clover (RC) and tall fescue (TF) favored tall fescue when the nitrogen rate was increased and harvest was delayed. This enhancement was maintained across all three years; however, to a lesser degree. In Georgia, as the nitrogen rate increased, the yield of both tall fescue and orchard grass (OR) increased. This enhancement was of a greater proportion in orchard grass than it was in tall fescue.

The species composition results of the sites with predominant warm-season grass composition are shown in Table 3.

In North Dakota both big bluestem (BB) and switchgrass (SW) competed with the cool-season grass smooth brome (SB), which favored the warm-season species greatest at 112 kg ha^{-1}. Smooth brome competed more with big bluestem than with switchgrass, especially at the highest nitrogen rate. At 56 kg ha^{-1}, the competition big bluestem and switchgrass was more balanced than at a higher nitrogen rate, while maintaining a competitive advantage over smooth brome. In Kansas, side oats (SO), switchgrass and little bluestem (LB) all showed a decrease in yield over the course of the three-year study when harvested at peak standing. However, when harvested at the end of the growing season, yields were maintained more effectively. As the nitrogen rate increased up to 112 kg ha^{-1}, side oats yield increased, switchgrass and little bluestem also showed an increase in yield as the nitrogen rate increased, but to a lesser degree, while yellow sweet clover decreased.

In summary, biomass yield and stand quality were significantly affected by management practices. Biomass yield was associated with stand quality. Established stand quality was maintained or improved by delayed harvest until the end of the growing season or after the killing frost with fertilization. However, nitrogen fertilization has a negative impact on the persistence of legume species. More obvious biomass yield and stand quality responses to management practices should be observed in 2011 since the field research is getting into a long-term process. More significant changes in biomass yield and persistence of stand quality affected by nitrogen fertilization and harvest timing are expected.

Table 2. Species composition of sites with predominant cool-season grass mixtures. Yields reported in Mg ha^{-1}

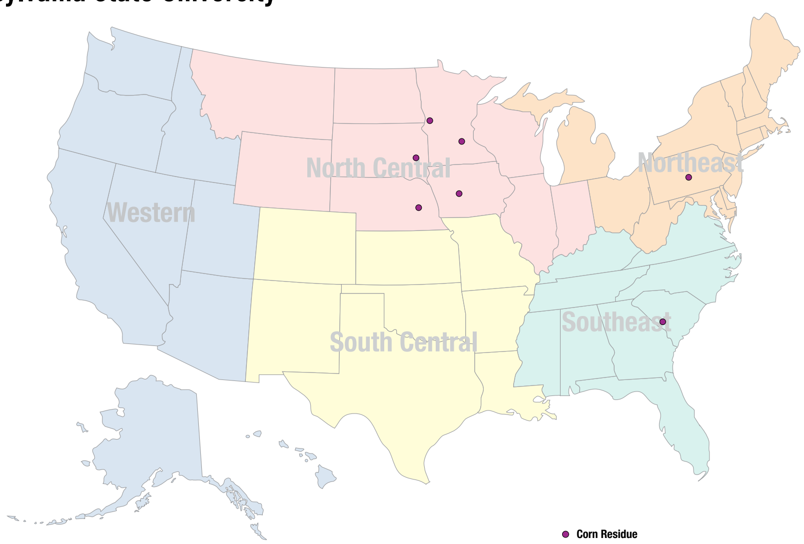
State	Species	Year	Harvest Timing		N-Rate (kg ha^{-1})		
			Peak	EGS	0	56	112
Montana	Alfalfa	2008	-	-	-	-	-
		2009	70.2	49.2	62.1	58.3	58.8
		2010	44.4	16.3	43.5	24.2	23.4
	Pubescent Wheatgrass	2008	-	-	-	-	-
		2009	12.0	50.4	29.6	34.2	29.9
		2010	55.6	83.7	56.5	75.8	76.6
Missouri	Red Clover	2008	18.9	15.8	24.3	18.0	9.7
		2009	21.3	19.1	27.2	21.0	12.5
		2010	17.9	15.8	20.8	17.8	11.8
	Tall Fescue	2008	62.7	71.1	53.7	66.8	80.2
		2009	51.9	58.0	42.3	54.3	68.2
		2010	57.1	65.4	53.5	61.7	68.7
Georgia	Tall Fescue	2008	47.1	50.6	46.9	49.3	50.4
		2009	65.9	59.1	60.3	62.7	64.4
		2010	52.7	45.9	44.2	49.0	54.6
	Orchard grass	2008	.	.	.	.	.
		2009	13.7	15.4	9.0	17.8	16.9
		2010	15.7	13.5	9.7	17.3	16.8

Table 3. Species composition of sites with predominant warm-season grass mixtures. Yields reported in Mg ha^{-1}

State	Species	Year	Harvest Timing		N-Rate (kg ha^{-1})		
			Peak	AKF	0	56	112
North Dakota	Big Bluestem	2008	29.2	33.4	35.8	33.4	24.7
		2009	22.9	26.5	12.1	27.0	35.0
		2010	32.0	37.9	22.4	33.4	49.1
	Switchgrass	2008	27.3	31.7	31.8	34.1	22.8
		2009	29.9	24.9	25.6	34.7	21.9
		2010	22.1	21.1	21.1	24.2	19.6
	Smooth Bromegrass	2008	6.6	7.6	5.3	7.1	8.8
		2009	16.8	15.9	28.4	8.3	12.3
		2010	17.9	19.8	32.1	15.0	9.5
Oklahoma	Switchgrass	2008	30.1	30.1	31.3	30.7	28.3
		2009	28.9	28.9	30.0	28.3	28.3
		2010	28.9	28.9	30.0	28.3	28.3
	Little Bluestem	2008	37.7	37.7	33.7	37.7	41.7
		2009	38.9	38.9	35.0	40.0	41.7
		2010	38.9	38.9	35.0	40.0	41.7
Kansas	Sideoats	2008	20.1	22.1	20.9	18.2	24.2
		2009	24.1	24.6	28.6	19.4	25.1
		2010	14.6	15.2	9.2	14.5	21.0
	Switchgrass	2008	15.4	14.8	14.4	16.2	14.7
		2009	18.7	17.5	13.6	21.2	19.6
		2010	8.8	13.1	7.3	11.7	13.9
	Little Bluestem	2008	19.4	19.8	22.8	18.7	17.3
		2009	12.1	18.9	14.2	14.2	18.1
		2010	8.4	11.6	7.3	12.1	10.6
	Yellow Sweetclover	2008	27.2	19.8	23.4	23.9	23.1
		2009	8.9	11.2	16.9	7.9	5.4
		2010	39.3	32.9	59.0	32.4	16.9

Corn Stover

Doug Karlen, Team Lead, USDA-ARS
Stuart Birrell, Iowa State University
Shannon Osborne, USDA-ARS
Tom Schumacher, South Dakota State University
Jeff Novak, USDA-ARS
Jim Frederick, Clemson University
Jane Johnson, USDA-ARS
Lowell Rasmussen, University of Minnesota-Morris
John Baker, USDA-ARS
John Lamb, University of Minnesota
Gary Varvel, USDA-ARS
Richard Ferguson, University of Nebraska
Paul Adler, USDA –ARS
Greg Roth, Pennsylvania State University



Corn stover, which consists of the leaves, stalk, husks, cob and tassel, was one of the most abundant potential feedstock materials for biofuel production identified in the Billion Ton study. To determine the amount that could be harvested in a sustainable manner, a collaborative research team with members from the USDA-Agricultural Research Service (ARS) and several universities was established as part of the Sun Grant Regional Feedstock Partnership (Table 1). A general map and images showing landscape conditions for each research location are shown in Figure 1.

Table 1. Stover team's principle investigators, institutions, and locations

Principle Investigators	Institution	Location
Doug Karlen, Team Leader Stuart Birrell	USDA-ARS Iowa State Univ. (ISU)	Ames, IA Ames, IA
Shannon Osborne Tom Schumacher	USDA-ARS South Dakota State Univ.	Brookings, SD Brookings, SD
Jeff Novak Jim Frederick	USDA-ARS Clemson Univ.	Florence, SC Florence, SC
Jane Johnson Lowell Rasmussen	USDA-ARS Univ. of Minnesota Morris	Morris, MN Morris, MN
John Baker John Lamb	USDA-ARS Univ. of Minnesota	St. Paul, MN St, Paul, MN
Gary Varvel Richard Ferguson	USDA-ARS Univ. of Nebraska	Lincoln, NE Lincoln, NE
Paul Adler Greg Roth	USDA-ARS Pennsylvania State Univ.	Univ. Park, PA Univ. Park, PA

The core treatments implemented in 2008 at each location consist of no-tillage or the least amount possible for economic crop production (e.g., Coastal Plain soils near Florence, SC, have a naturally occurring hardpan, so in-row subsoiling is needed each year prior to planting), three residue removal rates (none, approximately half, and the maximum collectable amount), and four replications. Leveraging the Sun Grant Partnership funds with long-term ARS research expanded both the number of treatments being evaluated as well as the number of years of study. For example, at Mead, NE, the rainfed and irrigated studies were initiated in 1999 and 2001, respectively. At Morris, MN, the study was initiated in 2005, taking advantage of a tillage experiment established in 1995. At Ames, Iowa, two studies were initiated in 2005 and one in 2008. Additional treatments being evaluated at one or more of the locations include additional tillage practices (e.g., chisel plow or strip-tillage), use of cover crops, rotation with soybean, and the application of biochar.

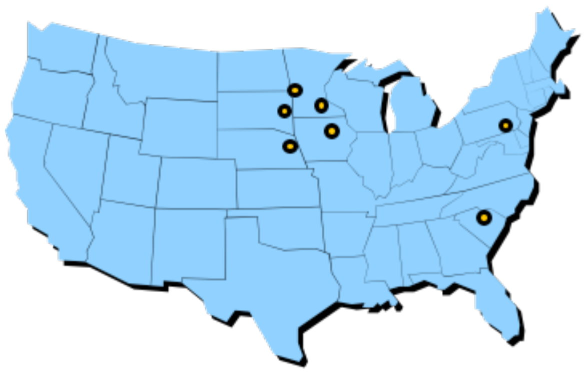


Figure 1. Location of corn stover research sites

Ames, IA

Brookings, SD

Florence, SC

Morris, MN

St. Paul, MN

Mead, NE

University Park, PA

For each experimental site, soil samples were collected to a depth of 3 to 5 feet, divided into increments of 0 to 2-, 2 to 6-, 6 to 12-, 12 to 24-, 24 to 36- and 36 to 60-inches, and analyzed for several soil quality indicators (e.g., total soil organic carbon, total nitrogen, pH, bulk density, and soil-test P & K) to establish a baseline for measuring effects of the various stover removal rates.

Whole plant samples were collected and fractionated into bottom, top, cob, and grain fractions. Plant parts lying on the ground within the sampling area (16.4 ft^2 [8]) were also collected. Harvest index

[8] ft^2 = square feet

Figure 2. Residue cover following stover harvest at Morris, MN.

values and total nutrient uptake were collected using those samples. Stover was collected using a variety of mechanical harvesting techniques, all resulting in post-harvest soil surface cover differences as shown for the Morris, MN (Fig. 2). The stover was analyzed for nutrient concentrations to estimate nutrient removal. The common data set consists of this soil and plant data. It is being uploaded into the Knowledge Development Framework (KDF) and the USDA-ARS Renewable Energy Assessment Project (REAP) database that is being developed.

Additional data being collected at some but not all locations includes greenhouse gas emissions (carbon dioxide-CO_2 and nitrous oxide-N_2O), nitrate nitrogen (NO_3-N) and phosphorous (P) concentrations in water leaching through the soil profile, microbial biomass carbon, particulate organic matter, glomalin related soil proteins, the humic acid fraction of soil organic matter, aggregate stability, lignin, cellulose and other structural carbohydrates, and energy values for the various stover fractions.

Crop yield responses associated with stover harvest have been variable with (1) no detectable short-term effects at Brookings, Florence, Morris, or University Park; (2) trends for increased yield with stover harvest for no-till treatments at Ames and Mead; and (3) site differences at the three St. Paul managed locations (Fig. 3). Baseline soil analyses have been completed but only a few comparisons can be made. At Florence, total soil organic carbon (SOC) at the 0 to 2-inch depth has remained unchanged. Longer-term data leveraged from the ARS plots at Brookings showed that through the first eight years SOC decreased as residue removal rates increased (Fig. 4). Additional soil samples collected from that site

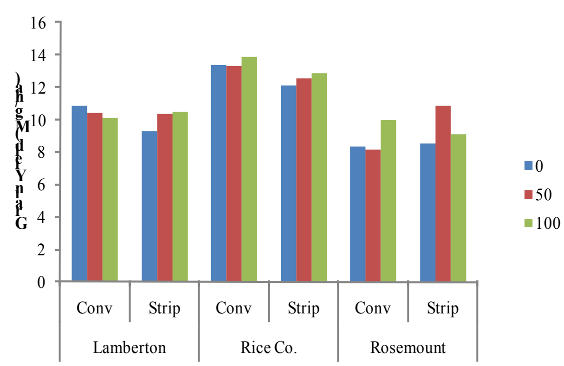


Figure 3. 2010 grain yield response to stover harvest at three Minnesota sites.

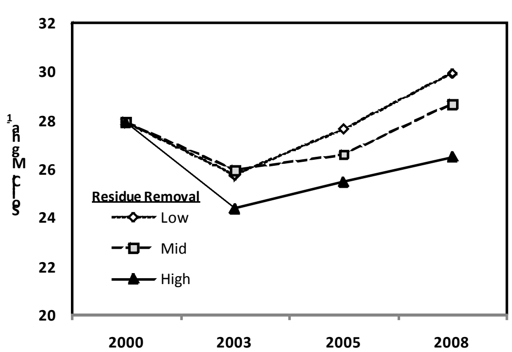


Figure 4. Eight-year residue removal effect on SOC in the top 15 cm (6 inches) near Brookings, SD.

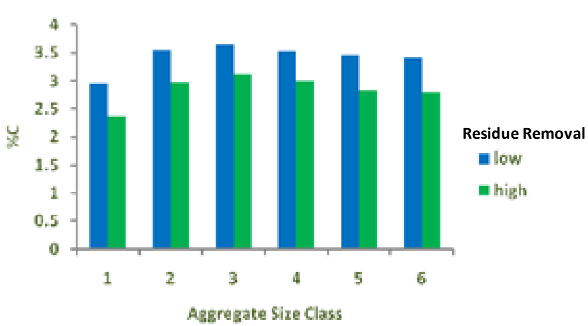


Figure 5. Residue removal effects on SOC in six soil aggregate size classes from the surface 5 cm (2 inches) near Brookings, SD.

Table 2. Average partnership macro-nutrient removal and estimated replacement value using 2011 current fertilizer prices for northeast Iowa.

	N	P	K
Range (lb/acre)	20-32	1.4 – 5.5	24 - 45
Mean (lb/acre)	25.5	3.0	35
Value ($/ton)	$5.98	$2.27	$9.81
Total Value ($/ton)	$18.06		

in 2008 because of the Partnership funding showed higher total organic carbon (TOC) in all aggregate size classes from the low removal treatment than in the high removal treatment (Fig. 5). Higher total protein was also measured in soil samples from the low removal treatment than from the high removal treatment. Initial data from Ames and St. Paul shows that as the amount of harvested residue increased soil CO_2 fluxes decreased. Nitrous oxide (N_2O) emissions were also higher from non-removal sites than from the high-removal sites in MN.

Economic analysis has been used to quantify the nutrient replacement cost associated with harvesting corn stover. The average macronutrient (nitrogen, phosphorous, and potassium) values for the 2008 and 2009 harvests are presented in Table 2. Fertilizer cost, driven primarily by oil prices, is the main factor causing the total value to fluctuate between \$10 and \$20 per dry ton.

Planned activities for 2011 include soil, plant composition, greenhouse gas emission, and life-cycle analyses to quantify energy and carbon balance for cob harvesting systems. Effects of stover harvest on soil compaction properties will be assessed. This partnership has led to the development of a solid database of the sustainable corn stover harvest guidelines.

Corn Stover Tool

To date, sustainable residue removal analyses have been focused on quantitative soil organic carbon and GHG emissions. These environmental processes are currently being investigated with the DayCent computer simulation model. Development of the Corn Stover Tool has been focused on full, dynamic integration of DayCent with RUSLE2, WEPS, IFARM, and other simulation models. Several challenges have emerged with that integration, but the Corn Stover Tool is currently functioning within the framework for a number of the key scenarios being evaluated by the stover removal team. Integration tasks that have been outlined in the past and that remain under development are 1) the establishment of a yield calibration module for DayCent, 2) the generic soil module for DayCent, 3) and the generic management module for DayCent. Each of these has seen significant progress over the last several months, and will remain under development for the quarters ahead.

A key accomplishment this quarter is the exchange of data from the fully integrated NRCS erosion and soil conditioning index models into DayCent. Management practices and erosion values from WEPS and RUSLE2 now dynamically provide those same inputs into the DayCent model. Methodologies to synchronize local weather data with field level crop managements allowing a look at carbon sequestration and GHG emissions on a daily and annual basis at the field level. With the integration of DayCent into the Stover Removal Tool, field level analysis will be able to be completed on Regional Partnership field trial experiments to study the impacts of the various management practices under investigation.

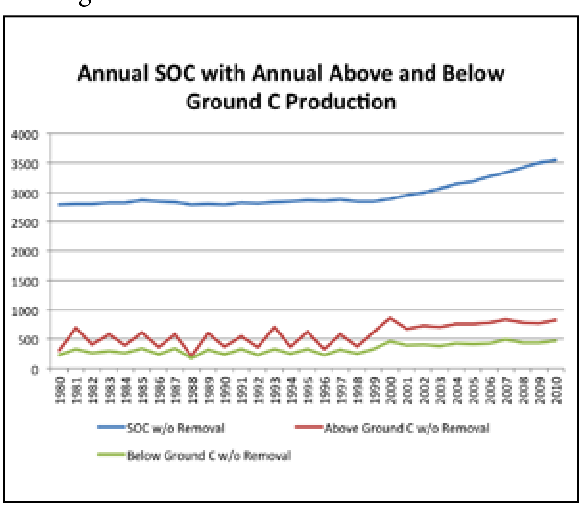


Figure 1. Results for annual SOC with actual local weather data

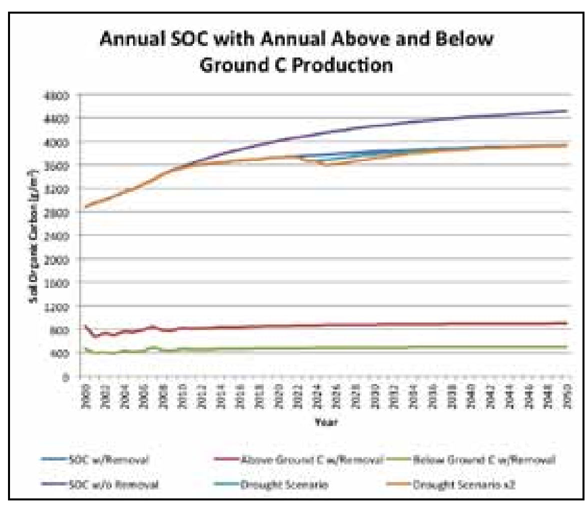


Figure 2. Project annual SOC and above and below ground C production

Current modeling efforts with the Stover Removal Tool include fields from several counties in Iowa with management data provided by our cost-share partner Monsanto. Using field history data provided by DayCent developers at the Natural Resource Ecology Laboratory at Colorado State University, a "spin-up" was preformed starting from year 0 to bring the field to equilibrium. The spin-ups use local weather and management data to account for the local weather patterns and historical use of the land. Starting in 1980, weather events for that year forward were synched with managements to accurately model the past 30 years of carbon generation and sequestration and GHG emissions. It can be seen in Figure 1 that the model is capable of capturing weather event impacts on carbon generation and sequestration such as the drought years of 1983 and 1988. The figure also included above- and below-ground carbon generation. The management scenario modeled is a corn/soybean rotation up through 1999 and continuous corn rotation from 2000 forward.

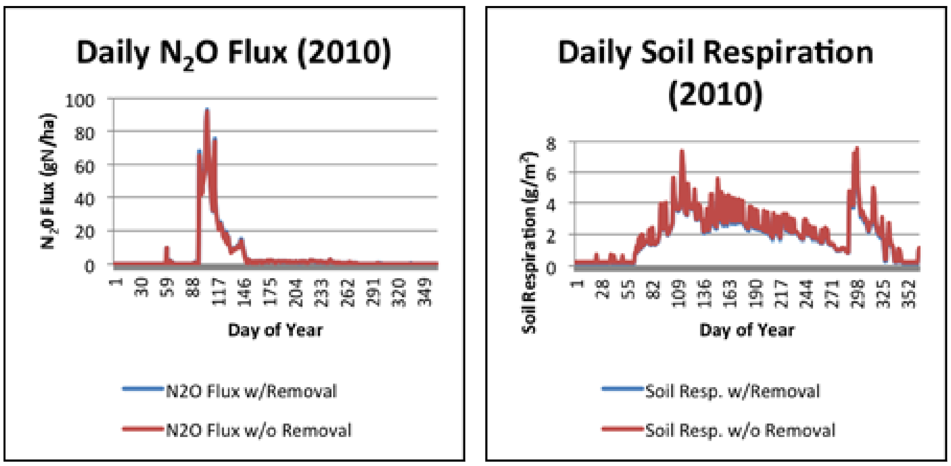


Figure 3. Daily N_2O flux and soil respiration for 2010 management scenario

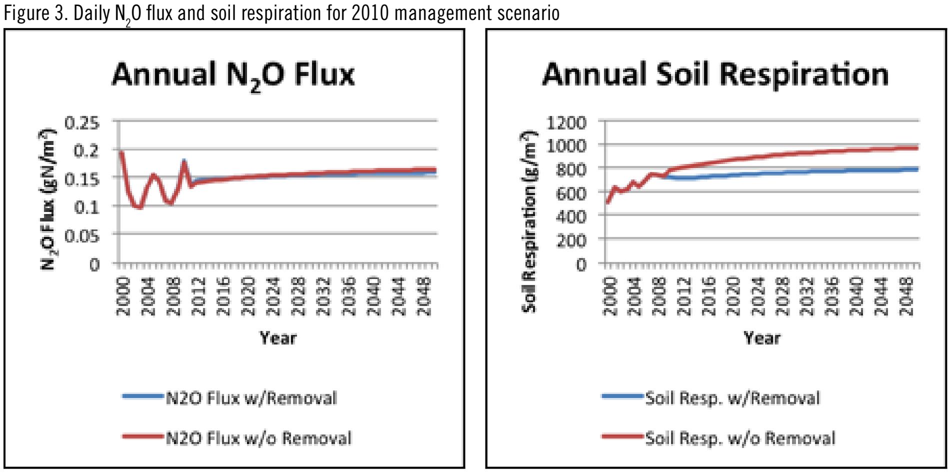


Figure 4. Annual N_2O flux and soil respiration for projected continuous corn management scenario

Management projections through 2050 were then made using various scenarios to demonstrate impacts managements have on the carbon sequestration and GHG emissions. An average weather year was used for each year with analysis performed on actual removal rates versus zero removal. Analysis was also performed to see how carbon sequestration was impacted by a drought year scenario and a scenario that included a three year period that had two drought years. Figure 2 shows the results of such analysis. Figure 3 show the N_2O flux and soil respiration, respectively, for the year 2010 while Figure 4 shows the projected annual.

These are critical data outputs in achieving a comprehensive multi-factor residue removal analysis. Over the next quarter these results will investigated with the field trial principal investigators cross walking the data that has been collected over the first three years of the project. The team will target a joint publication of verified integrated analysis results, and subsequent sensitivity based projections as soon as the verification process is completed.

A Commercial Scale Corn Stover Harvest Case Study

A cooperative research project being conducted by Monsanto, Archer-Daniels-Midland, and John Deere scientists and engineers is an integral part of the Corn Stover Team Regional Partnership. This project brought together a dedicated group of industry, university and federal research scientists, farmers, and entrepreneurs who collectively have developed a sustainable, commercial scale corn stover harvest and utilization strategy in eastern Iowa. The project was designed to determine how to provide farmers and rural communities with an additional income stream and biomass end users with a sustainable source of animal feed or bioenergy feedstock, without losing the ecosystem services that corn stover provides by reducing erosion and maintaining or improving physical, chemical, and biological attributes of soil quality.

Corn stover has been harvested in both Benton and Linn Counties for three years. The study began by identifying a co-coordinator with ties to the community. Discussions with individual farmers were held to understand their perspectives and to determine what value they placed on corn stover. Following the individual discussions, a presentation and discussion of the proposed project was held with a larger group of farmers and other members of the community. Further discussions were held with individual farmers as they enrolled in the program. This level of community involvement helped ensure the success of the project and mitigated some concerns about unusual activities organized by three large corporations.

Enrolled fields were fairly typical for the area, with an average size of 118 acres and a dominant silty clay loam soil texture. Nearly all of the fields were being managed in a corn-soybean (CS) rotation or had been planted to corn for two or more years [continuous corn (CC)]. Average corn yields were 194, 191, and 182 bu/acre in 2008, 2009, and 2010, respectively. A major difference between the fields selected for 2008 and 2009 was the average slope. In 2008 fields were enrolled in the program without any selection criteria. Over half of the 38 fields enrolled that year had average slopes greater than 4% which meant that large amounts of stover were needed to prevent erosion losses and that stover could not be harvested without putting the soils at risk. In 2009 fields were screened for low average slopes prior to enrollment so that all but three of the enrolled fields had an expected harvest rate of over 1 dry ton/acre assuming average grain yields.

The interview process usually took over an hour, with most of the time spent covering the first field. Additional fields managed by the same farmer typically had very similar management histories, enabling the interview to proceed rapidly once an initial set of management practices was defined. Scheduling difficulties prevented face to face interviews with some farmers in both 2008 and 2009. These farmers were provided interview forms to fill out on their own, but the data that was returned was often quite sparse and follow up telephone conversations were required to complete them. Streamlining and automating data collection from the interview process is one of the current priorities for the project. Two years of management information were collected to establish a baseline before initiating any stover harvest. All field operations occurring during this period, including tillage, fertilizer application, planting, spraying, and harvest along with the crop yield were recorded. The specific equipment used and soil disturbance depths were recorded to allow matching of the farmer's practices to operation descriptions in RUSLE2. Additional information on fertilizer application rates, chemical applications and fuel use were collected as part of the interview to facilitate a complete life cycle analysis (LCA) of the farming system.

With guidance from the corn stover team, crop residue requirements for each field were estimated by using the soil conditioning index (SCI) within the RUSLE2 erosion model. These tools require two basic types of information: 1) A short history of farming operations, rotations and crop yields that can be obtained from the farmer or local agronomist and 2) field specific information that can be obtained from the Soil Survey Geographic (SSURGO) Database or Web Soil Survey. As part of the enrollment process, farmers were asked to participate in an interview where specific fields were identified and farm management information was collected. The fields were identified in a plat book by the farmer and then a satellite image and outline of the field was obtained and returned to the farmer for verification. After the field location and shape were verified a distinctive field sign was placed at a field entrance specified by the farmer and GPS coordinates were recorded. Field crews subsequently used these signs to identify the correct fields prior to raking, baling or removing any stover bales from the field.

Field stover requirements were estimated with RUSLE2 by changing anticipated corn yield in 10 bu/ac increments until either the erosion (ER) or organic matter (OM) subfactors within the SCI were at their lowest positive value. Slope and crop rotation were the primary factors affecting stover requirements within the fields examined. Soil types were similar across fields and within rotations and farm management practices were also relatively similar for all participating farmers. For soils with slopes of 2% slope or less, the organic matter subfactor was limiting, but for areas with slopes of 2.5% or greater, the erosion subfactor became the most limiting factor. The overall SCI score, which is a weighted sum of the OM and ER subfactors plus a field operations (FO) subfactor, reached a minimum of 0.4 just prior to the point were erosion was predicted to become the limiting subfactor. When the ER factor is close to zero, RUSLE2 estimates soil loss at 2.5 tons/acre which is about half of the soil loss tolerance or T factor for these fields. Wind erosion is not a significant factor in this part of Iowa so the wind erosion prediction system (WEPS) was not used. Field stover requirements were similar for CS and CC fields, if stover was harvested in every year corn was planted. Harvesting stover every other year in CC fields allowed larger quantities of stover to be harvested due to the carry over in organic matter from the previous year's corn crop, but this may not address the farmer's residue management needs.

The corn stover was baled in a three step operation, often referred to as a "two pass" system. Following grain harvest, various rakes were used to create windrows. Raking was done at an oblique angle to the corn rows (Figure 1), which evens out mechanical wear on the rake. No mowing or shredding was done prior to raking. Both of those operations can increase the amount of stover collected, but they can also increase stover water and ash content because a higher percentage of stalk bottoms are collected. Mowing or shredding also increases stover cover loss due to wind or rain.

A variety of large round balers were tested in cooperation with various equipment manufacturers (Figure 1). Bales were removed from the field using a Bühler/Inland 2500 round bale carrier in 2009 and 2010. This machinery addition greatly facilitated moving bales from the harvest area to the field edge, a process referred to as staging. Average baling rates were 1.2 ± 0.5, 1.7 ± 0.6, and 1.3 ± 0.3 dry tons/acre in 2008, 2009, and 2010, respectively. As a percent of total stover produced, this averaged 30 ± 15% in 2008 and 47 ± 18% in 2009. Harvesting stover at these rates thus left a substantial amount in each field to help sustain ecosystem services.

Figure 1. Raking and baling steps when collecting corn stover at target rates.

Only about 50% of the fields enrolled in the program were harvested each year. In 2008 the non-harvested fields were primarily those with average slopes that were too steep for sustainable harvest because the residue was needed to prevent soil erosion and sustain soil organic matter. In 2009, an effort was made to enroll flatter fields where stover requirements to meet the SCI were lower. This pre-screening was actually too successful because it resulted in much more available stover than was needed to meet the project objectives. For the 2010 season, a running estimate of anticipated total stover harvest was maintained during enrollment based on farmer reported average slopes and crop rotation for the fields being considered. Overall, this project showed that some excess enrollment is required because all fields will not be able to be harvested due to weather and/or timing issues. The estimation method used for 2010 appeared to successfully manage field enrollment so that the harvested amount was better able to match project needs. The project also showed that an experienced stover harvest crew can often identify parts of the fields that were harvestable.

Stover harvest rates as well as the potential risks and/or benefits this practice presents to farmers have been the subject of much debate. This project demonstrated that conservation planning tools developed by the NRCS can be used to determine stover retention requirements based on specific management targets for soil organic matter accumulation and erosion control. The retention targets vary based on slope, soil types, location, cropping history and farm management. Management targets for erosion or soil organic matter accumulation will likely vary from farm to farm. In this study, an estimated soil loss rate of 2.5 tons ac^{-1} yr^{-1} was identified as the maximum allowable rate. Soil organic matter was also expected to increase because the predicted SCI had to be positive or the field was not enrolled. As prediction tools improve, the specific ones used to predict the amount of stover needed to meet management targets will likely change over time. However, the important steps are determining specific management targets for the various factors affected by residue removal and developing specific stover retention targets that are consistent with those management targets

This cooperative, commercial scale project has shown that corn stover can be harvested for with commercially available equipment without at rates consistent with specific stover retention targets. Field average slope and crop rotation were the best predictors of stover retention targets within the study area and could be used during field enrollment to estimate stover harvest rates. Partial field harvests, by avoiding steeper parts of the fields, allowed more fields and area to be harvested for stover than if whole field averages were used to estimate retention targets. Currently this requires field operators to use their judgment or simple tools such as tilt meters to avoid slopes. Improved guidance systems and/or variable rate harvest machinery should improve the ability of farmers to harvest some stover while still ensuring that enough is left in the correct parts of fields to meet management targets.

Peer-Reviewed Publications

Johnson et al. 2009. Soil processes and residue harvest management. p. 1-44. *In* Lal and Stewart (eds.) Carbon management, fuels, and soil quality Taylor and Francis, LLC, New York.

Johnson et al. 2010. Conservation considerations for sustainable bioenergy feedstock production: If, what, where, and how much? Journal of Soil and Water Conservation 65 (4):88A-91A.

Johnson et al. 2010. Nutrient Removal as a function of corn stover cutting height and cob harvest. BioEnergy Res. 3:342-352.

Johnson et al. 2011 Crop Residues of the Contiguous United States: Balancing feedstock and soil needs with conservation tillage, cover crops, and biochar Sustainable. In: Proc. Feedstocks for Advanced Biofuels. SWCS 28-30 September, 2010, Atlanta, GA.

Johnson et al. 2011. Soil management implications of producing biofuel feedstock. p. In-Press. *In* J. Hatfield and T. Sauer (eds.) Soil management: Building a stable base for agriculture. American Society of Agronomy Series. American Society of Agronomy, Madison, WI.

Karlen, D.L. 2010. Corn Stover Feedstock Trials to Support Predictive Modeling. Global Change Biology – Bioenergy 2:235-247.

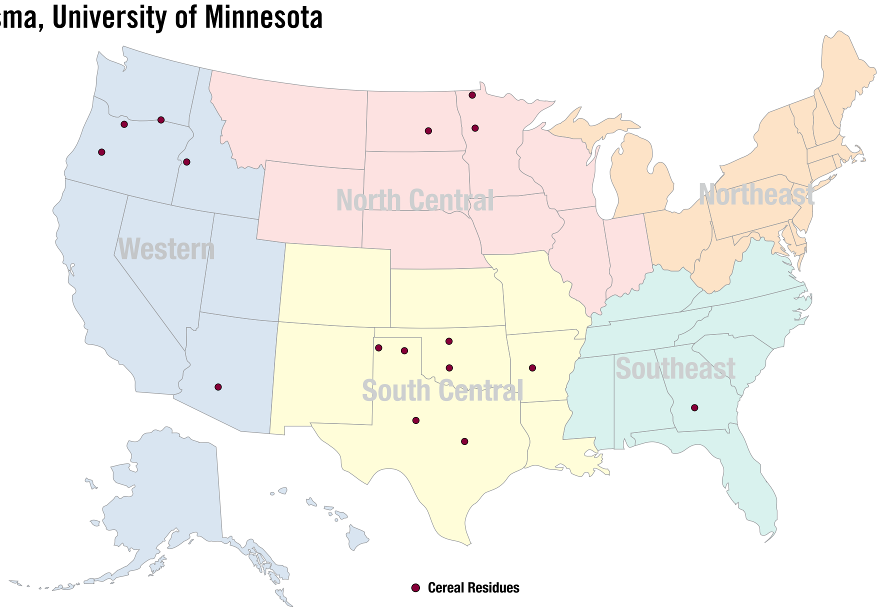
Karlen et al. 2011. Monitoring Soil Quality to Assess the Sustainability of Harvesting Corn Stover. Agron. J. 103: (Accepted for publication 6/25/2010).

Wilhelm et al. 2010. Balancing limiting factors & economic drivers for sustainable Midwestern U.S. agricultural residue feedstock supplies. Industrial Biotechnology 6:271-287.

Wilhelm et al. 2010. Vertical Distribution of Corn Stover Dry Mass Grown at Several U.S. Locations. BioEnergy Res. DOI: 10.1007/s12155-010-9097-z (available online).

Cereal Residue

Russ Karow, Team Lead, Oregon State University
Brad Brown, University of Idaho
Bill Bruening, University of Kentucky
Hal Collins, USDA-ARS
Chris Daley, Oregon State University
Jeff Edwards, Oklahoma State University
Mike Flowers, Oregon State University
Mike Halbleib, Oregon State University
David Huggins, USDA-ARS
Dewey Lee, University of Georgia
Mike Ottman, University of Arizona
Joel Ransom, North Dakota State University
Jochum Wiersma, University of Minnesota



Cereal grains (wheat, barley, oats, sorghum and rice) are among the most widely grown crops in the United States. An assumption by many is that large amounts of cellulosic residue should be available from cereal crops given the acreage. The goals of this project are to 1) catalog grain yields and use this information in concert with harvest index values to determine possible residue yields; 2) document the temporal variability of grain yields in environments where major weather events could dramatically affect crops; 3) estimate the amount of residues that are needed to maintain soil quality in terms of reducing erosion susceptibility and maintaining soil organic matter levels; and 4) identify existing uses of cereal residues in areas where residues are already being harvested toward the end of determining the prices that would be needed to draw residues toward biofuels use.

Grain Yields - Ten years of National Agricultural Statistics Service (NASS) county-level yield data (1999-2008) were collected, analyzed for errors and then used to create yearly and multi-year grain yield maps for all the small grains - wheat, barley, oats, sorghum and rice - across the United States. These maps are available as a web resource. Wheat dwarfs all of the other grains in terms of grain production. In “30,000-foot” analyses, wheat can be used as the surrogate for assessing areas where cereal straw may feasibly be harvested for biofuels production.

Harvest Index - Harvest index (HI) is a mathematical value that is determined through field work. It estimates the amount of straw that is produced for each unit of grain produced. Grain weight is divided by grain plus straw weight to determine the value. The historic harvest index value for wheat, and an easy axiom, was 0.375 which means that for every 60 pound bushel of wheat grain that was produced, 100 pounds of straw was produced [60/(60+100)= 0.375). It has been postulated that newer grain varieties in general are more efficient in grain production than older varieties, i.e., they produce less straw per unit grain, but specific data was not available to test this hypothesis. Field trials were conducted across the United States by project collaborators in 2008 and 2009 crop years to test this idea. While significant variation was observed in harvest index (0.20 to 0.70), the average value across locations and years was 0.44. This suggests that 76 pounds of straw is produced, on average, for every bushel of grain [60/(60+76) = 0.44].

Residue Yields – Using the NASS grain yield information and determined harvest index value for wheat, it was possible to generate potential wheat residue yield maps for the nation. These are "gross" maps that would suggest areas where residue yields are of an adequate level to support siting of a biofuels plant but are maps that need to be adjusted to account for temporal variation in residue levels and for the amount of residue that needs to be left on the ground for soil conservation and soil quality purposes.

Temporal Nature of Straw Availability – In assessing the ten years of NASS x HI data, it became obvious that there were areas that on average had residue yields that were high enough to warrant possible residue harvest but that also had years in which there was likely no or limited yield due to freeze out or loss of crops due to drought or some other natural disaster. Siting of a biofuel plant in an area that would not have available raw product in one of ten years did not seem reasonable from a business perspective, so such areas were removed from "net" residue maps.

Residue Needed for Soil Erosion Control and Soil Quality Maintenance – Many cereal grain growers across the Unites States have crop insurance that is federally supported or receive benefits from federal farm programs. In nearly all cases, in order to participate in these programs, growers must have an approved soil conservation plan on their lands. Most of these plans require leaving crop residues on or near the soil surface to reduce erosion potential from rain or wind. Such requirements limit the acreage that is available for residue harvest. There is also considerable interest these days in maintaining or enhancing soil quality, sometimes as a factor independent of conservations needs. Reliable measurement of the effects of crop residue removal or addition on soil quality is work that requires decades to do as changes are often very small and somewhat temporal in nature. Versus initiating experiments to test the effect of cereal straw removal on soil quality, the cereal stover group opted to use existing data. Existing data are in the form of long-term experiments that have been conducted across the nation and around the world and in some cases for a century or more. The group arranged for a symposium to be held at the 2009 American Society of Agronomy meeting in Pittsburg, PA. This meeting was held in conjunction with Soil and Crop Science Societies of America – the Tri Societies. In this symposium, managers of long-term cereal plots were asked to report what the data available to them told about the effects of residue removal on soil quality. Presenters were also asked to prepare journal articles summarizing their findings. These articles will be published as a symposium series in *Agronomy Journal*, Volume 103 in January 2011. The summary article for the seven article series was written by Dr. David Huggins, project team member. The abstract of his article is given below.

Evaluating Long-Term Impacts of Harvesting Crop Residues on Soil Quality
David R. Huggins,* Russell S. Karow, Harold P. Collins, and Joel K. Ransom
Published in Agron. J. 103:1–4 (2011)

Utilizing crop residues as biofuel feedstocks will involve trade-offs between bioenergy production and agroecosystem services. Consequently, agricultural production managers and policymakers need to critically evaluate current functions of crop residues in light of increasing demands for agricultural intensification including bioenergy. At issue are the short- and long-term impacts of residue harvest

on the sustainability of soil resources and related food and energy production and the often disparate economic, environmental, edaphic, climatic, technological, and logistical factors involved. Although field studies cannot address all scenarios, long-term studies can provide insights on how crop residue harvest will impact key factors of agricultural sustainability such as soil organic matter (SOM). This topic was the major theme of the 2009 International American Society of Agronomy symposium entitled "Residue Removal and Soil Quality—Findings from Long-Term Research Plots." The seven papers in this special Agronomy Journal section were developed from this symposium and draw on long-term studies from Europe, Canada, Australia, and the United States to examine residue harvest impacts on SOM and factors related to long-term sustainably. In combination, these papers conclude that residue harvest will impact SOM, although the nature of the effects is situation-dependent. Also clear is that the assessment of harvesting residues must be placed in a farming systems context that includes an evaluation of economic and environmental trade-offs specific for a given farm and location. Therefore, future challenges include the development of science-based, site-specific decision aids that enable growers to make economically sound and environmentally sustainable choices regarding residue harvest, development of science-based, site-specific decision aids that enable growers to make economically sound and environmentally sustainable choices regarding residue harvest.

A general conclusion that can be drawn from these papers and from other work that addresses the amount of cereal residue that must be left in place for soil maintenance purposes is that in most situations, at least 3000 pounds of residue should be left on the ground. If mechanical harvest is then considered, agricultural engineers have estimated that at least 3000 pounds of residue is needed for efficient harvest. Combining these two values together suggests that a "net available" residue map should only include those areas of the United States, where using wheat as our surrogate, yields exceed 79 bu/a[9] (79 bu x 76 lb straw per bu with a harvest index of 0.44 = 6004 lb straw). If such a value is indeed used, this narrows areas available for wheat residue harvest to several dozen across the country, at most. Maps of these potential sites are available on the web.

Existing Uses of Straw in Areas of Possible Residue Harvest – Not surprisingly, given the entrepreneurship of the American agricultural community, agricultural professionals have known for many years those areas of the country where straw residues are readily and reliably available. In many instances, markets have already been built around these locations. In order to understand the potential for biofuels use of residues in these areas, it is necessary to understand the dynamics of existing use. This is an area of current investigation in the cereal stover project. Dr. Jim Julian, economist with Oregon State University, is characterizing straw markets in two areas in Oregon with the goal of determining what type of work and procedures are needed to obtain an accurate assessment of a straw market. A report on these two markets (the Willamette Valley of western Oregon and Boardman area of eastern Oregon) will be written as well as a recommendation on what resources will be needed to do assessments in other parts of the country. What Dr. Julian has found to date is what was suspected for at least some portion of the straw in these high residue areas - markets for straw already exist at prices far higher than what is postulated as the likely purchase price in the biofuels market.

Next Steps – While work done on this project to date paints a pessimistic picture for cereal residue harvest if looked at from the "30,000 foot" level. The real conclusion is that cereal residue harvest needs to be evaluated on a smaller scale. The focus needs to shift to the farm and small region scale where science-based decision aids can be developed to assist growers and agricultural professionals in making decisions in both time and space regarding residue harvest. It may be possible to economically harvest some portions of fields on an annual basis without affecting soil quality. It may be possible to harvest all residue from a field in some specific part of a cropping system that has been designed to accommodate residue harvest. If small-scale biofuels plants are designed, it may be possible for a group of neighborhood farms to sustainably provide the feed stuffs for such a plant where the same would not be possible for a large plant. One of our project goals over the coming year is to identify scientists who are working on decision aids for farm scale residue harvest and provide incentives for these individuals/groups to collaborate and share their findings on a national level.

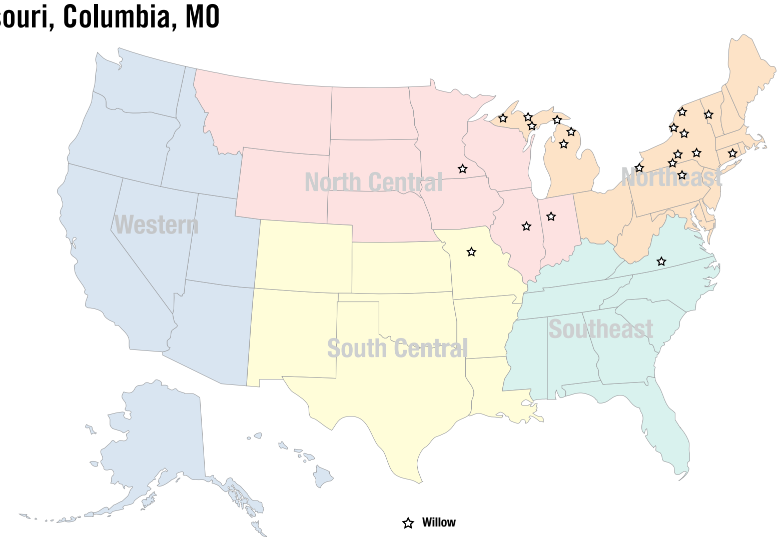
[9] bu/acre = bushel/acre

Woody Energy Crops

Tim Rials, Team Lead
University of Tennessee

Willow Biomass Crop Feedstock Development Plan for the Northeast and Midwest U.S.

Timothy Volk, Willow Coordinator, The State University of New York-ESF
Lawrence Smart, Cornell University
Ray Miller, Michigan State University
Tom Corbin, Middlebury College
Yulia Kuzovkina, University of Connecticut
Arbor America, Westpoint, IN
Belleville-Henderson Central School, Belleville, NY
Double A Willow Nursery, Fredonia, NY
East Lycoming School District, Hughesville, PA
Piedmont Bioproducts, Gretna, VA
SUNY Delhi, Delhi, NY
SUNY Potsdam, Potsdam, NY
USDA-Natural Resources Conservation Service, Big Flats, NY
University of Illinois at Urbana-Champagne, IL
University of Minnesota, Southern Research and Outreach Center, Waseca, MN
University of Missouri, Columbia, MO



Background on Willow Biomass Crops

Willow biomass crops are being developed as perennial feedstock that simultaneously produces a suite of rural development and environmental benefits in addition to providing a renewable feedstock for bioproducts and bioenergy. The shrub willow cropping system is built around planting genetically improved shrub willow varieties on properly prepared marginal land and managing it as a perennial crop. Willows are planted as unrooted dormant hardwood cuttings in the spring using tractor mounted planters. Following the first year of growth, the willows are cut back close to the soil surface to force coppice regrowth, which increases the average number of stems per stool from 1–4 to 8–13 depending on the variety. After 3 – 4 more years the stems are mechanically harvested during the dormant season. New Holland forage harvesters, with a specially designed short rotation coppice head, cut and chip the willow into consistent sized chips that are collected and delivered directly to end users with no additional processing. The plants resprout the following spring and grow for another 3 – 4 years before they are harvested again. Experience in Europe indicates that the crop can be maintained for at least seven three-year rotations. Recent economic analysis indicates that willow crops are marginally profitable under current conditions with a 5.5% internal rate of return (IRR) over seven three-year rotations. Increasing yields by 2 oven dry tons (odt) ha^{-1} [10], or 17%, increases the internal rate of return by 51% (from 5.5% to 8.3%). Increasing yields by 50% improves the internal rate of return by 132%.

Willow Biomass Crop Sun Grant Feedstock Partnership

This project supports a network of 22 yield trials across the Northeast and Midwest and into the Southeast. This extensive network is possible because collaborators have donated land, labor and materials for many of these trials. In addition, team members and collaborators have effectively leveraged other funds from state, federal and private sources. The network consists of three groups of trials. The first group of two trials was planted in the 1990s and is included to provide data on long term data production patterns in these perennial systems. The second group of eight trials was established before the start of the Sun Grant Feedstock Partnership and includes new willow varieties developed as part of the SUNY-ESF program. The third group of 12 trials was established as part of this program with new willow varieties from the SUNY-ESF program. Trials are 0.25 - 1 ha[11] in size and include 6 - 30 willow varieties with 3 or 4 replications.

Group 1: Existing Willow Yield Trials Planted in the 1990s

These two trials were planted in 1993 and 1997 in Tully, NY (Table 1) and are the oldest willow trials in the United States. They contain willow varieties that were selected from the Ontario Ministry of Natural Resources, the University of Toronto and from the wild in the Northeast U.S. Six of these varieties are currently being propagated and sold commercially in the Double A Willow nursery (www.DoubleAWillow.com) for biomass production and other applications. These trials provide essential data on long-term production patterns that are needed to model the system's production, economics and environmental benefits. These trials are being maintained and yield data have been collected from the fifth and fourth harvest rotation respectively.

The 1997 trial contains four willow varieties (SX61, SX64, SX67 and SV1) that are being produced in commercial nurseries and sold as planting stock for biomass crops. Results from this trial indicate

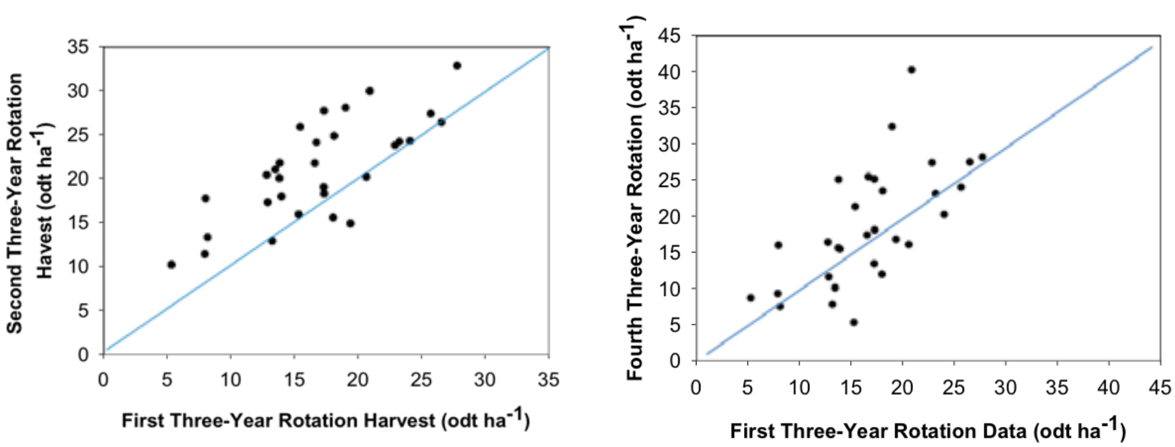


Figure 1. Changes in production from the first to second (left) and first to fourth (right) rotation harvest for 30 willow varieties in a trial planted in Tully, NY in 1997. Varieties above the 1:1 line on each graph increased production over the rotations represented.

that willow yields increase from the first to the second rotation by 19.4% (Fig. 1). The increase was 21.6% for the four commercial varieties. This increase is associated with the perennial nature of willow.

[10] 1 ton ha^{-1} = 893 pounds (lbs) per acre
[11] ha = hectare

During the first rotation the plants are building both belowground and aboveground systems. Willow resprouts after being harvested and makes use of the existing root system, which allows more carbon to be allocated to aboveground biomass. The increase in yield across all willow varieties from the first to fourth rotation was 13.6%, indicating that the yield of some varieties had decreased since the second rotation. However, yield of the four commercial varieties increased by 30.8% from the first to the fourth rotation, indicating that the yield of these varieties increased between the second and fourth rotation. Similar increases in willow yield over three rotations have been measured in a trial planted in Escanaba, Michigan, in 2002. In both New York and Michigan, clones of hybrid poplar included in these trials had stable or decreasing biomass production over multiple coppice rotations. These data show that increases in yield are still occurring in the later rotations for these commercial varieties, which will improve the internal rate of return from the crop and the system's greenhouse gas balance.

Group 2: Existing Yield Trials that Include New Varieties from the SUNY-ESF Program

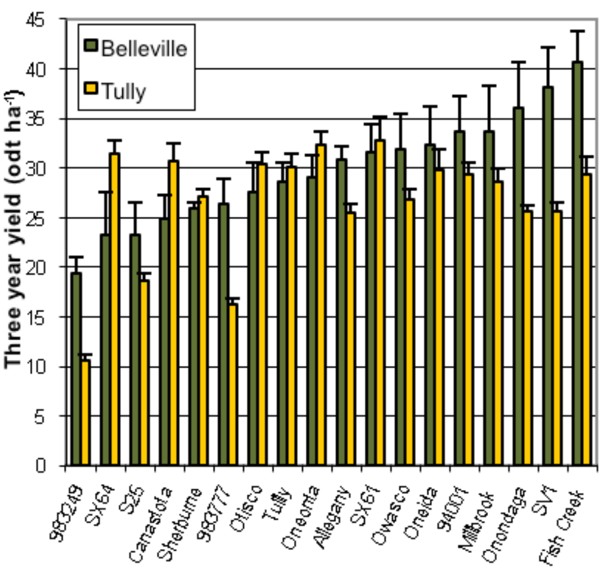


Figure 2. First three-year rotation yield of 18 willow varieties planted at sites in central (Tully) and northern, NY (Belleville). Varieties with names or beginning with 98 are crosses from the SUNY-ESF program. These are the first yield trials with these new varieties.

Eight yield trials with new willow varieties from the SUNY–ESF program were established in four states between 2005 and 2008 before the start of this program. These trials were established with support from other funding agencies, but that support has ended, so they are being maintained and monitored as part of this program. These trials are providing key information about how new willow varieties that are being sold commercially perform over a range of conditions. Four of the trials have completed their first rotation and are being maintained to collect essential second rotation data. These are the only trials in North America that contain these improved willow varieties in their second rotation.

First three-year rotation yield data from two trials planted in 2005 with 18 varieties in central and northern New York reveal that the varieties respond differently at the two sites (Fig. 2). At Belleville, the top five varieties had yields of 35.6 odt ha^{-1}, with 'Fish Creek' producing the highest yield at 40.8 odt ha^{-1}. The top five varieties at Tully produced 31.5 odt ha^{-1}, with 'SX61' (a reference variety) producing the most at 32.8 odt ha^{-1}. At both sites three of the top five yielding varieties were new varieties bred at SUNY-ESF. Results discussed above indicate that willow yield increases by about 20% from the first to second rotation, which means that the top five varieties at Belleville should produce about 42.7 odt ha^{-1} (14.2 odt ha^{-1} yr^{-1})[12], which will exceed the anticipated yields of 12 odt ha^{-1} yr^{-1} (5.3 odt $acre^{-1}$ yr^{-1}) in the second and subsequent rotations. Second rotation yield at the Tully site should be around 37.8 odt ha^{-1} (12.6 odt ha^{-1} yr^{-1}).

Group 3: New Yield Trials Established Under the Sun Grant Feedstock Partnership Program

This suite of 12 willow yield trials in eight states has focused on expanding the range of sites where willow biomass crops are being tested. Protocols for data collection and monitoring are being coordinated so that they are the same across all the sites.

[12] 1t ha^{-1} yr^{-1} (ton per hectare per year) = 893 pounds (lbs) per acre per year

Surveys of Regional Trials for Pests and Diseases

As the area planted to willow expands, it will be prone to outbreaks of pests and diseases. These threats to production and the long-term yield production will need to be managed at minimal expense using low or no inputs of pesticides. The ideal strategy is to breed, select, and deploy cultivars that display durable, horizontal resistance developed through breeding. The main objective of this aspect of the project is to evaluate pest and disease incidence on commercial and pre-commercial willow varieties across a range of sites.

Surveys of pests and diseases were timed to identify damage from key pests present in early-, mid-, and late-season. The field trials included in pest and disease surveys were 2005 Tully, 2005 Belleville, 2006 Constableville, 2007 Fredonia, 2008 Big Flats, and 2008 Potsdam. Trials planted in Michigan have also been surveyed, but are not included in this summary. Key outcomes are that pest and disease resistance varies among varieties according to their genetic diversity groups and that pest and disease pressures vary significantly by environment and geographic location. This is highlighted by survey results for the incidence of beetle damage (mainly Japanese beetle and imported willow leaf beetle), which is severe on 'SV1', low on 'SX61' and 'SX64', and intermediate across members of the other diversity groups (Fig. 3). These data also demonstrate highest levels of beetle damage in Big Flats, with regularly low damage in Constableville. These results provide a basis for future characterization of factors involved in pest and pathogen defense and will guide future breeding efforts.

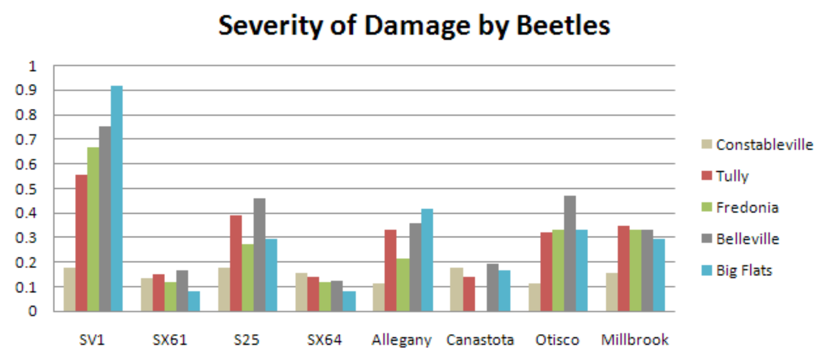


Figure 3. Normalized results of beetle damage surveys for varieties representative of eight genetic diversity groups across five sites over five growing seasons (2006-2010).

Anticipated Results for 2011

Over the next year four of these trials will complete their first three-year rotation and two others will complete their second rotation. As this database is developed, predicting yields of willow biomass crops across multiple regions of the country will become much more accurate and site-specific. Data will be used to improve economic and environmental models, develop recommendations for selecting varieties for specific regions and sites, improve crop management recommendations, and provide feedback for ongoing breeding. Without this information, the deployment of willow biomass crops will encounter difficulties due the uncertainty about willow production potential in different regions. Having regionally based datasets will provide additional confidence for potential growers, investors and project developers with plans to deploy willow biomass crops. Data collected from pest and disease surveys will provide essential information to develop breeding and selection programs to avoid serious impacts on yield as crop acreage expands.

In 2011 the following specific results are anticipated:

- Publication of first-rotation yield data from the 2005 Tully, 2005 Belleville, 2006 Constableville and 2006 Waseca trials. This will be the first data published on the production potential of this suite of new willow varieties across a range of sites.
- Publication of yield data for the first four rotations of the 1997 trial in Tully, NY.
- First three-year rotation harvest and summary of yield trials in Middlebury, VT. An adjacent fertilizer trial that was planted mechanically will provide one of the first opportunities to compare production in hand planted yield trials and machine planted trials. The harvested willow will be used for tests in the new CHP facility at Middlebury College.

- Harvest and summarize the first three-year rotation results data from 2008 trials in Escanaba, MI, Big Flats, NY, and Fredonia, NY. This will expand the range of sites and geographical regions where yield data are available for willow biomass crops.
- Summarize data from the first five rotations of the 1993 Tully trial to provide data on long-term production trends and the spread of willow stools over time, which is often thought to be the main factor that limits the lifespan of these systems.

Table 1. Willow biomass crop yield trials included in the Sun Grant feedstock development program

Inception	Yield trial Establishment year and Name	Collaborators*	Trtmnts† (No. of clones)	Data collected‡	Next Harvest
Long-term trials	1993 Tully, NY	ESF	19	Surv, Copp, Harv1 through Harv5	2012
	1997 Tully, NY	ESF	32	Surv, Copp, Harv1 through Harv4	2012
Existing network of trials	2005 Belleville, NY	ESF, BHCS	18	Surv, Copp, Grwth, Rust, Insct, Harv1	2011
	2005 Tully, NY	ESF	18	Surv, Copp, Grwth, Rust, Insct, Harv1	2011
	2006 Constableville, NY	ESF	30	Surv, Copp, Grwth, Rust, Insct, Harv1	2012
	2006 Waseca, MN	UMinn	26	Surv, Copp, Grwth, Harv1	2012
	2007 Middlebury, VT	MC	30	Surv, Copp, Grwth	2010
	2008 Big Flats, NY	CU, NRCS	8	Surv, Copp, Rust, Insct, Grwth	2011
	2008 Escanaba, MI	MSU	26	Surv, Copp, Rust, Insct, Herb, Grwth	2011
	2008 Fredonia, NY	CU, Double A	28	Surv, Copp, Rust, Insct, Grwth	2011
1st yr of Sun Grant funding	2009 Delhi, NY	ESF, Delhi	20	Surv, Copp	2012
	2009 Gretna, VA	ESF, Pied. Bio.	20	Surv, Copp	2012
	2009 Skandia, MI	MSU	20	Surv, Copp, Rust, Insct, Grwth	2012
	2009 Potsdam, NY	CU, Potsdam	16	Surv, Copp, Rust, Insct	2012
	2009 Brimley, MI	MSU	20	Surv, Copp, Rust, Insct, Grwth	2012
	2009 Storrs, CT	UConn	20	Surv, Copp	2012
New trials estab. 2010	2010 Franklin, MO	MU	30	nd	2013
	2010 Hughesville, PA	ESF, ELSD	20	Surv	2013
	2010 Lake City, MI	MSU	20	Surv, Rust, Insct, Copp	2013
	2010 Onaway, MI	MSU	20	Surv, Rust, Insct, Copp	2013
	2010 Savoy, IL	UIUC	20	Surv	2013
	2010 West Point, IN	ESF, Arb. Am.	20	nd	2013

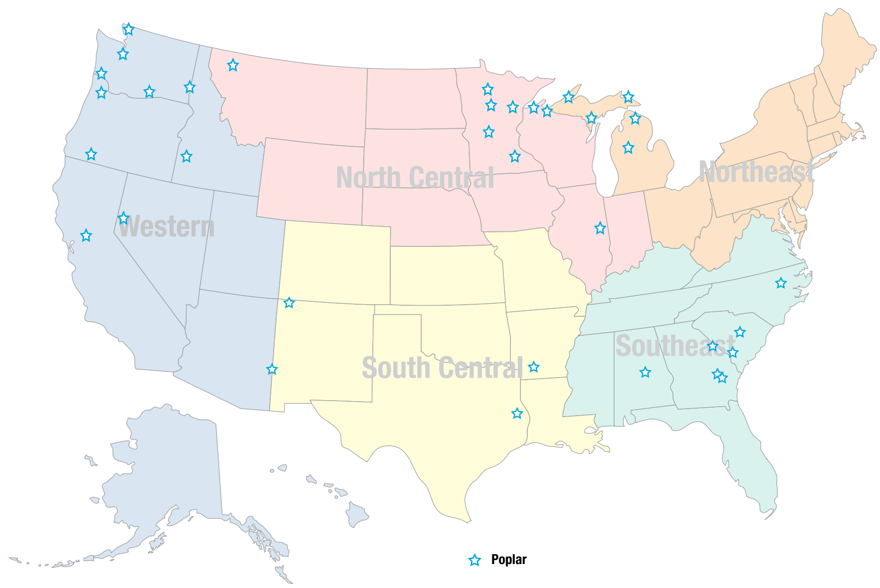
*Full names of collaborators are as follows: **Arb. Am.** = Arbor American, Westpoint IN; **BHCS** = Belleville- Henderson Central School, Belleville, NY; **CU** = Cornell University, Geneva, NY; **Delhi** = SUNY Delhi, Delhi, NY; **Double A** = Double A Willow, Fredonia, NY; **ELSD**= East Lycoming School District, Hughsville, PA; **ESF** = SUNY Environmental Science & Forestry, Syracuse, NY; **MSU** = Michigan State University, Escanaba, MI; **NRCS** = USDA Natural Resources Conservation Service, Big Flats, NY; **Pied. Bio.** = Piedmont Bioproducts, Gretna, VA; **Potsdam** = SUNY Potsdam, Potsdam, NY; **UConn** = University of Connecticut, Storrs, CT; **UIUC** = University of Illinois at Urbana-Champagne, IL; **UMinn** = University of Minnesota, Waseca, MN; **MU** = University of Missouri, Columbia, MO; **MC** = Middlebury College, Middlebury, VT.

† Willow clone (variety) planted is considered the treatment in all of the above trials, with the aim of testing the production potential of all clones across multiple locations.

‡Explanation of data collection codes are as follows: **Soil** = soil samples have been collected from the site, **Surv** = survival estimates taken within the measurement plot (collected simultaneously with production and growth estimates), **Copp** = first year production at time of coppice, **Grwth** = annual growth estimates including diameter of all stems and height of tallest stem, generally done in years between harvests, **Rust** = surveys for presence and severity of *Melampsora* rust, Insct = surveys for the presence and extent of insect/pest damage, **Herb** = herbivory surveys, **Harv#** = Biomass production measured at harvest, which are performed on a three-year rotation and are numbered consecutively, **nd** = no data collected to date.

Hybrid Poplar Energy Crop Development Plan

Bill Berguson, Poplar Coordinator, University of Minnesota-Duluth
Brian Stanton, GreenWood Resources, Inc.
Randy Rousseau, Mississippi State University
Mike Cunningham, ArborGen, LLC



Background

Poplar is one of the woody species groups under consideration as a potential biomass energy crop due to several characteristics including rapid growth, ease of commercial-scale propagation, ability to regrow from established root systems, potential for hybridization and inherently high genetic diversity. The purpose of poplar woody crops research being done under the DOE/Sun Grant Regional Biomass Feedstock Partnership is to determine yields and production costs of poplar woody crops using current management practices and genetics and improve upon the established baseline yields through cooperative genetic improvement and yield tests in a national network of field research sites. This work is being done by a group of academic and industry cooperators having unique sets of field tests and extensive genetic resources. The current cooperators in the poplar woody crops feedstock research include the University of Tennessee, the University of Minnesota, Mississippi State University, Michigan State University, ArborGen LLC (South Carolina) and GreenWood Resources (Oregon). Together this group manages a program to evaluate the yield potential of woody biomass crops in the various regions of the country and combines genetic resources to produce new fast-growing genotypes to further improve biomass yield. At this time, research is being done in 22 states on sites encompassing a wide variety of soil types and climatic conditions (see map). The ultimate goal is to develop and demonstrate fast-growing, disease-resistant poplar genotypes suitable for a wide geographic range of the United States and evaluate the optimal sites for biomass production leading to adoption as a commercially viable energy cropping system.

In addition to the attributes mentioned above, woody crops play an important role in the spectrum of potential energy crops due to the flexibility in harvest timing of these crops. Discussions related to the logistics of procuring biomass for future processing facilities have highlighted the importance of harvest timing and integration of harvesting biomass from the various proposed biomass sources. The allocation of labor and equipment, vagaries of weather and storage issues are all considerations that become very important when the time-window for harvesting is limited. The potential exists to harvest woody energy crops over a wide time period during the dormant season. Also, if trees are harvested and stored at field sites in whole form, trees can be stored for a long time period without further treatment. Woody crops are viewed as an important complement of a multi-feedstock scenario by diversifying harvest timing and providing potential insurance against extreme weather events when harvesting can be difficult from other annually-harvested sources.

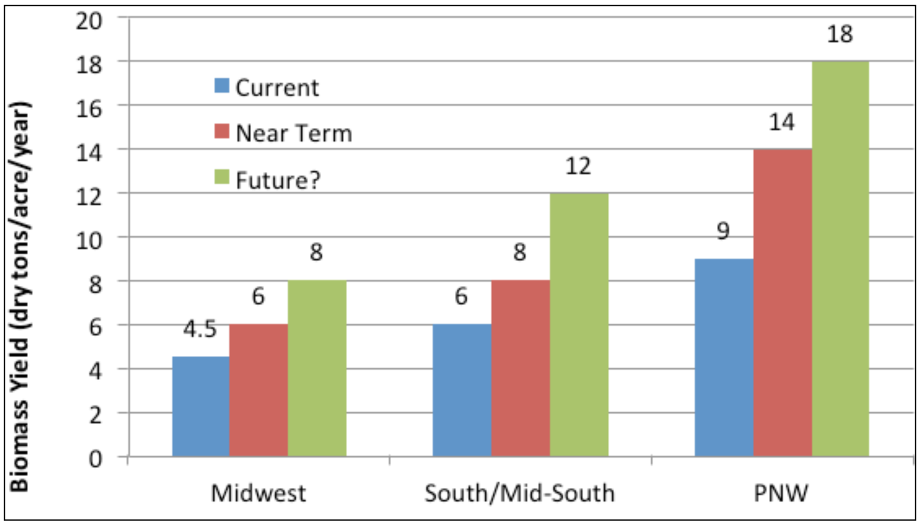


Figure 1. Current, near term and future expected poplar yields through research in three regions of the U.S.

Poplars are currently being grown commercially in Minnesota and Oregon for fiber and energy on longer harvest rotations, typically ranging from seven to fifteen years. The stand management practices for this type of production system are well established and the cost of production can be estimated with a reasonable level of certainty. However, yields can be greatly improved through genetic improvement research and potentially through changes in management systems, notably systems regenerating through coppice growth after harvest. The following graph shows expected improvements in yield through time in three major regions of the United States assuming continued investment in research.

As shown in the above graph, current commercial-scale yields of woody crops on an annualized basis (referred to as mean annual increment or MAI) range from four dry tons per acre per year in the cooler Upper Midwest to nine dry tons per acre per year in the Pacific Northwest. Yield differences are reflective of the growing season as well as the intensity of research leading to improved genotypes in the regions. These yields are expected to increase significantly in the near term with increases to six, eight and fourteen dry tons in the Midwest, South/Mid-South and Pacific Northwest, respectively, assuming continued research efforts in genetic improvement. As a point of reference, the average production of corn grain is roughly four tons per acre per year with additional production of stover of approximately three tons. With continued research, the potential exists to create a very energy-efficient biomass production system with much lower financial and energy inputs than typical agronomic crops. The implication of lower production costs will be explored later in this report.

Current Sun Grant Poplar Studies

The network of study sites supported under the DOE/Sun Grant program is the most extensive woody crops research program in North America. At this time, over 70 sites are contained in the Sun Grant network and include studies of large-block biomass yields of a variety of clones, clone tests of new genotypes, and breeding archives that will provide the foundation for the current breeding program. The Sun Grant research sites consist of recently planted sites (those planted in 2009 and 2010) as well as sites that existed before the Sun Grant Program. The resources of the Sun Grant Program are being used to continue measurements of annual biomass production and genetic performance on many of these older sites. In this way, the assets of the various cooperators are being made available to the Sun Grant Program and the Sun Grant funding is more effective by utilizing existing resources.

Yield Analyses

Studies of the biomass yields of poplar under a short-rotation system are underway in the various regions. These consist of larger-sized blocks of single-genotypes in replicated field tests. In the case of Minnesota research, yield blocks of a variety of clones are planted at a minimum of 7 X 7 trees with three replications to minimize edge-effects that lead to overestimation of yield, a problem inherent to many smaller-scale research plots. Analysis of longer-term yield data in Minnesota shows that gains of 1.2 to 1.4 times that of the current commercial standard (clone NM6) are possible. Of particular interest is the ability of new genotypes exhibiting high annual rates of production under high-density conditions. This attribute is very important in short-rotation, repeated-coppice management systems.

Also, sites are being located in the Southeast region in commercially managed stands and measurement plots are being established to develop a dataset of baseline yield for poplar in the region. Prior to the DOE/Sun Grant Program, much of the yield data from the southeastern United States was proprietary to forest products companies and not available to the public. The first of these data will be available in the spring of 2011 and represent some of the highest-quality, publically available data on poplar production in the region.

Studies of yields underway in the Pacific Northwest continue to show average production of nine dry tons per acre with individual clones attaining fourteen dry tons per acre per year. A study of a coppiced stand in the lower Columbia River region shows average production of ten dry tons per acre per year after five years. This rate of production is expected to increase through reduction of the time to first-harvest to three or four years.

Genetic Improvement

The area of research having the greatest potential to improve biomass yield in the near- and long-term is genetic improvement. Based on past experience, clone performance is very site-dependent and a network of clone trials in the various regions is essential to ensure stable and predictable biomass production. The development of a genetically-diverse set of disease-resistant, high-yielding hybrids adapted to regional conditions is critical to the success of the program. Potential growers of poplar will need to be provided with proven genetic materials with predictable performance under a given set of conditions. The aim of new research being done as part of the Regional Biomass Feedstock Partnership is to consolidate the large genetic resources of the cooperators programs in one cohesive effort to achieve this goal. Taken together, the genetic resources of the DOE/Sun Grant poplar team comprise one of the most extensive collections of existing clones and parental populations in the world. These collections of parent material serve as an important foundation for the DOE/Sun Grant poplar breeding and are essential to continued yield improvement.

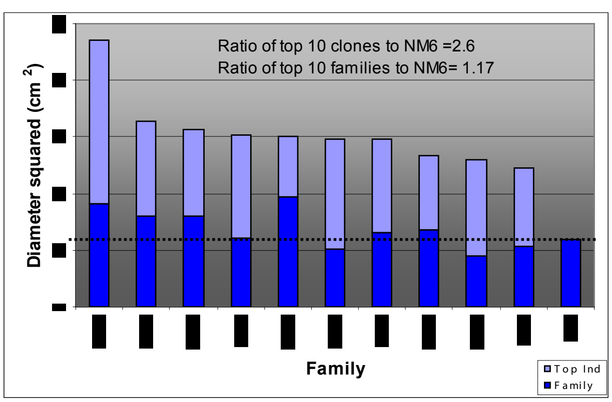


Figure 2. Relative biomass yield (diameter^2) of the ten highest-yielding families and top individual clones relative to the commercial standard clone NM6 (rightmost bar) after four years in field genetics test in central MN.

An example of the importance of genetic improvement is shown in Figure 2. This graph shows the relative biomass of new genotypes compared to NM6, the standard commercial poplar clone in Minnesota. This trial shows the average production of the ten highest-yielding families and the highest-yielding clone within each family. The rightmost column represents the biomass yield of the commercial standard, NM6. The ratio of the ten highest yielding clones to NM6 after four years is

2.6 with the ratio of the average production of all clones within a family (30 clones per family) is 1.17. Based on this and other similar studies, the potential to improve biomass yields through breeding is very high. The goal is to produce a suite of genetic material having adaptability to a range of conditions in the United States and select elite hybrids from these tests for commercial production. The poplar team has a large collection of *Populus deltoides*, *P. nigra*, *P. maximowiczii* and *P. trichocarpa* to support a national poplar breeding effort. The beginning of the breeding work will begin in 2011. Parental stock is currently being selected for this effort with breeding to begin in February of 2011.

Clone Tests

In addition to breeding, the Sun Grant poplar team has amassed collections of individual clones that have undergone a level of field testing in the "home" environments of each cooperator. In 2009 a set of consolidated hybrid field trials were established that brought together twenty clones from each of four collections (Upper Midwest, Mid-South, South, and Pacific Northwest) for testing in all regions. At this point, four studies with six replication of each of eighty genotypes have been established. This effort is expected to continue annually to expand the geographic range of sites.

Economic Analysis

While yield is a critical part of biomass production, it is helpful to combine yield and production costs to provide a more complete picture of the economic feasibility of producing biomass energy through dedicated energy crops such as poplar. Through the assistance of industrial cooperators in Minnesota (Verso Paper Company), a cash-flow model containing management inputs necessary to achieve optimal production on unirrigated agricultural soils typical of those in many regions of the United States was developed. Input on the management practice, frequency of application and other information such as herbicide rate applied were verified through discussion with Verso Paper staff. In order to provide some degree of "arms-length" from disclosure of industrial cost of production, a combination of published custom rate sheets for agricultural operations and contacts with agricultural contractors were used to fill in the cost data for each practice. In one case, a single-harvest, twelve year rotation with one year added for site preparation was used. Then the stumpage price (direct revenue to the landowner) was varied to estimate a breakeven production price. The total discounted production cost is $450.00 per acre with the yield held at 48 dry tons per acre at harvest reflecting current commercially attainable yield in Minnesota. The breakeven price per dry ton at a 4% discount rate is estimated to be $15.63 per dry ton using input costs only. By comparison, a higher-density, multiple-coppice rotation system with higher planting costs (1742 trees/acre) results in an estimated production cost of $19.20 per dry ton, slightly higher than the longer-rotation system. The average annual cost per acre is $38.59 and $43.13 per acre for the single-harvest and multiple-harvest management systems, respectively. In comparison, the annual per-acre production cost of common agronomic crops is much higher. Using published production cost data from the FINBIN website maintained by the University of Minnesota (http://www.finbin.umn.edu/), the total direct (site prep, seed, planting, cultivation, herbicide, fertilizer, etc.) and indirect costs (buildings, machinery, interest, etc.) costs for selected crops was calculated. The total cost of corn production on owned land is reported to be $555 per acre including direct and indirect costs of $400 and $155, respectively. Conducting a similar analysis for wheat in Minnesota, the total direct and indirect input cost is $275.00 per acre annually. While markets for both energy and agricultural commodities ultimately will determine the crop to be grown, energy cropping systems are much less intensive than most commodity crops and could be grown efficiently assuming energy markets are sufficiently high to warrant widespread planting.

Reports/Presentations

The project team has completed the drafts of reports describing research history, genetic development, yields and economics of biomass production. These reports will be reviewed and compiled into a composite document that describes the programs in the respective regions. As a result of this process, a paper describing the program history, biomass yields, economics and future research direction in the Pacific Northwest and Lakes States was drafted and is undergoing review as part of the "Sustainable Feedstocks for Advanced Biofuels Workshop" that was recently held in Atlanta, GA, in September. This workshop was coordinated by the national Soil and Water Conservation Society and included a range of potential energy crops as well as biomass from agricultural crop residues. Bill Berguson presented the review of the woody crops research at this meeting with emphasis on the current commercial application of woody crops in Minnesota and the Pacific Northwest. Brian Stanton, Jake Eaton (GreenWood Resources) and Bill Berguson are coauthors of this paper.

Education and Outreach

Sam Jackson, Team Co-lead, University of Tennessee
Kim Cassel, Team Co-lead, South Dakota State University

BioWeb

The Sun Grant BioWeb (http://bioweb.sungrant.org/) is an online resource for information and data on bioenergy and bioproducts created from biomass. This resource allows data to be dynamically compiled into practical and relevant content on a particular topic of interest. The content is available at varying levels of complexity for use by a diverse range of audiences. This project has engaged some of the country's top experts to provide a comprehensive analysis of the current state of biomass, alternative paths for biomass development, and economic and policy considerations. BioWeb also describes regional differences and opportunities related to biomass.

Information found on this site is useful for scientific researchers, policy makers, large- and small-scale industry, agricultural producers, and anyone who wants to learn more about biomass and its uses. BioWeb is not new research or unvetted ideas. Rather, it is a first-of-its-kind organization and packaging of existing work, reviewed by academic professionals for accuracy. This resource complements existing research and educational efforts. BioWeb fills a niche that can benefit all agencies, organizations, and individuals contributing to the advancement of a feasible and valuable biobased industry for America.

To date, BioWeb has 110 topical sections. The content for these sections was authored by individuals or groups at 18 different universities and colleges, one private industrial firm, and two federal agencies, including two U.S. Department of Energy National Laboratories and four U.S. Department of Agriculture agencies.

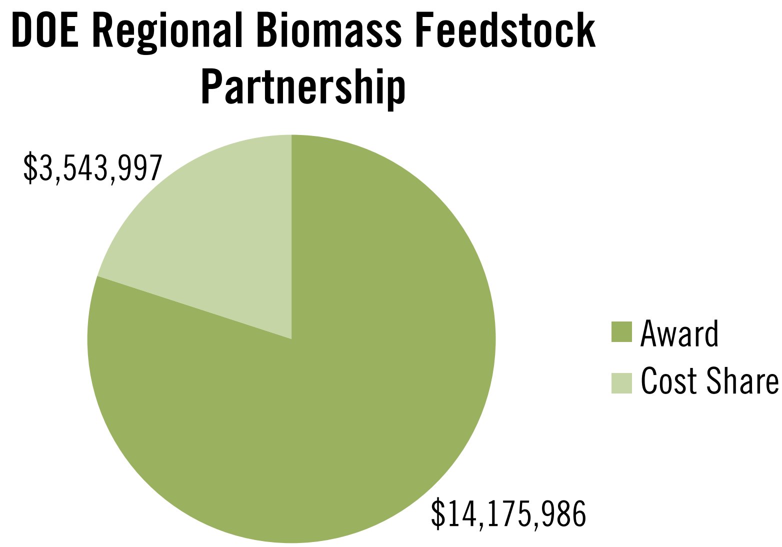
Since the public launch of the resource on April 15, 2007, the site has garnered 44,242 unique visitors and 152,514 page views. Fifty percent of these visitors originated from standard search engines (Google, Yahoo, etc.) while the remaining visitors came via direct links from associated websites. The top four countries of origin for visitors to BioWeb were (in order) the United States, Canada, United Kingdom, and India. The top content areas (ranked in number of page views) include cellulosic ethanol technologies, dry grind corn ethanol technologies, and pyrolysis for the production of biopower.

BioWeb plans for the coming year include adding new content based upon priorities identified from the previously conducted content review. This content development will include traditional content and will also include two new features. One feature will be the addition of a clearinghouse page for K-12 curricula available for teachers. Several entities have developed these materials and it is important to make educators aware of these resources. Another new feature of BioWeb will be a section for current issues or position papers on current topics. These will not be peer reviewed pieces (and would include a disclaimer stating as such) and would be authored by selected experts. These will come in monthly and be featured on the BioWeb front page. Not only would such a feature provide frequent additions to the site, it would also allow BioWeb to maintain current information for topics that are in the media and of great public interest.

eXtension

In February 2010, Sue Hawkins, Coordinator of eXtension Farm Energy COP attended the SGA meeting and Regional Biomass Feedstock Partnership meeting to engage the groups in developing a feedstock COP for eXtension. The decision was made start the effort with the switchgrass group developing content and FAQs. Shortly thereafter the opportunity for a Bioenergy CAP grant came about and the group was broadened to include 12 land-grants and six partners. Enhancement of the Farm Energy COP with feedstock development, logistics content as well as business models was identified as a key objective of the Extension component of the CAP grant. A letter of intent was submitted and the group led by SDSU was invited to submit a full proposal. A decision is pending.

FUNDING



U.S. DEPARTMENT OF ENERGY

Research was supported by funding from the North Central Regional Sun Grant Center at South Dakota State University through a grant provided by the U.S. Department of Energy Office of Biomass Programs under award number DE-FC36-05GO85041.