Precision Conservation Using Multiple Cellulosic Feedstocks

Final Report

September 1, 2007 - September 24, 2011

College of Agriculture and Biological Sciences
South Dakota Ag Experiment Station
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Executive Summary

The concept for this project was an outgrowth of a producer focus group meeting (9 January 2007) cosponsored by SDSU and SD Corn Growers Association. Participants identified concerns about sustainability of corn stover harvesting and the need for new approaches to meet the future demands of the bioenergy industry. The project was designed to demonstrate and evaluate precision conservation practices that integrate and compliment biomass production for cellulosic ethanol production from multiple feedstocks. Precision conservation applies conservation practices to local field zones to optimize protection of natural resources, sustain soil productivity, and protect ecological goods and services within the landscape. This project evaluated precision conservation practices on producer fields on typical landscapes found in Eastern South Dakota that are most likely to be involved in intensive biofuels production. Management practices involving multiple cellulosic feedstocks were evaluated at four sites located in MLRAs 102A , 102C, 55B, and 55C. Perennial grasses (e.g. switchgrass (*Panicum virgatum*) and prairie cordgrass (*Spartina pectinata*)) were evaluated for productivity and for impacts on soil quality in eroded landscapes. Corn (*Zea mays*) was also evaluated in parallel strips across landscape positions. Multiple symposiums, field tours, and media interviews were used to provide information about multi-cellulosic feedstocks applied to undulating landscapes. Twelve publications and technical guidelines have been generated and published as a result of this project thus far including two online comprehensive publications related to corn and switchgrass production.

This project demonstrated the advantages and disadvantages of growing perennial grasses with corn in landscapes with eroded soils and seasonal wetlands. While the productivity of corn is highest in well-drained upland landscape positions, the productivity of prairie cord grass is highest in wet locations within the landscape. Switchgrass could be ideally grown in landscape positions where past erosion has made it difficult to obtain good stands of corn and where there is significant potential from erosion. Comparisons of cultivated plots with a nearby prairie remnant benchmark showed that soil organic matter, wet aggregate stability, and other measures of soil quality experienced a sharp decline in soil quality since the beginning of cultivation more than 100 years ago. This project demonstrated that perennial grasses can slowly improve soil over time. In a relatively short period of time perennial grasses improved wet aggregate stability, often used as an early indicator of management impacts on soil quality. Perennial grasses such as switchgrass and mixed grasses-forbs dominated by big blue stem (*Andropogon gerardii*) were found to have less variability in production than corn grain across landscape positions. The results support the concept that perennial grass could provide a compatible feedstock with corn in areas where row crops have the most vulnerability to stress and erosion hazard. Implementation of this strategy requires a transition period of one to two years and this must be included in the planning process by the bioenergy industry, producers, and policymakers. The successful application of this strategy presumes an active and vibrant bioenergy feedstock market and a change in thinking about field orientation and logistics.

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Introduction

Biofuel processing plants will initially use corn stover and cobs as the cellulosic feedstock of choice. Over time other sources of cellulose will be used to develop drop-in fuels supplementing traditional fuels such as gasoline and diesel. Perennial grasses are promising future bioenergy feedstocks that could be used in the Northern Great Plains and the Upper Midwest with an added advantage of improving soil and water resources. Precision conservation applies conservation practices to fit the unique environmental and production challenges of local sites rather than relying on a one size fits all approach to conservation. Terrain characteristics in Eastern South Dakota change often over short distances. In this region it is not unusual to have wet lands and eroded soils in the same field along with highly productive farmland. Precision conservation provides an approach that can be used to optimize protection of natural resources, sustain soil productivity, and protect ecological goods and services within the landscape.

The goal of this project was to demonstrate and evaluate site-specific conservation practices that integrate production of multiple sources of cellulosic bioenergy feedstock with natural resource conservation. Specific objectives of the project were to: 1) apply precision conservation practices by using biomass crops (annual and perennial) that are chosen for their adaptation to, and conserving impacts on contrasting soil environments occurring in the farm unit; 2) demonstrate, evaluate, and develop soil management practices that include site-specific corn stover removal rates and management practices to protect the landscape from erosion and sedimentation, promote soil quality, and maintain a positive carbon balance; 3) develop site specific technical guidelines that can be incorporated into technical standards, fact sheets, and handbooks for NRCS personnel, extension educators, crop and environmental consultants, and producers.

This project demonstrated how a producer could incorporate a combination of crops (annual and perennial) for combined biofuel and feed production. Corn stover and switchgrass were grown together in alternating strips in four MLRAs (102A, 102C, 55B, and 55C) in Eastern South Dakota. These sites were used to gather information on the feasibility of growing annual and perennial crops concurrently within fields to maximize environmental and agronomic potential. Our project demonstrated advantages and challenges of using multiple feedstocks in an eroded landscape. These experiences and insights were shared with others through field tours and development of production guidelines for both corn and switchgrass. Additional feedstocks were used at our central demonstration site near Colman SD. These included mixed grass-forb plantings dominated by big blue stem, and prairie cordgrass for use in frequently flooded parts of the landscape. Biomass production and soil quality measurements were taken across three parts of an eroded landscape (summit, backslope, and footslope) in replicated strips. Residue removal treatments were included as part of the study to evaluate the immediate impacts of corn stover removal and grass harvest for biofuel production. A prairie remnant within two miles of the Colman SD site provided a benchmark comparison with long term cultivated land and for use in evaluating the potential for recovery of soil quality through perennial grass plantings on degraded parts of the landscape.

Project Activities

Project Implementation

Project activities began in the fall of 2007 with visits to potential study sites in MLRAs 55B, 55C, 102B and 102C. Site selections were confirmed in the spring of 2008. Agreements with producer collaborators were made for land use and management at 4 sites (Warner, SD (MLRA 55B), Woonsocket, SD (MLRA 55C), Flandreau, SD (MLRA 102B), and Colman, SD (MLRA 102C) (Figure 1). Each site was surveyed with a survey grade GPS and mapped for topography and past erosion. Plot plans and location maps are given in Appendix A. Corn, switchgrass, and prairie cordgrass were planted at all four sites. Four randomized replications were established with the exception of Colman where six replications were established. At Colman an additional treatment of mixed native prairie grasses and forbs was included in the study. This mix included 90% big bluestem, and five other grasses (switchgrass, indian grass, little bluestem, sideoats grama, and Canadian wild rye). Forbs in the mixture included maximilian sunflower, purple coneflower, prairie coneflower, purple prairie clover, sawtooth sunflower, and Canadian milk vetch. All sites include three landscape positions. Plots were laid out in strips that ran approximately perpendicular to the general contour of the land. Each management strip (main plots) was split into residue removal sub-plots. Baseline measurements of soils were made at all sites and weather stations were established at two primary sites (Flandreau and Colman). A third weather station was later added to the Warner site.

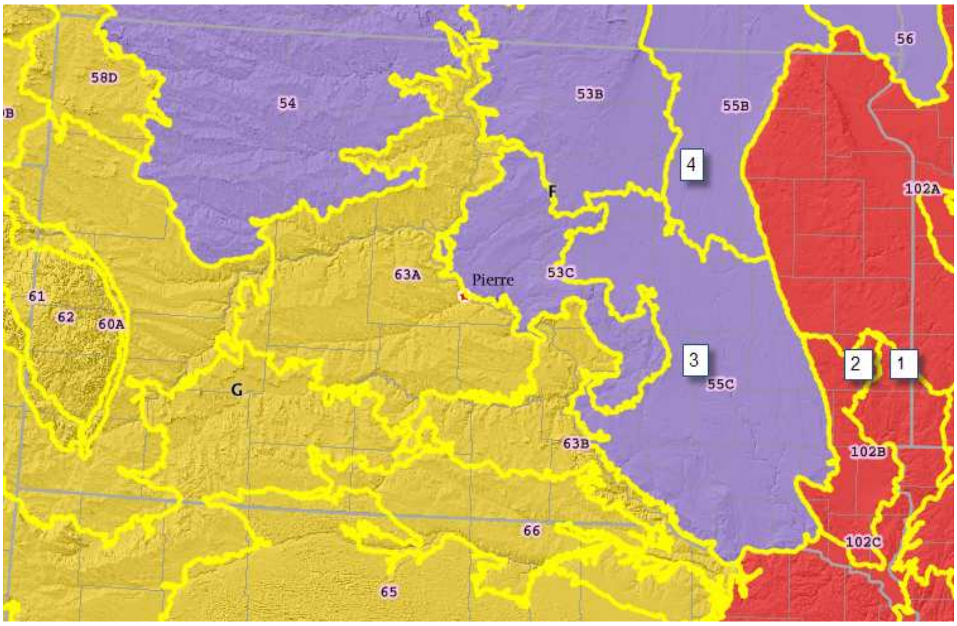

Figure 1. Map of MLRAs in South Dakota showing location of CIG demonstration sites. 1. Flandreau site (MLRA 102C), 2. Colman site (MLRA 102B), 3. Woonsocket site (MLRA 55C), 4. Warner site (MLRA 55B).

Evaluation of the sites included biomass and grain yield measurements, and basic soil quality measurements such as wet aggregate stability. The Colman and Flandreau sites were the subject of more intensive evaluations that included evaluation of soil organic matter and carbon, field water content and ET measurements (Flandreau site), and more detailed soil quality measurements including aggregate wettability, pore size evaluations (tension infiltration) (Flandreau site), particulate organic matter, and microbial hydrolytic activity. Measurement of a prairie remnant benchmark for soil quality and soil organic matter was also made at the Colman site.

Harvest of biomass for yield estimates was conducted using small plot collection procedures on well-defined plot locations by landscape position. However stover removal and perennial grass harvest was conducted across entire treatment strips using commercial scale equipment (Figure 2).

Figure 2. Harvesting corn stover for residue treatments at the Flandreau site.

A biofuel advisory group was established in the fall of 2007 with the first meeting in January 2008. Agronomic educators were included in the advisory committee and served as liaisons between landowner cooperators and University researchers. Educators were also involved in monitoring plots throughout the life of the project. Other members of the advisory group included NRCS personnel, commodity group representatives including CIG grant partner SD Corn Growers Association (http://www.sdcorn.org), key administrators, interested producers, and the nonprofit Ecosun Prairie Farms, Inc. (http://ecosunprairiefarms.org/). The advisory group considered information and offered input on the CIG project and other biofuel projects that were related to the CIG project. The purpose of the advisory meetings were to provide information on the progress of projects, provide input on strengths and weaknesses of projects, coordinate activities occurring between research and demonstration projects, and to brainstorm on future activities and research needed in the area of biofuel feedstock production. Due to the time commitment needed for advisory group meetings it was determined that annual rather than semi-annual meetings would be more appropriate. Advisory meetings were held in the first quarter of each year of the project.

After three project years (2007-2010) a 12 month no-cost extension was requested to collect an additional year of data. The first two years of the project were required for grass stand establishment and development. The inclusion of an additional year resulted in two years of biomass production data that reflected the higher yields associated with mature stands of grass and allowed for a more realistic economic projection over the life of a perennial grass stand (>20 years).

Technology Transfer

Symposium events, advisory meetings, and field tours were an integral part of project activities. An annual symposium and field tour highlighted research at our main production sites in 2009, 2010, and 2011. Project concepts and results were also given at local meetings, in press releases, and in media interviews (magazine and radio) during the lifetime of the project.

<u>2009 Symposium</u>

The program for the 2009 symposium and field tour, September 19, 2009 is given in Appendix B. The symposium was titled: "Agriculture for a Changing Environment, A Guided Tour of Selected SDSU Research Sites in Eastern South Dakota". State and Federal government officials, biofuel industry representatives, researchers, producers, SDSU staff and administration, and alternative energy industry representatives participated and attended this symposium and tour. Topics of discussion focused on discussions of carbon and energy enterprise and research in agriculture. The USDA-CIG project was highlighted in the afternoon field tour. Individuals from USDA-NRCS, SD Corn Utilization Council, representatives from the wind and biofuels industry, cooperating producers, SD State Government, Conservation Districts, and collaborating researchers were invited to attend.

There was an exceptional level of audience participation and interaction at this symposium. Presentations given by biofuel industry representatives provided a better understanding of supply chain and efficiency challenges and how results from this and other research could contribute to overcoming these and future challenges. Inclusion of wind energy representatives provided an interesting discussion on how alternative energy producers may cooperate to achieve common goals for energy independence.

The morning symposium was opened by Dr. Don Marshall, acting Dean of the College of Agriculture and Biological Sciences, South Dakota State University. Kelly Nichols (sub. for Jim Nichols) presented an overview of the Midwest Center for Wind Energy, challenges of wind energy production, and a tour of a wind turbine he jointly owns and operates. Mike Roth (POET) presented an overview of the biomass supply chain for ethanol production critical for POET to continue ethanol production. Mr. Roth presented an overview of current on-going research conducted by POET and the direction their company is taking to improve ethanol production efficiency. Brian Stork, CEO of Hanson County Oil Producers (biodiesel producer) presented an overview of the approach their company is taking in efficiently producing biodiesel. Dr. C. Gregg Carlson (SDSU Plant Science) provided an overview of the potential to use stranded electricity to produce nitrogen fertilizer. Dr. Carlson explained that during off-peak periods, electricity produced from wind turbines and hydroelectric plants goes unused, becoming stranded. This electricity could be used to produce hydrogen gas from water instead of natural gas to produce ammonia, the base for all nitrogen fertilizer. Dr. Tagir Gilmanov presented an overview of tower flux measurements of CO_2 exchange, methods and results of research conducted at the SD Opportunities Farm near Lennox SD. An additional tower has been installed and is currently operating at a research site near Bristol SD where CO_2 exchange is being measured in a switchgrass monoculture. Mr. Jeff Hemenway presented an overview of the Conservation Innovation Grants (CIG) and Conservation Stewardship (CSP) programs. Among the items of interest was the ability of producers cooperating in selected types of research to earn additional points used in eligibility ranking for participation in the CSP. There were lively discussions during and after the presentations with participation of nearly all who attended.

Industry, government, and researchers agreed that sustainability and improved productivity are important to success and that precision conservation offers multi-faceted benefits. Attendance numbers (36) were impacted by weather patterns as cool wet conditions transitioned to favorable conditions for field operations at the time of the meeting reducing the number of producers who were able to attend the meeting.

The afternoon consisted of guided tours of the CIG project research sites located near Flandreau and Colman SD. Dr. Tom Schumacher (SDSU Plant Science) acted as the guide which included several speakers. Mr. Brian Scott (SD Dept. of Agriculture) provided an overview of the Feedlot Renovation Project he is involved in during the trip from the Midwest Center for Wind Energy to Flandreau. Overviews of research and demonstration conducted at the Flandreau and Colman sites were presented by Dr. Schumacher with Dr. Todd Trooien (SDSU Ag & Biosystems Engineering) presenting focused information on water use of corn and switchgrass gained from research conducted at the Flandreau CIG site. The tour continued to EcoSun Farms near Colman where Dr. Schumacher (sub. Dr. Carter Johnson) provided an overview of the goals and purpose of EcoSun Farms. Dr. Vance Owens and Dr. Arvid Boe presented information and demonstrated switchgrass and prairie cordgrass production and grass cultivar development respectively for potential biofuel feedstocks.

Figure 3. Dr. Kevin Kephart, Vice President for Research at South Dakota State University, commenting on the prospects for biofuel production at the 2009 CIG project field tour.

<u>2010 Symposium and Tour</u>

On August 16th, 2010 a field tour was held at the Colman site. The tour was attended by 57 individuals representing federal, state, and local government, Congressional Representatives, SD & MN Cooperative Extension Service, and private farming operations. The tour provided examples and information for production alternatives for maintaining productivity and soil quality in extreme conditions. See attached agenda (Appendix C) for more information.

Figure 4. Dr. Carter Johnson discussing switchgrass and mixed grass-forb management to 2010 field tour participants.

Figure 5. Dr. Gregg Carlson presenting information about the ethanol biofuels industry at the 2010 symposium sponsored by the CIG project. Mixed grass-forb bales are in the background.

2011 Field Tours

Two field events were given in 2011 using funds from collaborating projects and conference fees (Ecosun Prairie Farms field day, July 15, 2011 and a field tour as part of the America's Grasslands: Status, Threats and Opportunities Conference held in Sioux Falls, SD, August 15, 2011). The CIG research plots at the Colman SD site were included as part of the tours with presentations highlighting results of the project and illustrating the concept of multicellulosic feedstocks for conservation and production.

Additionally numerous one-on-one and small group tours of the CIG demonstration and research plots were given throughout the growing seasons of 2010 and 2011.

Conference Presentations

Project results were highlighted at several conferences during 2008-2011. This included participation in the CIG showcase at annual SWCS meetings in 2008, 2010, and 2011. A list of presentations made at national conferences is given below.

Eynard, A and Schumacher,T.E. 2011. A rapid, cost-effective, and greener FDA method for soil quality analysis. Soil Carbon Sequestration Conference Abstracts, University of Guam, Mangilao, Guam, August 2011.

Eynard, A , Schumacher, T.E., and Kohl, R.A 2011. Soil Polysaccharide Measurements in the Evaluation of Soil Quality for Multifunctional Agriculture. Soil Carbon Sequestration Conference Abstracts, University of Guam, Mangilao, Guam, August 2011.

Clay., D.E., T. Schumacher, S.A. Clay, and V. Owens. 2009. The agronomic and environmental cost of removing corn stover. Symposium: The environmental and ecological challenges of biomass production. Abstract 2009.51901 American Society Agronomy National Meetings, Pittsburg PA, Nov 1-5, 2009

Heimerl, R.K., Schumacher, T.E., Schumacher, J.A, Johnson, W.C. 2011. Spatial comparison of soil properties between native prairie and restored agricultural land. SWCS Annual Conference Abstracts, Washington D.C., July2011.

Owens, V., C.Hong, S. Osborne, T. Schumacher,and D. Clay. 2010. Environmental Impact of Growing Herbaceous Perennials for Bioenergy Abstract 2010.57726, Agronomy Society National Meetings, Long Beach, CA, Oct.31 - Nov. 3, 2010

Riedell, W.E., S.L. Osborne, T.E. Schumacher, J.L. Pikul Jr. 2010. Native Grassland Management effects on Biomass Production and Soil C Sequestration. Soil and Water Conservation Society 65th International Annual Conference Abstracts, St. Louis, MO, July18-21, 2010

Reitsma, K.D., T.E. Schumacher, D.E. Clay, C.O. Hong, C.G. Carlson, D.D. Malo, T. Trooien, L. Janssen, G. Warman, A. Boe, V.N. Owens, P.O. Johnson, G. Erickson, and I. Graves. Cellulosic Feedstock Productions in Fields of Complex Topography. Annual International Meeting, Soil and Water Conservation Society. St. Louis MO. July 21, 2010.

Schumacher, T.E., Eynard, A, Heimerl, R.K., Reitsma, K.D., Schumacher, J.A, Clay, D.E., Osborne ,S.L., Stetson, S. and Papiernik, S.K. 2011. Management Impacts on Biologically Active Carbon within Eroded Landscapes. Soil Carbon Sequestration Conference Abstracts, University of Guam, Mangilao, Guam, August 2011.

Schumacher, T.E., Skiles, P., Clay, D., Carlson, G., Malo, D.D., Trooien, T, Warman, G., Boe, A., and Owens, V. 2008. Precision Conservation Using Multiple Cellulosic Feedstocks. 2008 SWCS Annual Conference (Tucson, AZ) Abstract Book page 115.

Vahyala, I.E., Schumacher, T.E. and Osborne, S. 2011.Soil Structure Changes In Bioenergy Crop Residue Management Systems.2011 ASA-CSSA-SSSA Conference Abstracts, San Antonio Texas, October 2011.

Publications

The results of the project were highlighted in a number of extension publications and peer reviewed publications. An MS thesis and a PhD dissertation were based in part on studies conducted on CIG demonstration and research plots.

Carlson, C.G., D.E. Clay, C. Wright, and K.D. Reitsma. 2010. *Ethanol Production can Have a Neutral Impact on Food Production*. ExEx8165. South Dakota State University, South Dakota Cooperative Extension Service Brookings SD.

Clay, D.E., K.D. Reitsma, S.A. Clay (eds.), 2009. "Best Management Practices for Corn Production in South Dakota. EC929". South Dakota State University, SD Cooperative Extension Service. http://pubstorage.sdstate.edu/AgBio_Publications/articles/EC929.pdf *Selected as 2010 Outstanding Agronomic Educational Material (>16 pages). American Society of Agronomy.

Heimerl, R.K. 2011. Comparisons of Soil within a Till Plain across Contrasting Land Uses. MS Thesis. South Dakota State University.

Reitsma, K.D. and D.L. Deneke. 2011. "The Role of Rotation in Cropping Systems Management" in Alternative Practices for Agronomic Nutrient and Pest Management for South Dakota. D.L. Deneke (ed.). pp. 45 -56. South Dakota State University and South Dakota Department of Agriculture.

Reitsma, K.D., R Gelderman, P. Skiles, K. Alverson, J. Hemenway, H.J. Woodard, T.E. Schumacher, D.D. Malo, and D.E. Clay. 2008. Nitrogen Best Management Practices for Corn in South Dakota. FS 941. SDAES. SDSU. Brookings. 57007.

Reitsma, K.D., R. K. Heimerl, and T.E. Schumacher. 2011. Estimating Soil Productivity and Energy Efficiency Using the USDA Websoil Survey, Soil Productivity Index Calculator, and Biofuel Energy Systems Simulator. Pp. 425 – 443, In Clay, D.E. and J. F. Shanahan (eds.) GIS Applications in Agriculture; Nutrient Management for Improved Energy Efficiency. CRC Press, Boca Raton.

Reitsma, K.D., and Malo D.D. 2011. Integration of USDA-NRCS Web Soil Survey and Site Collected Data. Pp. 81 –98, In Clay, D.E. and J. F. Shanahan (eds.) GIS Applications in Agriculture Vol II; Nutrient Management for Improved Energy Efficiency. CRC Press, Boca Raton.

Reitsma, K.D., T.E. Schumacher, V.N. Owens, D.E. Clay, A. Boe, and P.J. Johnson. 2011. "Switchgrass Management and Production in South Dakota" IGrow, South Dakota State University Extension. http://igrow.org/up/resources/03-2006-2011.pdf

Reitsma, K.D., T.E. Schumacher, and D.E. Clay. 2011. "Soil Quality" in Alternative Practices for Agronomic Nutrient and Pest Management for South Dakota. D.L. Deneke (ed.). pp. 9 -16. South Dakota State University and South Dakota Department of Agriculture.

Schumacher, J.A., S.K. Papiernik, T.E. Schumacher, and K.D. Reitsma, in-press. Identifying Conservation Hotspots Using Tillage Erosion Modeling. , In Mueller, T.E. and G. Sassenrath (eds.) GIS Applications in Agriculture; Soil Conservation. CRC Press, Boca Raton.

Vahyala, I.E. 2011. Soil Structure Changes in Bioenergy Crop Management Systems. Ph.D. Dissertation, South Dakota State University.

Funding Received and Expended

Funds Received from USDA-NRCS –CIG: $493,109

Funds Received for Match from South Dakota State University: $494,087

Funds Expended:

Table 1. Project Expenses

Category	NRCS	South Dakota State Univ	Total
Salary & Fringe Benefits	$294,140	$347,949	$642,089
Travel	23,167	0	23,167
Supplies & Contractual	97,028	0	97,028
Tuition Remission/Stipend	4,809	0	4,809
Indirect	73,966	146,138	220,104
Total	$493,109	$494,087	$987,196

Results

Site Descriptions and Resources:

Four unique sites representative of South Dakota were used in the project. The site representing MLRA 55B was located near Warner SD (98^{O} 32’ 54” W, 45^{O} 16’ 21” N; SW1/4, Section 21, T121N, R64W of 5th principle meridian, Brown County, SD). Approximately 75% of the land in MLRA 55B is used for cropland. Annual precipitation is around 13.5 inches. The principal soils at the demonstration site have natric horizons (soils high in sodium content) that limit productivity. This site was also next to a stream with the lower portions of the plot subject to annual flooding events. (Additional detailed information about the climate, physiography and soils of this site are included in Appendix C).

The site representing MLRA 55C was located close to Woonsocket SD (98.288588^{O} W, 43. 922722^{O} N; NW1/4, Section 9, T105N, R62W of 5th principle meridian, Sanborn County, SD). Close to 58% of the land in MLRA 55C is used for cropland. The area is imperfectly drained and has poorly defined drainage ways and wetlands. The region receives about 21.5 inches of precipitation annually. In contrast to the Warner plots the soils at this site are coarser and have low water holding capacities. (Additional information about the resources at this site are given in Appendix C).

More intensive observations were made at the other two sites including MLRA 102B and MLRA 102C. The plots representing MLRA 102B were located near Flandreau, SD (96^{O} 36’ 37.77” W, 44^{O} 4’ 47.73” N; NE1/4, Section 17, T107N, R48W of 5th principle meridian, Moody County, SD). Seventy one percent of the land in MLRA 102B is used for cropland and receives annually 22 inches of precipitation. The Big Sioux River is less than one half mile from the plot area. The site has rolling land with drainage ways and associated wetlands. The site includes highly productive soils used in crop production as well as soils with wetness and annual flooding issues that result in poor productivity. The plot areas on this site included replications that contained both the poorer and higher productive soils associated with this region. (Additional information about the resources at this site are given in Appendix C).

The MLRA 102C site at Colman SD (96^{O} 50’ 37.878” W, 44^{O} 1’ 23.139” N; SW1/4, Section 33, T107N, R50W of 5th principle meridian, Moody County, SD) included a mixed grass-forb big blue stem dominated treatment in addition to switchgrass and corn strips. Additionally prairie cordgrass was planted into formerly farmed seasonal wetlands as part of the demonstration. Approximately 74 % of the land area in MLRA 102C is used for cropland. The region is characterized by a large number of small potholes. Annual precipitation is at 22 inches. This site had six replications. Four of the replications included the relative productive Wentworth and Egan upland soils while two replications included the relatively lower producing Dempster and Talmo soils with lower water holding capacities. The lower parts of the landscape are dominated by poorly drained Worthing and Baltic soils that are often associated with spring flooding and seasonal wetlands. (More information about the resources at this site are found in Appendix C).

Feedstock Production:

Biomass Yields

Based on a combination of locations and years, landscape position affected total biomass only 2 of 14 times. In 2010, the footslope position at Warner was completely flooded due to above average precipitation, and yield of both switchgrass and corn at this position was 0 Mg ha^{-1}, while no difference was noted between the other two landscape positions. The summit had higher yields than either backslope or the footslope at Flandreau in 2010. There was a landscape position X residue treatment interaction in two location-years but the effects were not consistent. At Colman, biomass generally declined with residue removal except at the footslope position, but uneven flooding at the base of the slope was likely the cause. On the other hand, biomass tended to be higher with residue maintenance at Flandreau.

Species had the greatest effect on yield and was significant in 11 of 13 location-year combinations. Approximately 75% (Flandreau, Woonsocket) to 80% (Colman, Warner) of the corn stover was removed from the field after grain harvest. Based on this removal rate, corn stover yields were always greater than warm-season grass mixtures at Colman and greater than switchgrass at all location-year combinations except Colman in 2011 and Flandreau in 2010. Colman was the only location where both switchgrass monocultures and warm-season grass mixtures were compared with each other and with corn. Production of switchgrass and warm-season grass mixtures was similar during the seeding year (2008), but switchgrass yield was higher than grass mixtures each year thereafter. In other work in South Dakota and Minnesota, switchgrass monocultures, or mixtures in which switchgrass comprised one-third or one-half of the seeding mix, were higher yielding than monoculture stands of big bluestem and indiangrass or their two-way mix (Owens unpublished data). Biomass yields for 2011 and 2010 are given in Tables 2 and 3.

Table 2. Biomass yields from 2011. (SU = summit; BS = backslope; FS = footslope)

	Corn			Switchgrass			Mixed Grass - Forbes		
Location	SU	BS	FS	SU	BS	FS	SU	BS	FS
	----Mg ha^{-1}----			----Mg ha^{-1}----			----Mg ha^{-1}----		
Colman	7.0 ab	7.3 a	5.3 ab	5.1 b	7.8 a	6.4 ab	4.3 b	5.8 ab	5.3 ab
Flandreau	NA	NA	NA	7.3 b	8.8 a	7.7 ab	NA	NA	NA

Means within a row with similar letters are not significantly different (Tukey's HSD $P \leq 0.05$)

Table 3. Biomass yields from 2010. In 2010 a landscape by crop interaction was only observed in Flandreau. Crop means for Colman were 7.0 a, 5.8 b, and 3.6 c Mg ha^{-1} for corn, switchgrass, and mixed-grass forbs, respectively. (SU = summit; BS = backslope; FS = footslope)

	Corn			Switchgrass			Mixed Grass - Forbes		
Location	SU	BS	FS	SU	BS	FS	SU	BS	FS
	----Mg ha^{-1}----			----Mg ha^{-1}----			----Mg ha^{-1}----		
Colman	7.2	7.5	6.2	5.2	6.5	5.6	3.3	4.4	3.1
Flandreau	9.0 a	6.1 ab	3.8 b	5.5 ab	4.8 b	6.4 b	NA	NA	NA
Warner	7.3 a	7.2 a	0	5.4 b	5.4 b	0	NA	NA	NA
Woonsocket	7.3 a	6.2 a	6.3 a	4.3 b	3.5 b	3.4 b	NA	NA	NA

Means within a row with similar letters are not significantly different (Tukey's HSD $P \leq 0.05$)

While corn stover biomass production remained relatively constant across years at each location, biomass from switchgrass and warm-season grass mixtures increased each year after establishment (Fig. 6). In other work, we have seen an increase in production from both monoculture switchgrass and mixtures of native grasses after the establishment year. It is common for these native grasses to take up to three years to fully establish and achieve optimum yield capabilities.

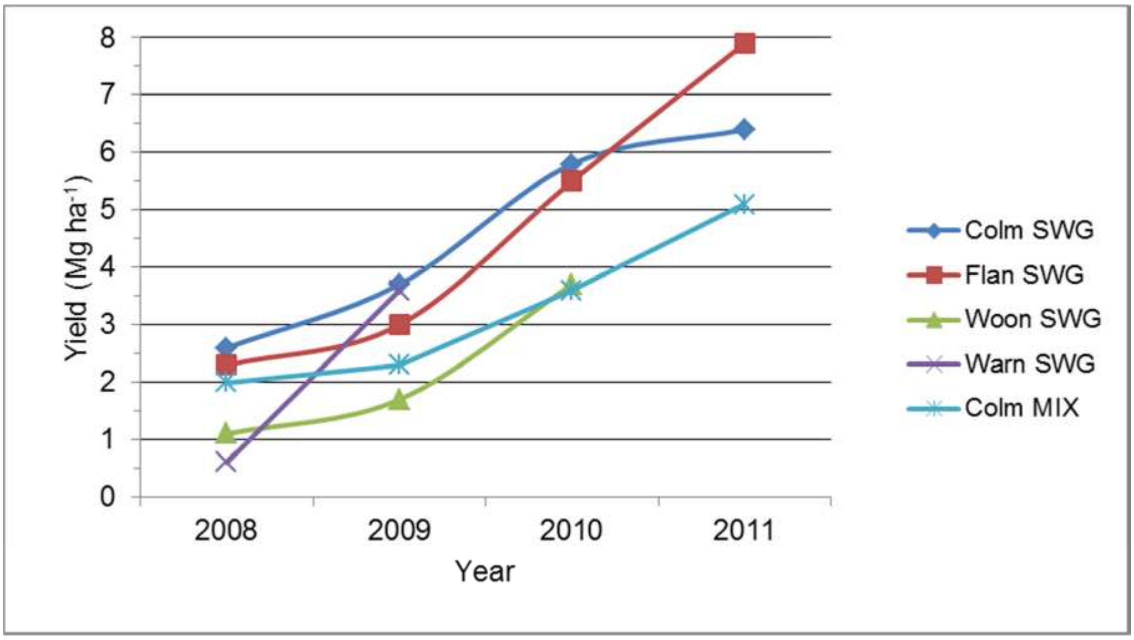

Figure 6. Progression of perennial grass biomass yields over time from the establishment year until the conclusion of the project averaged over landscape positions and residue management treatments. (Colm = Colman site; Flan = Flandreau site; Woon = Woonsocket site; Warn = Warner site).

Corn Grain Yield

In general corn grain yields were more sensitive to landscape position than perennial grass yields. This was in particular observed in the lower landscape positions when temporary flooding or saturated soils conditions occurred in the spring. In these cases there was a distinct landscape position effect. At Colman two of the replications were in particular prone to flooding. Figures 7 and 8 illustrate the impact of temporary spring flooding on corn grain development and subsequent grain yields at the Colman site.

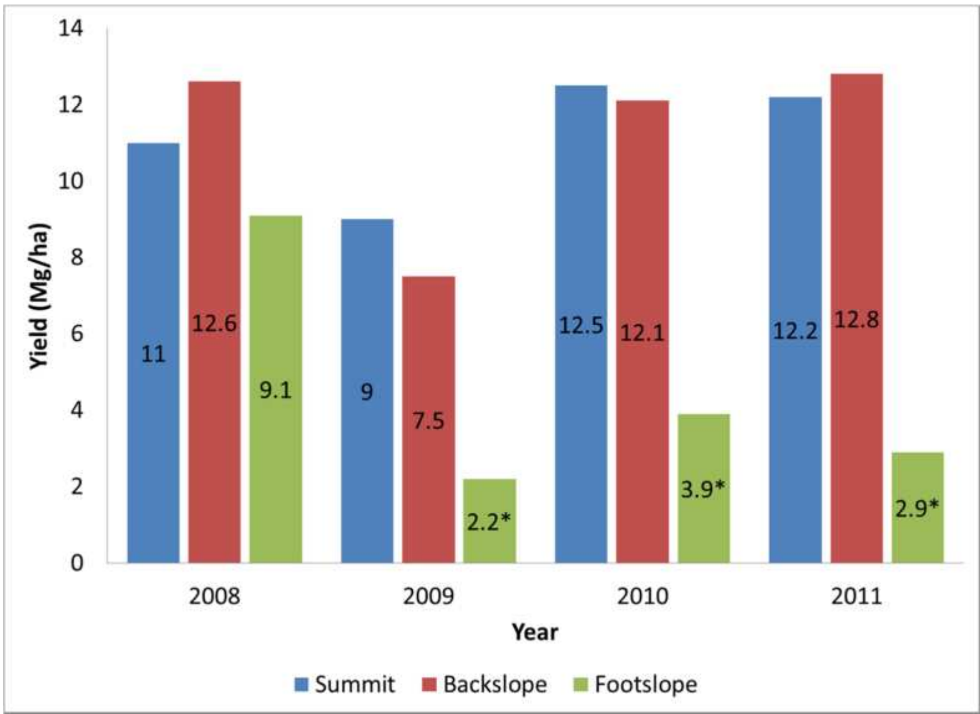

Figure 7. Corn grain yields (15.5% moisture) by landscape position on flooded replications at the Colman site. The asterisk represents a significantly lower yield within a given year (Tukey's HSD $P \leq 0.05$).

Grain yields were not reduced significantly at replications and sites where temporary flooding was not observed although there was a trend to lower yields in the wetter landscape positions at most sites. Generally flooding had a proportionately greater impact on corn grain yield than biomass yields. It should be noted that in most cases the reduced grain yields were not related to lower plant populations if corn emerged. Due to logistics our yield measurements generally excluded the worst case scenarios where corn did not emerge or where planting could not occur because of standing water or saturated soil conditions. There was often a delay in planting the plots due to wetness in the foot/toe slope positions. The impact of this delay is not accounted for in our grain yield measurements.

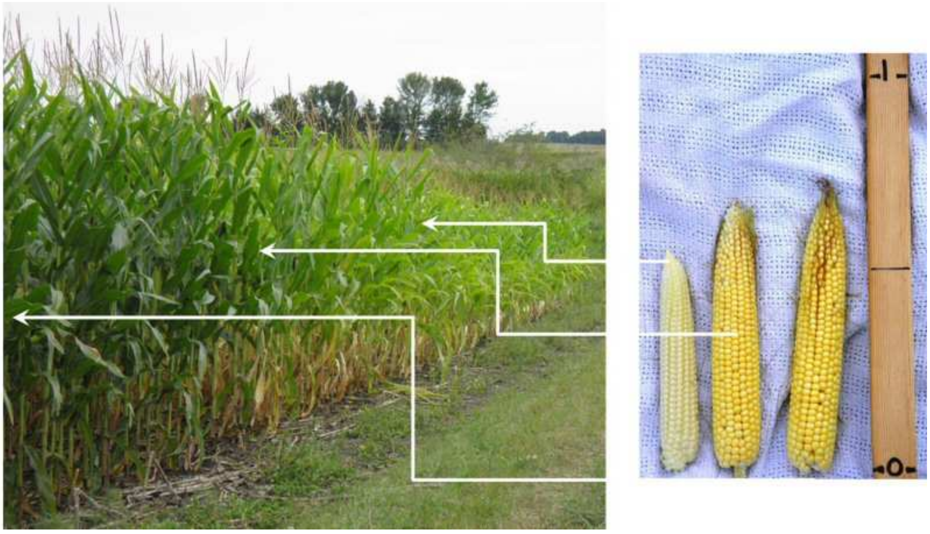

Figure 8. Illustration of the effects of spring flooding on the foot/toe slope region of the CIG plots for corn development. Corn grain yields were most affected by flooding. Grass biomass yields tended to be more stable across landscape positions.

Residue removal had little to no effect on grain yield. This is not surprising given the relatively short duration of the study. However visual observations of increased weed emergence were noted on treatments where the corn stover was removed. Figure 9 illustrates the appearance of residue removal plots after corn planting in June (removal plot in the center of photo). Also one can easily see where grass was harvested the previous fall.

Figure 9. Residue removal treatment (center) immediately after planting at Colman SD. Far right half of the corn plot is the residue maintained treatment.

Prairie Cordgrass Establishment and Biomass Production

Significant differences were found among landscape positions and between species for biomass production along an environmental gradient near Colman, SD. Biomass production increased from the shoulder to the swale positions (Table 4). Plots containing prairie cordgrass produced more biomass than adjacent plots composed of only switchgrass. However, the density of the stand of prairie cordgrass was highly variable along the gradient and appeared to be unrelated to landscape position. The samples taken for this study were only in those regions where cordgrass had established. The range in the contribution of prairie cordgrass to total biomass in the area which it had been planted, based on a visual assessment, was from 20% to 100%, with a mean of 75%. Biomass data for prairie cordgrass were not collected from the other three locations (i.e., Flandreau, Warner, and Woonsocket) because of heavy mortality in prairie cordgrass due to sensitivity to herbicides used to promote the establishment of switchgrass where the seeded switchgrass plots overlapped with the transects of transplanted prairie cordgrass.

Table 4. Effect of landscape position on prairie cordgrass and switchgrass biomass production along an environmental gradient near Colman, SD in 2011.

Effect	**Mg dry matter per hectare**
Landscape position	
Shoulder	5.9a†
Backslope	10.1b
Swale	13.0c
Species	
Prairie cordgrass	11.9a
Switchgrass	7.5b

†Means within effects followed by different letter are significantly different by LSD (0.05).

No differences were found between years, between wetlands, or between plant spacing (0.9 vs. 1.5 m spacing) for biomass production of prairie cordgrass in October of 2010 and 2011. Overall, biomass production exceeded 12.5 Mg of dry matter per hectare. This experiment demonstrated that transplanting seedlings in the spring was a highly effective method for establishing prairie cordgrass in cropland depressions that had a long history of conventional tillage and annual row-crop production. It also showed no advantage of the narrow spacing over the wide spacing for biomass production. This was important because stand establishment could be done quicker and with fewer plants using the wider spacing. The ability of prairie cordgrass to spread rapidly in to unoccupied interstitial spaces by rhizomes over a period of two years was evident (Table 5).

Table 5. Effects of year, wetland, and plant spacing on means of biomass production of prairie cordgrass near Colman, SD. Standard errors are given in parentheses.

Effect	Mg dry matter per hectare
Year	
2010	12.0 (0.6)
2011	13.3 (0.7)
Wetland	
#1	12.9 (0.6)
#2	12.4 (0.6)
Spacing	
0.9 m	13.3 (0.6)
1.5 m	12.0 (0.6)
Grand mean	12.7 (0.4)

Other methods for establishing prairie cordgrass in seasonal wetlands/cropland depressions investigated were a wide spacing (3.0-m) transplant method and seeding with a drill designed for establishing grasses in no-till environments. The planting rate for the seeded plots was about 4 kg per hectare and the row spacing was 20 cm.

Table 6. Effect of transplant and seeding methods on the means and standard errors for 2011 prairie cordgrass biomass production.

Establishment method	Mg dry matter per hectare
Wide-spacing transplant in 2009	13.2 (1.0)
Early spring seeding in 2010	14.7 (1.4)
Late fall seeding in 2009	13.0 (0.8)

The wide spacing transplant and seeding methods were highly effective for establishing high biomass yielding monocultures of prairie cordgrass (Table 6). The successful establishment from both spring and fall (i.e., dormant) plantings indicated flexibility for timing of seeding, which is important because of the unpredictability of water levels in seasonal wetlands, particularly in the spring.

Soil Quality:

Benchmark Comparisons

Soil quality measurements were used as an early indicator of management induced changes in soil functioning. Early indicators of changes in soil performance in productivity and ecological functioning include measurements of particulate organic matter, aggregate wettability, and wet aggregate stability. An opportunity for establishing benchmarks for these values existed at the Colman site. A prairie remnant managed by the Nature Conservancy with similar soils and topography compared to the CIG plots was located within 2 km of the demonstration site.

Figure 10 describes the location of samples collected in 2010 for establishment of benchmarks from the CIG plots. A matched location was sampled at the Sioux Prairie site (no history of cultivation).

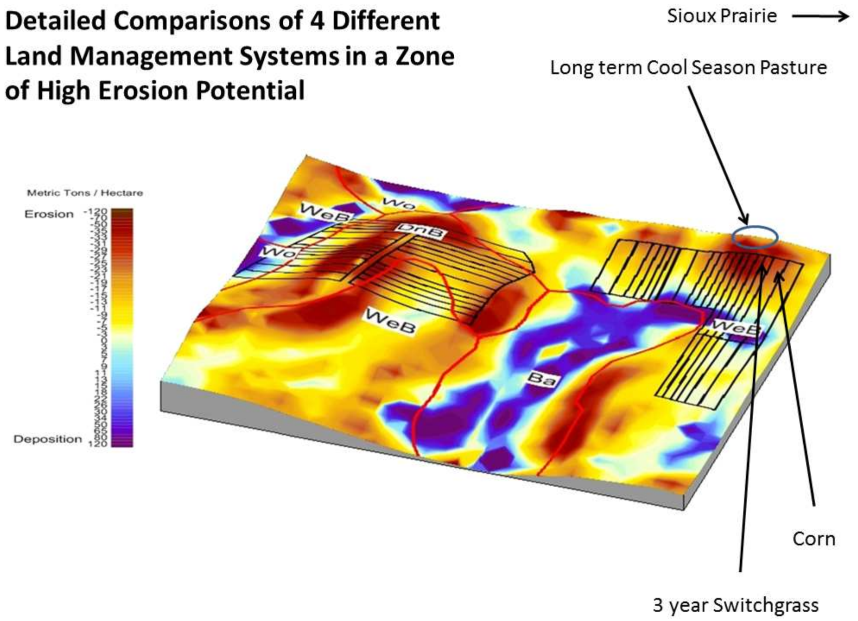

Figure 10. A map of the CIG Colman demonstration site showing severely eroded zones (red areas) and the location of samples collected for benchmark analysis. A site with similar soil and topography was sampled on the Sioux Prairie, a prairie remnant within 2 km of the site.

Particulate and soil organic matter fractions in the top 15 cm were highest in the prairie remnant benchmark (Fig. 11). The comparison with the long term cultivated sites indicated a 50% reduction in organic matter has occurred since cultivation commenced at the site 100-120 years ago. The effect of three years of switchgrass on soil organic matter levels is not yet apparent at the CIG demonstration site.

Aggregate wettability is related to the internal physical structure, chemical makeup, and stability of the aggregate. Wettability is often related to soil organic matter content. The prairie remnant benchmark and the long term pasture both had significantly greater water uptake rates than the long term cultivated sites (Fig. 12). Sometimes wettability is increased under conditions of low aggregate stability so this measure must be interpreted in conjunction with wet aggregate stability measurements.

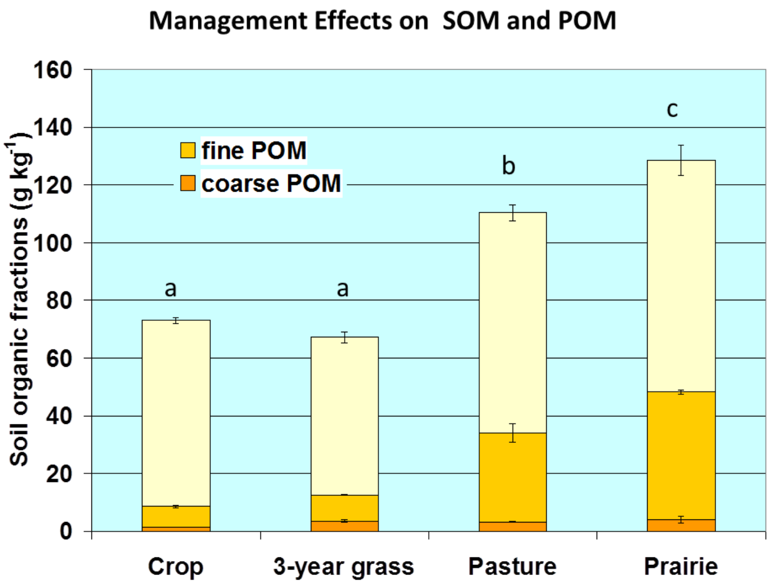

Figure 11. Particulate organic matter fractions of soil organic matter benchmarks for the prairie remnant compared to long term cultivated sites. Sample sites were similar in all aspects except for cropping history. (LSD $P \leq 0.05$)

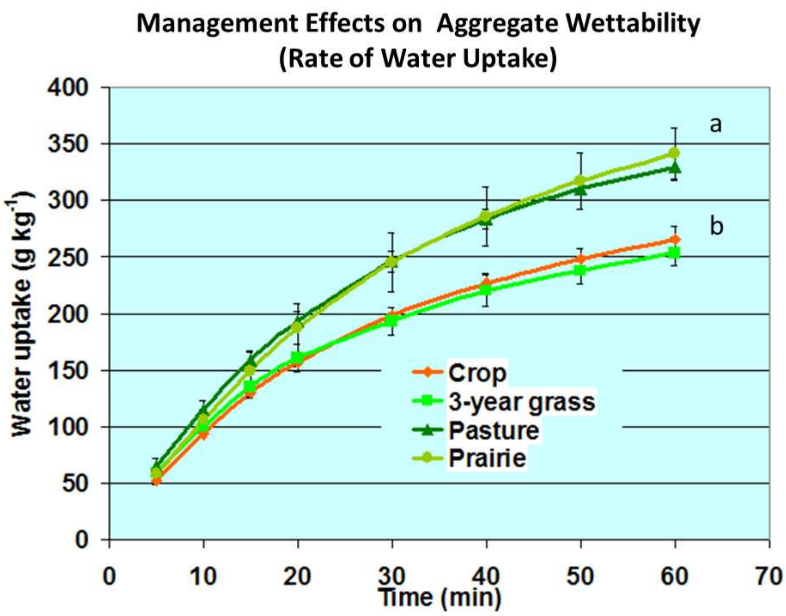

Figure 12. Aggregate wettability benchmarks for the prairie remnant compared to long term cultivated sites. Sample sites were similar in all aspects except for cropping history. (LSD $P \leq 0.05$)

Wet aggregate stability measurements were much higher in the prairie remnant than the cultivated sites (Figure 13). The long term pasture immediately adjacent to the CIG demonstration plots had similar aggregate stability values. The aggregate stability measurements for the long term annual cropped land were lower by almost three times compared to the prairie remnant and long term pasture. Interestingly, the switchgrass treatment in the CIG plots shows an increase in wet aggregate stability relative to the corn treatment (representing a history of at least 100 years of annual cropping). This indicates that positive effects of growing switchgrass on degraded soils can be observed in a relatively short time period. A relative difference in aggregate stability between management systems is often the first indication that management is improving soil functions.

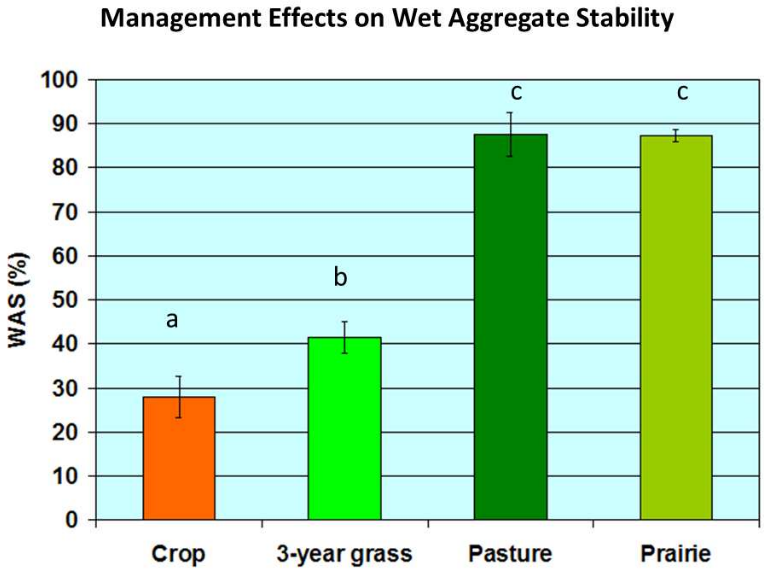

Figure 13. Wet aggregate stability benchmarks for a prairie remnant compared to long term cropped land with a past history of erosion. Sample sites were similar in all aspects except for cropping history. (LSD $P \leq 0.05$)

Soil Quality Comparisons between Treatments

Soil organic matter (SOM) changes are difficult to detect in a short time period of < 5 years due to soil variability and the complex mixture of soil organic compounds making up soil organic matter. An examination of soil organic matter concentrations from the top 15 cm of soil at the Colman and Flandreau sites show no measureable changes in soil organic matter during the period of study between crops (Tables 7,8). There were no crop by landscape position interactions.

Particulate organic matter (POM) represents a fraction of SOM that is > 0.5 mm in size and represents partially decomposed organic matter. As such this fraction represents a relatively young fraction of SOM and is more sensitive to changes in management practices. A larger component of POM is an indication that over time SOM is beginning to build in the soil. At both the Colman and Flandreau sites the perennial grass treatments had greater amounts of POM than corn in 2009, but this difference disappeared in 2010 (Tables 7,8).

FDA measures the potential for microbial hydrolytic activity as such it is an index of the soil organic matter decomposition process. Often FDA measurements mirror the effects of management on the POM fraction of the soil. This was generally true for the Colman and Flandreau sites (Tables 7,8). Although some of the numeric differences were not always statistically significant.

Table 7. Colman site comparisons of soil organic matter (SOM), particulate organic matter (POM), wet aggregate stability (WAS), and microbial hydrolytic activity as measured by a fluorescein diacetate assay (FDA) averaged across landscape positions and residue treatments. Statistical comparisons are for columns within each year.

	SOM	**POM**	**WAS**	**FDA**
2008	g kg^{-1}	g kg^{-1}	%	mg kg^{-1} h^{-1}
Switchgrass	75 a	12 a	51 a	42 a
Mixed Grass	74 a	13 a	47 a	43 a
Corn	76 a	13 a	49 a	44 a
2009				
Switchgrass	81 a	19 a	49 a	85 a
Mixed Grass	80 a	17 ab	49 a	82 a
Corn	81 a	15 b	46 a	75 b
2010				
Switchgrass	73 a	14 a	36 a	47 ab
Mixed Grass	72 a	14 a	37 a	50 a
Corn	73 a	12 a	28 b	43 b

Table 8. Flandreau site comparisons of soil organic matter (SOM), particulate organic matter (POM), wet aggregate stability (WAS), and microbial hydrolytic activity as measured by a fluorescein di-acetate assay (FDA) for crops averaged across landscape positions and residue treatments.. Statistical comparisons are for columns within each year.

	SOM	**POM**	**WAS**	**FDA**
2008	g kg^{-1}	g kg^{-1}	%	mg kg^{-1} h^{-1}
Switchgrass	82 a	12 a	46 a	41 a
Corn	81 a	12 a	45 a	35 a
2009				
Switchgrass	85 a	21 a	54 a	79 a
Corn	82 a	16 b	44 b	73 a
2010				
Switchgrass	79 a	16 a	42 a	50 a
Corn	80 a	17 a	30 b	64 a

Wet aggregate stability was increased relative to the corn treatment after 2-3 years at both Colman and Flandreau (Tables 7,8). Wet aggregate stability is frequently one of the most sensitive indicators of management induced changes in soil quality.

Soil Pore Size Characteristics

Soil pore characteristics were measured in-situ at the Flandreau site using a tension inflitrometer. A significantly larger mean equivalent pore radius of 227 µm was measured in corn where biomass was not harvested in comparison to 195 µm when the biomass was removed ($LSD_{0.05}$ = 37) (Figure 14). Biomass harvest did not affect the mean equivalent pore radius in the grass plots. However grass plots had a significantly greater mean equivalent pore radius than both the residue removed and residue retained treatments in the corn plots.

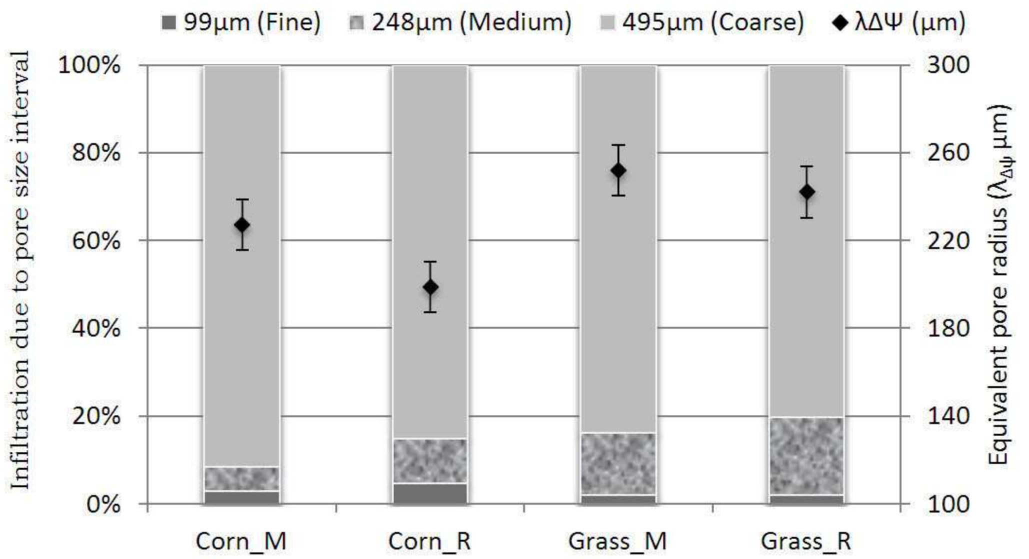

Figure 14. Effect of crop on macropore development. Pore size intervals are divided into fine, medium, and coarse pore sizes in relationship to infiltration rates based on tension infiltrometer data. The data point represents the equivalent pore radius associated with near saturated water flow.

The effect of residue removal at Flandreau on mean equivalent pore radius was the only observable significant effect on corn residue removal in this study during the relatively short treatment period of this study (3 years). However a direct reduction in macropores contributing to water flow as evidenced by a reduction in equivalent mean pore diameters suggests that caution be used when removing as much as 75% of the corn stover for biofuel as this resulted in statistically significant deterioration in soil structure. Harvest of switchgrass did not have the same effect and the growing of switchgrass generally improved macropore development in these plots.

Water Dynamics:

Soil water content

Soil water content was measured at two sites (Flandreau and Warner) during 2008-2011. For the purposes of this report the Flandreau, 2010 site will be used to illustrate study results. The water content was measured approximately every two weeks by neutron attenuation for each 0.3 m for the top 1.8 m of the soil profile. There were 3 landscape positions at the Flandreau site- top of hill (shoulder), mid-hill (backslope), and bottom of hill (footslope). Each landscape position had four replicates.

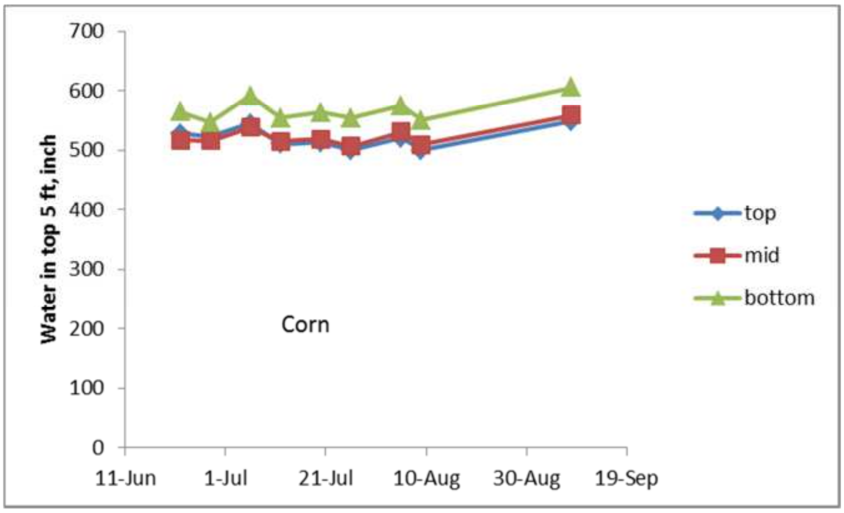

Figure 15. Volumetric soil water content in the corn plots, Flandreau site, 2010.

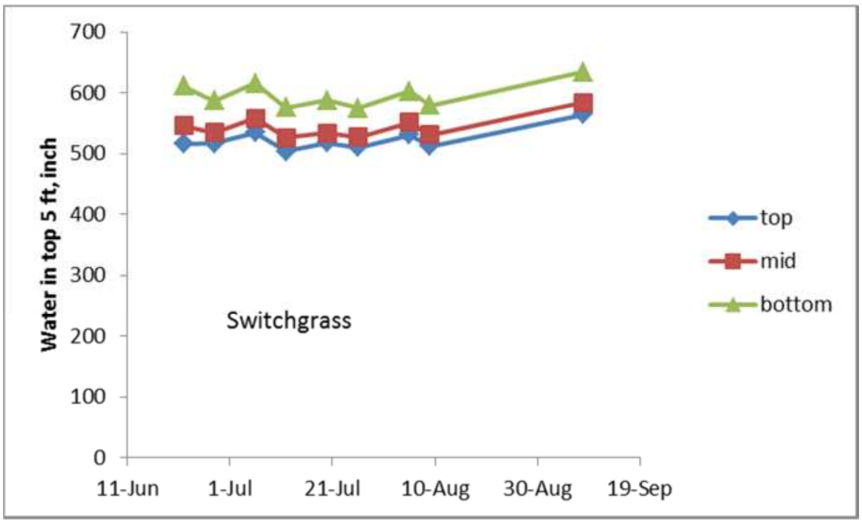

Figure 16. Volumetric soil water content in the switchgrass plots, Flandreau site, 2010.

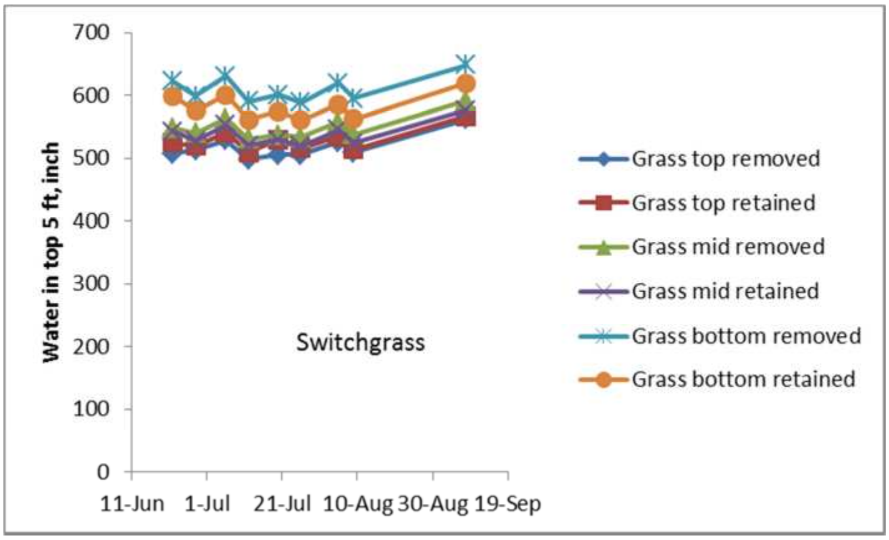

Figure 17. The effect of residue removal on volumetric soil water content in the switchgrass plots, Flandreau site, 2010.

Evapotranspiration

Crop evapotranspiration (ET_c) values (Tables 9,10) were calculated with a form of Penman equation. For the 2008 and 2011 season at Flandreau, alfalfa-based reference ET (ET_r) was downloaded from the SDSU Automated Weather Data Network web site (AWDN, data at climate.sdstate.edu). For the 2009 and 2010 seasons, weather data were collected with the on-site weather station. Those weather data were used in the software Ref-ET to calculate short-crop reference ET (ET_o) using the Penman-Monteith equation. Single crop coefficients were used to calculate ET_c with the corresponding reference ET data. The maize crop curves for ET_o were from FAO 56 (1998). Switchgrass crop curves were not readily available. The crop coefficients used in this work were based on grass species with similar characteristics with published values in FAO 56.

The growing season of 2011 at Flandreau was a tale of two seasons. The early part of the growing season was wet and cool. After mid-July, the rain stopped and the heat started. The corn emerged on 4 June, reached full cover on 1 July, began senescing on 1 September and was done on 20 September. The switchgrass started greening up on 10 May, reached full cover on 10 July, began senescing on 15 August and was done on 7 September.

Water use (evapotranspiration, or ET) of corn and switchgrass were estimated using the form of the Penman equation used by the SD State Climate Office weather stations (climate.sdstate.edu). The weather data and reference ET values for the Flandreau weather station were used for this work. The Flandreau weather station is located 3 miles from the research site. The standard crop coefficient for corn was used. There are currently no crop coefficients available for switchgrass so a grass crop curve similar to other grasses was used, based on FAO 56.

Corn cardinal dates (emergence, full cover, senescence, and maturity) were based on visual observations at the site. Switchgrass dates are long-term averages based on discussions with switchgrass specialists (unpublished data).

Table 9. Water use of corn by month at the Flandreau site, mm.

Month	2008	2009	2010	2011
May	64.8	75.3	43.6	21.0
June	153.8	136.6	131.8	82.4
July	202.2	165.4	167.4	189.0
August	135.4	145.0	140.9	146.6
September	27.6	57.7	22.4	58.4
Total	583.8	580.0	522.6	497.4

Table 10. Water use of switchgrass by month at the Flandreau site, mm.

Month	2008	2009	2010	2011
May	31.1	36.2	24.6	31.4
June	89.4	79.8	85.9	90.2
July	148.1	121.5	136.1	154.0
August	96.9	103.0	110.9	110.0
September	27.3	53.7	39.6	27.4
Total	392.8	394.2	397.1	413.0

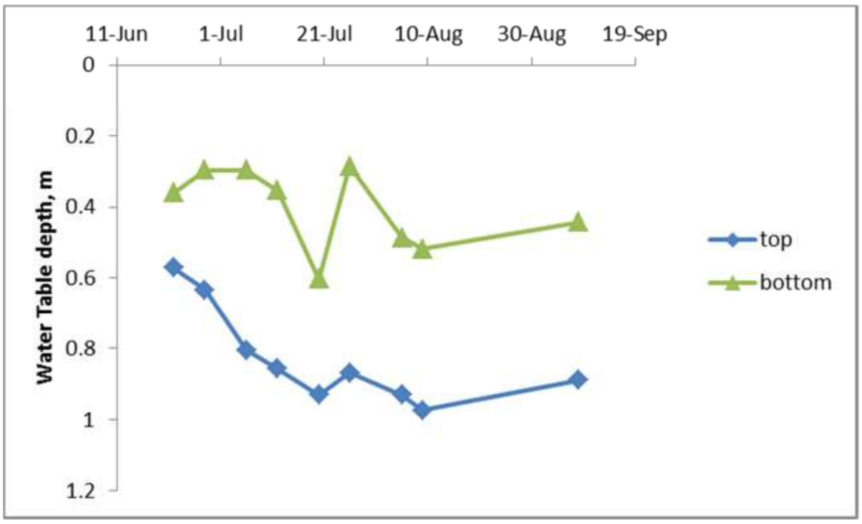

Figure 18. Water table depth in two corn plots at two landscape positions at the Flandreau site, 2011.

At the Flandreau site, the soil water content in the top 5 feet of the soil profile stayed high during the entire growing season (Fig 18). The minimum water content of 19.7 inches in the top 5 ft is an average volumetric content of 41%. The high water table at this site is keeping the water content high. Even during the drier second half of the 2011 growing season, when rain was infrequent, crops at this site should not have been experiencing stress due to inadequate soil water content because the high water table was providing adequate water for the crops.

Economic Feasibility:

The overall objective of capital budget analysis of this project is to measure the relative profitability of the three crop systems (multiple cellulosic feedstock, entirely switchgrass, entirely corn) depending on the landscape position, and on the residue management. The budget analysis contained in this report, which is based on yields, cost, and price data for 2008, 2009, and 2010, are necessary building blocks for construction of long term capital budgets and should be considered a preliminary subsequent to a more complete analysis.

The management scenarios examined in these preliminary budgets are sale of corn for grain and grass for hay production (at two different price levels). The annual budgets for corn include yields, costs, and returns for each year (2008, 2009, and 2010) using input price levels and average output prices for the crop year. The 2008 and 2009 budgets for switch grass and mixed-grass show the costs incurred to establish grass production on cropland. The budget for 2010 is the first year that production (hay yields) are obtained and the budgets reflect costs and returns using two output price scenarios ($40 per ton and $69 per ton).

The capital budgets (to be developed) will be based on price, cost, and management scenarios for a 10-year or similar long-term period and will include annualized costs of establishing switch grass, and mixed grasses.

Detailed Summary of Preliminary Budgets for 2008, 2009, and 2010

Profitability coupled with risks help farmers to make decisions. These two parameters determine farmers’ crop systems choices. Even if some farmers value the environment, they are sometimes forced to choose techniques more profitable than sustainable. The amount of risks that most farmers are willing to accept depends on the potential profits. Moreover, switching to a more sustainable crop system is a long process that requires time and money investment. The benefits of more sustainable crops systems are not often noticeable in the first few years and therefore farmers can be reluctant to change.

The analysis presented here are preliminary budgets for costs and returns in 2008, 2009, and 2010. The main profit variable examined is returns to management and labor. Other variables are also considered; gross return, total direct costs, and total costs. Gross returns are the long term average return assumed to be earned before deducting management fees and other input expenses; it is the total revenues from grain sales, insurance indemnities, and government payments. Returns to management and labor are net returns after deducting all expenses (total costs) from the gross returns. Total direct costs are all the variable costs associated with production; seeds, fuel, fertilizers, chemicals, machinery operating, etc. Total costs are total direct costs plus land charge and machinery ownership costs.

This economic analysis is based only on data from two sites of Flandreau and Colman. Farming practices on these lands are similar to local farming practices. Therefore additional data will be taken from the experiment and also from South Dakota State University reports and from South Dakota NASS.

This preliminary analysis presents a capital budget for the different crops and the landscape position; all corn, all switch grass, all mixed grass, corn foot slope, corn crest, corn back slope, switch grass foot slope, switch grass crest, switchgrass back slope, mixed grass foot slope, mixed grass crest, and mixed grass back slope.

The yields have been taken for the years 2008, 2009, and 2010. The budget for the perennial grasses has not been annualized yet. This budget is only done for the experimental farm; the generalization for an eastern South Dakota farm will be realized later.

Some of the data have been estimated, that is why these budgets can only be considered as preliminary budgets. Some key assumptions are:

- All budgets are estimates on a per acre basis and have not been weighted to a field level.
- The insurance costs and government payments have not been included in the budgets
- The grass seed cost have been estimated from Millborn Seed information on grass seed costs, at $7.50 per pound, and the rate of seeding was estimated at 10 lbs/acre.
- The co-products revenue for grass or corn has not yet been included.
- The machinery costs are estimated and will be more precise as we get the detailed management schedules. At this point custom rates for custom planting and harvesting of corn are used instead of a detailed breakdown of machinery ownership and operating costs. Custom rates for specific field operation (mowing, baling etc) were used for the grass hay budgets. The machinery custom rates were obtained from the 2010 Iowa State University custom rates survey.
- The operating interest has not been included at this time.
- The grass budget has not been annualized because we only have one year of yield data that can be used to estimate returns.

- The land charge is based on average cash rent for cropland or hay land for the East Central region of South Dakota (Janssen and Pflueger, 2011)
- Data on corn and grass yields and the major management practices were supplied from the field experiments and furnished by Mr. Kurt Reitsma. The unit costs were obtained from annual SDSU crop budgets, SD Agricultural Statistics Service and related sources.

Data in Table 11 contains a summary of gross yields, direct operating costs, and total cost – excluding management and labor charges for corn, switch grass, and mixed grass overall and by slope position (back slope, crest, and foot slope). Data in table 12 are gross returns and returns to management and labor for the corn budgets.

Table 11. Crop / grass yield, direct cost, and total costs per acre for 2008, 2009, and 2010.

CROPS	YIELDS (CORN: BUSHEL/ACRE GRASS: US TON /ACRE)			TOTAL DIRECT COSTS ($ PER ACRE)			TOTAL COST ($ PER ACRE)		
	2008	2009	2010	2008	2009	2010	2008	2009	2010
All Corn	151.0	109.4	138.1	301.9	385.1	281.4	410.9	514.1	414.6
All SWG			4.5	175.4	31.5	141.4	256.3	120.2	224.9
All MXG			4.5	175.4	31.5	141.4	256.3	120.2	224.9
Corn_BS	153.9	110.7	147.1	285.8	388.9	335.3	394.8	517.9	468.5
Corn_CRST	146.0	115.3	169.1	266.8	356.5	332.3	375.8	485.5	465.5
Corn_FS	153.0	102.3	98.3	313.3	365.8	308.8	422.3	494.8	442.0
SWG_BS			4.8	175.4	31.5	148.8	256.3	120.2	232.3
SWG_CRST			4.3	175.4	31.5	134.4	256.3	120.2	217.9
SWG_FS			3.8	175.4	31.5	122.0	256.3	120.2	205.5
MXG_BS			5.6	175.4	31.5	173.8	256.3	120.2	257.3
MXG_CRST			4.3	175.4	31.5	134.4	256.3	120.2	217.9
MXG_FS			3.6	175.4	31.5	116.0	256.3	120.2	199.5

SWG: Switchgrass – MXG: Mixed grass – BS: Back slope – CRST: Crest – FS: Foot slope

The corn budget results are greatly affected by the variability in yields across the three years and across landscapes and by variability in market prices ($3.78 in 2008, $3.23 in 2009, and $5.10 in 2010). Corn was highly profitable in 2008 and 2010, but had negative returns to labor and management in 2009. In fact, corn production revenues in 2009 did not even fully recover direct operating costs! The budgets also show that direct production costs per acre for corn are much higher than establishment costs for switch grass and mixed grass in the first two years, and also much higher than direct cost of grass harvesting (and maintenance) in the third year.

Table 12. Gross return and return to management and labor, all corn and corn by slope phase, 2008, 2009, and 2010.

Crops	Gross return ($ per acre)			Return to management and Labor ($ per acre)		
	2008	2009	2010	2008	2009	2010
All Corn	570.7	353.4	704.6	159.7	(160.7)	290.0
Corn_BS	581.7	357.5	750.2	186.9	(160.4)	281.7
Corn_CRST	552.0	372.3	862.2	176.2	(113.2)	396.8
Corn_FS	578.3	330.4	501.3	156.0	(164.4)	59.3

BS: Back slope – CRST: Crest – FS: Foot slope

Data in table 13 are gross returns and returns to management and labor for the grass budgets. In this case, only costs are incurred for years 1 and 2 while some returns are available from grass hay production in year 3. As mentioned earlier, two grass hay prices were examined: $40 / ton which was required as one of the hay prices to examine and $69 per ton which is the average "other hay (non-alfalfa hay)" price for 2010 (South Dakota Agriculture 2011 bulletin, June 2011).

Table 13. Gross Return and Return to Management & Labor for Grass Hay Production for Two Price Scenarios ($40 / ton and $69 / ton.

	Scenario: Grass Price = $40/ton						Scenario: Grass Price = $69/ton					
Crops	Gross return ($ per acre)			Return to management and Labor ($ per acre)			Gross return ($ per acre)			Return to management and Labor ($ per acre)		
	2008	2009	2010	2008	2009	2010	2008	2009	2010	2008	2009	2010
All SWG			178.8	(256.3)	(120.2)	46.1			308.4	(256.3)	(120.2)	83.5
All MXG			180.8	(256.3)	(120.2)	44.1			311.9	(256.3)	(120.2)	87.0
SWG_BS			191.0	(256.3)	(120.2)	41.3			329.5	(256.3)	(120.2)	97.2
SWG_CRST			171.2	(256.3)	(120.2)	46.7			295.3	(256.3)	(120.2)	77.4
SWG_FS			154.1	(256.3)	(120.2)	51.4			265.8	(256.3)	(120.2)	60.3
MXG_BS			225.4	(256.3)	(120.2)	31.9			388.8	(256.3)	(120.2)	131.6
MXG_CRST			171.2	(256.3)	(120.2)	46.7			295.3	(256.3)	(120.2)	77.4
MXG_FS			145.8	(256.3)	(120.2)	53.7			251.5	(256.3)	(120.2)	52.0

SWG: Switchgrass – MXG: Mixed grass – BS: Back slope – CRST: Crest – FS: Foot slope

The final analysis will show a representative farm model for eastern South Dakota, a full capital budget analysis with crops rotations and the profitability of each system depending on the landscapes to determine the breakeven prices. One of the limitations in this study is the fact that switchgrass and other energy crops (except corn) are perennial. The capital budget will therefore be calculated on a long term basis and then annualized. Also, different management scenarios in terms of co-products (such as corn stover) will be examined.

Potential for Transferability of Results

General production information about switchgrass and corn production developed as an outgrowth of this project has been successfully transferred through online publications. The specific results of this study pertaining to precision conservation will become more relevant as bioenergy cellulosic markets are more fully developed. The results of this study have generated questions about establishment of prairie cordgrass, switchgrass, and the use of other precision conservation approaches to improve eroded landscapes (eg. use of the pyrolysis byproduct biochar as a targeted amendment). This has resulted in the development and acquisition of grants addressing these specific questions.

Conclusions

Goal: Apply precision conservation practices by using biomass crops selected for their adaptation to, and conservation impacts on contrasting soil environments occurring in the farm unit.

The results suggest that perennial grass could provide a viable alternative to annual crop production in areas where row crops have the most vulnerability to stress and erosion hazard. Perennial grass crops have less variability of production across landscape positions. Placing perennial grasses in strategic locations within the landscape where corn and other annual crops produce poorly due to seasonal wet soils or poor quality soils could increase profitability of the farming operation in addition to providing wildlife habitat, run-off water filtering, soil stabilization, and carbon storage. However the successful application of this strategy presumes an active and vibrant bioenergy feedstock market. Incorporating multiple crop species into an undulating landscape with frequent swales or seasonal wetlands may require creative logistics including rethinking field layout. As an example in some cases fields built around linear wetlands may better suit prairie cordgrass plantings designed for bioenergy feedstocks. This could also apply to switchgrass seeding adjacent to the prairie cordgrass plantings and on backslopes where erosion protection is desired. The remaining areas of the field could be planted to annual crops such as corn and soybeans with less impact and higher yield potential than if the field was laid out without regard to seasonal wet areas or areas of high erosion hazard. Implementation of this strategy requires a transition period of one to two years and must be included in the planning process by the bioenergy industry, producers, and policymakers.

<u>Goal:</u> Demonstrate, evaluate, and develop soil management practices to protect the landscape from erosion and sedimentation, promote soil quality, and maintain a positive carbon balance.

Symposiums, field tours, and media interviews were used to provide information about multi-cellulosic feedstocks applied to undulating landscapes. A combination of no-till practices with corn and perennial grass production provided year round cover to all parts of the landscape thus minimizing erosion and sedimentation potential. There is significant room to improve the soil quality of soils in Eastern South Dakota as shown by the 50% loss in soil organic matter that has occurred in the topsoil since settlement and cultivation of the land. This project demonstrated that perennial grasses can slowly improve the soil over time. Although this project had a relatively short time frame a significant improvement was seen in wet aggregate stability, a key indicator of management impacts on soil quality and a predictor of improved potential for increased soil organic matter. Corn stover harvest at 75-80% removal rates resulted in a change in macropore structure. This suggests that caution be used when planning continuous and extensive harvest of stover over long periods of time.

<u>Goal:</u> Develop site specific technical guidelines that can be incorporated into technical standards, fact sheets, and handbooks for NRCS, Extension Educators, Crop and Environmental Consultants, and Producers.

Twelve publications have been developed thus far and others are being planned as the data is more completely analyzed and evaluated. Two online publications are currently available that detail extensive information that can be incorporated into daily use by producers, educators, consultants, NRCS staff, and other professional service providers. The technical guide "Switchgrass Management and Production in South Dakota" referenced at http://igrow.org/up/resources/03-2006-2011.pdf is a guide to establishing and growing switchgrass that provides much detail and was developed as an outgrowth of this project. The second online publication "Best Management Practices for Corn Production in South Dakota. EC929" referenced at http://pubstorage.sdstate.edu/AgBio_Publications/articles/EC929.pdf was selected as the Selected as the 2010 Outstanding Agronomic Educational Material (>16 pages). by the American Society of Agronomy. This publication was also developed as an outgrowth of this project.