Agronomic, environmental and economic performance of alternative biomass cropping systems

Lisa A. Schulte Moore  
*Iowa State University*, lschulte@iastate.edu

Kenneth J. Moore  
*Iowa State University*, kjmoore@iastate.edu

Richard B. Hall  
*Iowa State University*, rbhall@iastate.edu

Arne Hallam  
*Iowa State University*, ahallam@iastate.edu

Matt Helmers  
*Iowa State University*, mhelmers@iastate.edu

Follow this and additional works at: [http://lib.dr.iastate.edu/leopold_grantreports](http://lib.dr.iastate.edu/leopold_grantreports)

Part of the *Agronomy and Crop Sciences Commons, Bioresource and Agricultural Engineering Commons, Natural Resource Economics Commons, Natural Resources and Conservation Commons*, and the *Water Resource Management Commons*

**Recommended Citation**

[http://lib.dr.iastate.edu/leopold_grantreports/420](http://lib.dr.iastate.edu/leopold_grantreports/420)

This Article is brought to you for free and open access by the Leopold Center for Sustainable Agriculture at Iowa State University Digital Repository. It has been accepted for inclusion in Leopold Center Completed Grant Reports by an authorized administrator of Iowa State University Digital Repository. For more information, please contact digirep@iastate.edu.
Agronomic, environmental and economic performance of alternative biomass cropping systems

Abstract
If cellulosic biomass is to play a significant role in America's energy future, research needs to be conducted on the optimal production and placement practices. This project looked at a portfolio of biomass cropping systems that might be adopted for Iowa.

Keywords
Natural Resource Ecology and Management, Agronomy, Economics, Agricultural and Biosystems Engineering, Bioeconomy and energy, Economic and environmental impacts, Water quality quantity and management

Disciplines
Agronomy and Crop Sciences | Bioresource and Agricultural Engineering | Natural Resource Economics | Natural Resources and Conservation | Water Resource Management

This article is available at Iowa State University Digital Repository: http://lib.dr.iastate.edu/leopold_grantreports/420
Whether and where could a suite of alternative biomass cropping systems be competitive with a continuous corn system according to agronomic, environmental and economic measures?

The team evaluated this question through field experimentation, measurement and subsequent data analysis.

Background

With the passage of the Energy Independence and Security Act of 2007, the United States established an aggressive agenda to reduce dependency on fossil fuels and foreign oil. While corn grain has met much of the initial need, cellulosic biomass feedstocks are expected to provide a more sustainable solution in the long term. Cellulosic feedstocks pose numerous advantages including a higher energy output:input, fewer negative impacts on soil and water resources, and their ability to be grown across a wider range of climate and landscape conditions than corn grain. It is unlikely, however, that a single biomass cropping system will suit all of these purposes—a portfolio approach to bioenergy feedstock production is needed. Potential systems to be included in the bioenergy feedstock portfolio need to be developed, tested and compared to corn production systems.

The initial goal of the Landscape Biomass Project was to develop a portfolio of biomass cropping systems that together are productive, profitable, and mitigate negative effects of annual crops on soil and water quality. Specific objectives were to:

- Establish an experiment to test alternative biomass systems, as well as baseline topographic, hydrological and soil conditions for the experimental site;
- Evaluate and compare energy/fertilizer inputs versus biomass outputs among biomass production systems grown on different landscape positions;
- Evaluate and compare biomass production systems grown on different landscape positions in terms of their impacts on soil and water quality; and
- Evaluate and compare establishment, production, harvest, and transport costs of biomass production systems grown at different landscape positions.

Approach and methods

Several alternative biomass cropping systems were developed and compared to a conventional Continuous Corn system. The research team developed and tested several systems because of their potential to provide either

1. superior biomass yields (Continuous Corn, Sweet Sorghum/Triticale),
2. some biomass yield while mitigating some negative environmental impacts (Soy-Triticale/Soy-Corn, Corn-Switchgrass), or
3. some short-term biomass yield and superior long-term yield while strongly

Abstract: If cellulosic biomass is to play a significant role in America’s energy future, research needs to be conducted on the optimal production and placement practices. This project looked at a portfolio of biomass cropping systems that might be adopted in Iowa.

Principal Investigator: Lisa Schulte-Moore
Natural Resource Ecology and Management

Co-investigators:
Ken Moore
Agronomy
Richard Hall
Natural Resource Ecology and Management
Arne Hallam
Economics
Matt Helmers
Agricultural and Biosystems Engineering
Iowa State University

Budget:
$43,056 for year one
$23,785 for year two
$24,312 for year three
mitigating negative environmental impacts (Triticale/Aspen). As crop performance is strongly tied to site factors, these biomass cropping systems were evaluated across a series of landscape positions (at the summit, shoulder, backslope and the slope of the flood plain).

A long-term, randomized, replicated block experiment used to test and compare the five cropping systems across five landscape position was implemented in 2008-09 with this initial funding from the Leopold Center and ISU’s College of Agriculture and Life Sciences and Department of Agronomy.

### Results and discussion

**Agronomic performance:** Not surprisingly, the type of biomass cropping system used significantly influenced yield in all years of the experiment. The Continuous Corn system yielded the most biomass across the initial three years, and cropping systems that contained corn as a component of the system had the highest yields in the year with corn (Soy-Triticale/Soy-Corn, Corn-Switchgrass). Triticale/Sorghum was the second highest-yielding system. It is important to note that tree biomass within the Aspen/Triticale system has not yet been factored into this comparison as overall biomass accumulation is still low in comparison to herbaceous crops, and the system did not reach a harvest cycle within the first three years of the experiment.

- While the Triticale/Sorghum treatment showed the second highest yields, it also was the most challenging cropping system to manage. Seasonal weather and a lack of appropriate herbicides affected the ability to manage this crop and attain greater yields.
- Using corn as a nurse crop was an effective way of establishing switchgrass across all landscape positions for both varieties planted, ‘Cave-In-Rock’ and ‘Kanlow.’
- This study reinforces previous research indicating that the ‘Crandon’ aspen clone is adaptable for a variety of topographic positions. In addition, low rates of fertilizer at planting can nearly double ‘Crandon’ productivity during the first three years after establishment. We found significant year and fertilizer effects both for total aboveground dry biomass and for branch fraction of biomass for the aspen trees.

**Environmental performance:** Baseline analysis of 11 soil parameters showed that soil quality differs substantially across landscape positions, including levels of soil aggregation and organic matter pools, thus impacting the potential for soil carbon storage in the future. Soil aggregation and soil organic matter have ramifications for both crop productivity and water quality in the long term. Because soils change slowly over time, assessing the influence of cropping system on soil quality was beyond the time frame of this grant.

As for water quality, systems with corn in the crop rotation had higher N03-N concentrations in root zone soil water, especially directly following fertilization. Concentrations consistently were above the standard for N03-N concentration in surface waters used as a source for drinking water and total in-stream nitrogen concentrations to prevent potential damage to aquatic ecosystems in the region. The
Triticale/Aspen system never experienced values above either of these standards and the switchgrass never had values above the drinking water source standard. Values associated with the other systems were variable, likely dependent on crop, weather and timing of fertilization.

**Economic performance:** Both the Continuous Corn and the Soy-Triticale/Soy-Corn systems are profitable at both $40/Mg/ha ($16.50t/ac) and at $80/Mg/ha ($33.00t/ac); the Triticale/Aspen (on a 10-year rotation) becomes profitable; and, at $120/Mg/ha ($49.50t/ac), the Corn-Switchgrass also becomes profitable. The Triticale/Aspen system is the most profitable under the high-price scenario $120/Mg/ha ($49.50t/ac), but biomass is not expected to draw these prices without substantial adjustments in energy markets.

- In the first three years of work, landscape position generally did not significantly influence the yield of herbaceous crops, although there was a significant cropping system by landscape position effect in 2011. Researchers found a year by landscape position effect on the establishment of aspen trees; trees in the floodplain position had the lowest biomass in the first year, but the highest biomass by the third year of the experiment.

- Regarding NO3-N concentrations in soil water, there were no overall annual landscape position effects on NO3-N concentrations. There also was no observed interaction between the cropping system and landscape position or landscape position and month of year, although the upper four landscape positions (summit, shoulder, backslope, and toeslope) had lower NO3-N concentrations than the floodplain positions in October 2010.

- Landscape position did have a significant impact on initial soil parameters, including levels of soil aggregation, organic matter pools, and potential for soil carbon storage in the future. Differences in soil parameters by landscape position are likely to manifest themselves more substantially with time; such as with a longer sequence of data or in drought years.

These biomass cropping systems proved to be productive, profitable, and mitigate the negative effects of annual crops on soil and water quality. The systems containing corn are profitable at current biomass prices of $40/Mg/ha ($16.50t/ac), but pose concerns for water quality. These concerns could be offset by varying cropping system with landscape position, and establishing one of the perennial systems—either Triticale/Aspen or Corn-Switchgrass—in downslope landscape positions. The Triticale/Aspen system appears to have the highest potential for mitigating water-quality concerns associated with corn and also is more profitable over a 10-year period. Farmers may have concerns with establishing woody systems or lack of access to woody biomass markets. In these cases, switchgrass may be a more acceptable choice.
Conclusions

In the short term, this work quantified the initial agronomic, economic and environmental impacts of establishing diverse biomass systems and compared them to a conventional corn system. Some initial research findings include:

- Baseline soil quality differs substantially across landscape positions, including levels of soil aggregation and organic matter pools, which can affect crop yield, water quality, and the potential for future soil carbon storage in the long term.
- Establishment of perennial crops including both switchgrass varieties (‘Cave-In-Rock’ and ‘Kanlow’) and the ‘Crandon’ aspen clone was successful across all landscape positions.
- Continuous Corn and other cropping systems containing corn experienced the highest biomass yield overall, but also were associated with the highest nitrate-nitrogen (N03-N) concentrations in the root zone; thus posing the largest potential threat to surface water quality.
- Triticale/Sorghum was the second highest yielding cropping system, but also posed the greatest challenges in terms of timely management with seasonal weather variation and weed pressure.
- Both Continuous Corn and Soy-Triticale/Soy-Corn systems are profitable at biomass prices of $40/Mg/ha ($16.50t/ac); Triticale/Aspen is profitable at $80/Mg/ha ($337/ac); and Corn-Switchgrass is profitable at $120/Mg/ha ($49.50t/ac). The Triticale/Aspen system is the most profitable under the high price scenario of $120/Mg/ha ($49.50t/ac), but this price for biomass is not expected without substantial adjustments in energy markets.

Impact of results

The objectives outlined in the original proposal were achieved. The price garnered by corn and soybeans skyrocketed over the course of this study, substantially affecting the profitability of biomass crops and farmer willingness to adopt alternative cropping systems, including all but the Continuous Corn system investigated here. The team sees three ways that the alternative systems studied could become more cost-competitive with the traditional commodity crops grown in Iowa:

1. boosting the yields of alternative biomass crops through substantially greater investment in variety development via plant breeding and transgenic approaches, and crop management;
2. creating more demand for alternative biomass crops through substantially greater and sustained investment in developing new markets for these crops, and
3. developing Payment for Ecosystem Service schemes (USAID 2007) to compensate farmers for environmental benefits associated with alternative biomass cropping systems.

In reality, it is likely that all three pathways will need to be pursued simultaneously for the ideals that inspired the Energy Independence and Security Act of 2007 to be realized in Iowa and beyond. By providing baseline quantitative understanding on the agronomic, economic and environmental performance of a portfolio of alternative biomass cropping systems, this work provides foundational knowledge for scientists, investors, policymakers and farmers wishing to pursue any or all of these pathways.
Education and outreach

The Landscape Biomass Project research and demonstration site is already being extensively used for educational purposes, including the education of students, farmers, individuals from the agribusiness and bioenergy industries, and the public on implementation, benefits and costs of diverse, site-appropriate biomass cropping systems. Important project accomplishments to date include:

• Establishment of a fully instrumented research and demonstration site;
• Successful collaboration among 13 departments, colleges, centers, and other units at Iowa State University and three federal research labs;
• Establishment of a 10-member Farmer Advisory Board;
• Training of 29 undergraduate student research assistants, 17 graduate students, and one postdoctoral fellow;
• More than 50 presentations to diverse audiences through numerous professional meetings, classroom, and web-based outlets; and
• Eight theses, dissertations, and scientific papers at various stages in the publication process.

Leveraged funds

More than $3.8 million of funding—representing a 41:1 return on the initial investment from the Leopold Center—was obtained to support project development, implementation and data collection. The project startup funds from the Leopold Center and ISU allowed the project researchers to leverage outside funding from the USDA National Institute for Food and Agriculture, U.S. Forest Service, National Science Foundation, and others, and expand beyond the initial objectives.