# Switchgrass Production in Iowa:
# Economic analysis, soil suitability, and varietal performance

**E. C. Brummer, C. L. Burras, M. D. Duffy, and K. J. Moore**
**Iowa State University**

**under**
**Subcontract 90X-SY510V**

**Prepared September 2002**

**Research supported by**
**Office of Transportation Technologies**
**Activity No. EB 52 03 00 0**
**and**
**Office of Power Technologies**
**Activity No. EB 24 04 00 0**

**for**

**Bioenergy Feedstock Development Program**
**OAK RIDGE NATIONAL LABORATORY**
**Oak Ridge, Tennessee 37831-6422**

**managed by**

**UNIVERSITY OF TENNESSEE BATTELLE LLC**
**for the**
**U.S. DEPARTMENT OF ENERGY**
**under contract DE-AC05-00OR22725**

## TABLE OF CONTENTS



## CONVERSION FACTORS

1 ton/acre (T/A) = 2.24 Mg/ha = 2400 kg/ha
1 Mg/ha = 1000 kg/ha = 0.45 tons/acre
1 $g/m^2$ = 10 kg/ha
1 g/kg = 0.1%
1 mg/kg = 1 ppm (part per million)
1 kJ/g = 432.2 BTU/lb.

## EXECUTIVE SUMMARY

Biofuel production in the Chariton Valley in southern Iowa would have desirable environmental effects by converting land usually planted to annual row crops into perennial grass cover. Switchgrass, designated by DOE research as the most viable herbaceous biofuel crop, is native to Iowa and has been grown to a limited extent as a forage crop. Its productivity as a biofuel needs to be assessed; the characteristics of a desirable biofuel crop differ from those of a forage, and agronomic practices will likely need to be altered. Additionally, biofuel crops are targeted to the more erodible land in the region, land that varies considerably in soil characteristics, and hence, productive capacity. Reed canarygrass could complement switchgrass, particularly in wet areas, and its ability to form a dense sod may improve erosion control in some instances.

Economic and agronomic analyses of biofuel crops–primarily switchgrass, secondarily reed canarygrass–are needed to determine the feasibility of growing these crops in southern Iowa. In this report, we discuss preliminary research bearing on these issues.

The economic analysis of switchgrass production shows that yield and price are the determining factors for profitability. With moderate yields (3 tons/acre) and price ($50 per ton), switchgrass could produce a significant positive impact for the regional economy. Changing from a corn/soybean rotation to switchgrass will not make a substantial change in energy usage to produce the crop.

In field level trials, we have found switchgrass (cultivar 'Cave-in-Rock') yields to be relatively low when starting from long-term, poorly managed stands. However, yields improved to nearly 4.3 Mg $ha^{-1}$ (about 2 tons/acre) after two years of fertilization with 112 kg N $ha^{-1}$ and weed control. These yield levels are still low, but given that the stands in which the initial work was conducted were thin and poorly managed, we expect that yields can improve in well-managed stands. The one caveat is that the inherent productivity of some highly erodible land is quite low, and high production in these areas, primarily sideslopes, may not be realistic. Additionally, we found evidence of substantial erosion in some established switchgrass stands, a result that was unexpected. Based on our nitrogen treatments of 0 to 224 kg $ha^{-1}$, we determined that yield increases diminish as N applied rises above 112 kg $ha^{-1}$. Thus, this level of fertility appears ideal for biofuel production in southern Iowa.

Yields of various germplasm in small plot trials planted in 1997 ranged from 6.4 Mg $ha^{-1}$ in 1998 to 11.8 Mg $ha^{-1}$ in 1999 as the stands matured and filled in gaps. The highest yielding variety in 1999 was 'Alamo', at 17 Mg $ha^{-1}$. Alamo and several other lowland ecotypes produced the most biomass, higher than Cave-in-Rock, the normally recommended cultivar for southern Iowa. These trials suggest that higher yields are possible under optimum management and with superior cultivars. A cautionary note is that the lowland cultivars have not experienced a severe winter, and their winter hardiness may not be sufficient under those conditions. In all cases, switchgrass quality appears adequate for a biofuel; variation among cultivars exists, suggesting that further improvements in quality are possible.

Preliminary evaluation of reed canarygrass suggests that two harvests, one in late spring and the other after frost, yield the most biomass. Evaluation of a large collection of germplasm in Iowa and Wisconsin shows that higher yields are possible than those present in currently available cultivars. Quality of reed canarygrass may be problematic: ash, chlorine, and silica are higher than optimum.

More substantial discussion of the soil properties of fields and their relationship with biomass yield and quality will be completed over the next year. In addition, new experiments to evaluate the best performing switchgrass cultivars in large strip trials, to test reed canarygrass side-by-side with switchgrass in large plots, and to determine field level yields and quality of reed canarygrass are underway.

## PROJECT PERSONNEL

**Principal Investigators**


| | | |
|---|---|---|
| E. Charles Brummer | Project coordinator; Biomass crop breeding | |
| | brummer@iastate.edu | 515-294-1415 |
| C. Lee Burras | Soil quality and management | |
| | lburras@iastate.edu | 515-294-0559 |
| Michael D. Duffy | Agricultural economics | |
| | mduffy@iastate.edu | 515-294-6160 |
| Kenneth J. Moore | Biomass crop production and utilization | |
| | kjmoore@iastate.edu | 515-294-5482 |


**Technical Assistance**

| | |
|---|---|
| Michael Barker | Biomass crop management, evaluation, and breeding, and soil characterization |
| Patricia Patrick | Biomass quality laboratory analysis |
| Mark Smith | Biomass crop small plot harvesting |
| John Sellers | Large field plot assistance |

**Past Participants**

| | |
|---|---|
| Roque Lemus | Biomass crop management, evaluation, and breeding |
| Neil Molstad | Soil characterization |
| Virginie Nanhou | Economic analysis of biofuel production |

## ACKNOWLEDGMENTS


We thank Mark Downing and Sandy McLaughlin at Oak Ridge National Laboratory, Velvet Glenn, Marty Braster, and Jim Cooper at the Chariton Valley RC&D, John Sellers and his crew for help with the field-scale harvesting and plot maintenance, Mark Smith for assistance with variety trials, and a host of graduate and undergraduate students for help with plot work, stem-leaf separations, grinding, and quality analyses. Thanks also to Stan Henning and Russ Doorenbos for help with Cl and S analyses.

## INTRODUCTION

Marginal soils, widespread throughout southern Iowa, are unsuited to annual row crop–corn and soybean–production. Much of the landscape in southern Iowa is characterized by heavy, wet soils and significant slopes that allow substantial levels of erosion. On-farm integration of biofuel crops with grain and forage crops and livestock may foster the long-term environmental and economic sustainability required for agricultural systems.

Switchgrass has been chosen as the model herbaceous biofuel crop, and its adaptation to Iowa is well-known. Profitable use of biomass crops requires sufficient understanding of agronomic aspects of their culture and economic realities of their production. We intend to assess the productive potential of switchgrass across a range of soil types and landscapes, allowing us to more effectively pinpoint locations where it will perform well.

Reed canarygrass represents another potential biofuel crop, a cool-season grass alternative to switchgrass. With its different growth pattern–it is most productive in spring and fall–and tolerance to both wet and droughty soils, reed canarygrass complements switchgrass in a diversified biofuel program. Its strongly rhizomatous growth habit also make it appealing, particularly on soils on which switchgrass, a bunchgrass, does not form thick stands and erosion is a problem.

The research reported in this report is part of an ongoing project to understand the constraints to biomass production in southern Iowa and to develop production methods that will permit economically viable production of biofuel crops. Although labeled a “final” report, most of the experiments discussed are continuing in the field for one to two more years. Thus, only tentative conclusions are possible at this point. Similarly, the economic analyses are necessarily preliminary and could change as production parameters developed in other phases of this program are implemented on-farm.

In the report, tables and figures for each section follow immediately after the text for that section.

## RESEARCH PROJECTS

The research projects that will be discussed in this report are based on three objectives:

I. Economic potential of switchgrass as an agronomic crop for bioenergy
   1. Document on-farm costs and resource commitments for switchgrass production
   2. Assess regional economic impacts of large-scale switchgrass production
   3. Quantification of energy consumption for switchgrass production

II. Switchgrass production in relation to soil variability and environmental quality
   1. Landscape and nitrogen effects on switchgrass production potential.
   2. Quantification of soil properties and their relation to switchgrass yield and quality , and assessment of the erosion potential in switchgrass fields

III. Evaluate and develop switchgrass and reed canarygrass germplasm for bioenergy production and adaptation to Iowa
   1. Switchgrass cultivar evaluation for yield and biofuel quality
   2.1. Evaluation of harvest management and varietal performance of reed canarygrass for biofuel
   2.2. Evaluate diverse reed canarygrass germplasm and begin breeding new cultivars for bioenergy uses

## PROJECT PUBLICATIONS

Brummer, E.C., L. Burras, M. Duffy, K. Moore, M. Downing, and S. McLaughlin. 1997. Integration of technical aspects of switchgrass production in Iowa. p. 1445-1454. In: Making a business from biomass. Vol. 2. R.P. Overend and E. Chornet (eds.) Proc. 3rd Biomass Conf. of the Americas. Pergamon, Oxford, UK.

Duffy, M. and V.Y. Nanhou. 2001. Costs of Producing Switchgrass for Biomass in Southern Iowa. Iowa State Coop. Ext. Bulletin.

Duffy, M. and V.Y. Nanhou. 2001. Costs of Producing Switchgrass for Biomass in Southern Iowa. Iowa State Coop. Ext. Bulletin. 5$^{th}$ National Symposium on New Crops and New Uses, Atlanta, GA, Nov 10-13, 2001.

Hipple, P.C., and M.D. Duffy. 2001. Biomass production in the Chariton Valley area of south central Iowa: Farmers' motivations for adoption of switchgrass.

Lemus, R.W., E.C. Brummer, N.E. Molstad, C.L. Burras, K.J. Moore, and M.F. Barker. 2002. Biomass yield and quality of 20 switchgrass populations in southern Iowa, USA. Biomass and Bioenergy [in press].

Lemus, R.W. 2000. Cultivar and fertility effects on switchgrass biofuel production in southern Iowa. M.S. Thesis. Iowa State University, Ames.

Lemus, R.W., N.E. Molstad, E.C. Brummer, L. Burras, K.J. Moore, and R. Doorenbos. 1999. Switchgrass management for yield potential and biomass quality in the Chariton Valley, Iowa USA. Agron. Abstr. p. 110.

Lemus, R.W., N.E. Molstad, L. Burras, and E.C. Brummer. 1998. Switchgrass management and productivity in the Chariton River Valley, Iowa. Agron. Abstr. p. 276.

Molstad, N.E. 2000. Landscapes, soil morphology, and switchgrass management and productivity in the Chariton River Valley, Iowa. M.S. Thesis. Iowa State University, Ames.

Molstad, N.E., R.W. Lemus, C.L. Burras, E.C. Brummer, and K.J. Moore. 1999. Landscapes, soil morphology, and switchgrass yield in the Chariton River Watershed, Iowa. Agron. Abstr. 266.

## MANUSCRIPTS IN PREPARATION

Brummer, E.C., M.D. Casler, and K.J. Moore. 2003. Effects of harvest management and cultivar on reed canarygrass biomass yield and quality. To be submitted to *Crop Science*.

Brummer, E.C., M.D. Casler, and K.J. Moore. 2003. Evaluation of reed canarygrass germplasm for biofuel potential. To be submitted to *Crop Science*.

Burras, L., E.C. Brummer, J. Sellers, M. Braster, T. Jacobson, V. Glenn, M.F. Barker, and J. McLaughlin. 2003. On-farm switchgrass yield in the lower chariton river watershed of Iowa, 1999-2000. To be submitted to *Journal of the Iowa Academy of Science*.

Lemus, R.W., E.C. Brummer, N.E. Molstad, C.L. Burras, K.J. Moore, and M.F. Barker. 2003. Effect of nitrogen fertilization on field scale switchgrass yield in southern Iowa. To be submitted to *Agronomy Journal*.

## ANNUAL REPORTS

Previous annual reports are available on the web at:

http://www.public.iastate.edu/~brummer/ag/biomass.htm

# I. ECONOMICS OF SWITCHGRASS PRODUCTION

## A. The economics of switchgrass

### 1. Budget revisions

Budget revisions for switchgrass production were made to incorporate commonly used management practices as well as the new input prices and machinery costs and the new bale weight of 950lbs (instead of original 875lbs/acre). Only frost seeding scenarios (on cropland and grassland) were revised because they represent the most commonly used practices in southern Iowa.

*1.1 Modifications (including updated prices and custom rate charges)*

Increased seeding rates: from 6lb/acre to 10lb/acre for the establishment year, and from 4lb/acre to 7lb/acre for reseeding year

Simulation of different production costs for various reseeding probabilities: 25, 15, and 10 % reseeding probabilities

Simulation of different production costs using different levels of N fertilization: 100, 75, 50 lb. N/acre

*1.2. Outcome of changes*

An increase in seeding and reseeding rates (from 6 lb/acre to 10 lb/acre and from 4 lb/acre to 7 lb/acre, respectively) results in an increase in costs but the magnitude of the increase is relatively small (less than 1.5% increase without reseeding or 25% reseeding probability) (Appendix 2).

A change in reseeding probabilities produced relatively minor changes in production costs per ton. A change from 25% reseeding rate to no reseeding at all (0% reseeding rate) will induce a decrease in the costs of 2% or less (ie. less than $2.00 per ton). The impact of a reduction in reseeding probabilities decreases as the expected yield increases (Appendix 3).

A 50% reduction in nitrogen application rates (from 100lb N/acre to 50 lb N/acre) results in cost reductions of less than 6% assuming that the yields do not change. A 25% reduction in nitrogen application will result in a cost reduction of less than 3%. See Appendix 4 for details.

The assumption that yields do not change with a reduced nitrogen application rate is crucial to our findings. The results of N fertility trials, conducted by the agronomists' team, will help to establish more realistic assumptions. For example, if we assume that yields will decrease on cropland ($75 land charge) from 6tons/acre to 4 tons/acre (33% decrease) due to a reduction in N application per acre from 100 lb to 50 lb, there is a 20% increase in per ton production costs. For a 25% decrease in yields (from 4 tons to 3 tons per acre), the costs will increase by approximately 15%.

Reducing the N application rate will not necessarily result in a decrease in production costs as seen with these examples. The cost effect of reducing N application (increase or decrease) and its magnitude can only be assessed when yield results are available.

### 2. Handling, storage and transportation costs

*2.1. New additions*

To date, the costs estimated were only on-farm costs. The major addition in 2001 was the estimation of post harvest costs for handling, storage and transportation costs for switchgrass. We included dry matter losses in the storage costs at three different price levels for switchgrass ($40, $50 and $60/ton).

Few data are available on storage losses for switchgrass, not to mention switchgrass square bales. This is an area were more research is needed.

Input on handling, storing and transportation costs came from producers, resource persons from Chariton Valley and ISU. An extensive literature review helped fill the gap in the knowledge on these costs. Many assumptions had to be made in order to estimate preliminary costs of handling, storage and transportation. These preliminary costs will be reviewed by producers and the Chariton valley team before the final versions. The results presented here are preliminary results (details in Appendix 5).

*2.2. Summary of preliminary results on handling, storage and transportation costs*

Switchgrass bales should be stored covered and not directly on the ground to reduce the losses in dry matter and quality. For switchgrass prices equal or less than $40/ton, in-door storage (totally enclosed or open sides) does not seem to be an economically viable storage option. As prices increase (i.e. $50/ton, $60/ton), storage in a pole frame structure with open sides becomes an economically viable option.

For a price of $50/ton and a yield of 4 dry tons/acre, delivered costs of switchgrass will range from $69.00/ton to $101.00/ton, depending on storage options and the type of land used for production.

For switchgrass grown on grassland, delivered costs range from $69.00/ton with no storage to $91.00/ton for on-farm storage in a totally enclosed barn, to $95.00/ton for collective storage option.

For switchgrass grown on cropland, delivered costs range from $76.00/ton with no storage $98.00/ton for on-farm storage in totally enclosed barn, to $101.00 for collective storage option to.

## B. Budgets for alternative switchgrass cropping systems

Two main alternative switchgrass cropping systems were evaluated by agronomy researchers:

1. Establishing switchgrass with corn in the first year and,

2. Spring interseeding of legumes in an established stand of switchgrass. The legumes evaluated were the perennial legumes alfalfa, birdsfoot trefoil, and red clover.

A series of assumptions was made to complete the preliminary budgets. More data are needed to answer the questions that emerged during the preliminary estimations, particularly data on herbicide and fertilization programs.

1. <u>Establishing switchgrass with corn in the first year</u>

*1.1. Advantages*

Establishing switchgrass with corn presents the following advantages:

a. Extra protection against weeds during establishment with corn;
b. Protection against soil erosion;
c. Revenue for producers in the first year.

*1.2. Assumptions*

Many assumptions were made to estimate the preliminary budgets. Most of the assumptions come from a research article by Hintz et al. (1998). Costs assumptions (machinery costs, inputs, etc) were taken from ISU extension publications such as FM-1698 (Iowa Farm Custom Rate Survey, 2002), FM-1712 (Estimated Costs of Crop Production in Iowa, 2002), etc. The assumptions are:

a. Seeding rate of corn is 30,000 kernels per acre using a no-till planter
b. Seed rate for switchgrass is 6 lbs. PLS/acre

c. The N application rate varies with the previous use of the land: on grassland and on land previously used for corn production, 100lbs N/acre are applied; on land previously used for soybean production, 60lbs N/acre are applied
d. The use of insecticides is restricted to land previously under corn production
e. P and K fertilization and herbicide programs are similar to the ones used on switchgrass established alone
f. Only corn is harvested on the first year and the quality is not affected by switchgrass
g. Corn yield is 95 bushels per acre
h. Corn price per bushel is $1.85
i. No storage costs are included in costs estimates

*1.3 Preliminary budget estimations for switchgrass established with corn*

The preliminary budget is presented in detail in the Appendix. For switchgrass established with corn, corn revenue ranges from $42/acre on cropland previously under corn to $80/acre on cropland previously under soybeans. The difference is due to different pesticides and fertility needs. For grassland, corn revenue was estimated at approximately $71/acre.

Corn revenue can be used to reduce the prorated establishment costs for all the production years. The prorated establishment costs on cropland would be reduced from $26.01/acre to $ 20.13/acre or $14.86 following corn and soybeans, respectively. Grassland prorated estimated costs are reduced from $24.09/acre to $14.17/acre.

2. <u>Spring interseeding of legumes in an established stand of switchgrass</u>

*2.1 Advantages*

The advantages of the spring interseeding of legumes in an existing switchgrass stand are:

a. Reduction of nitrogen application rates because legumes add nitrogen to the soil;
b. Dual harvest where first harvest can constitute a source of good forage and second harvest can be dedicated to biomass production;
c. Some extra level of income for farmers through forage revenue.

*2.2. Assumptions*

The assumptions used for the estimations come from a variety of sources: the cropping systems research for biomass energy production by Hintz, Moore and Tarr (main source), ISU extension publications such as FM-1698 (Iowa Farm Custom Rate Survey, 2002), PM-1688 (General Guide for Crop Nutrient Recommendations in Iowa, 1999), FM-1712 (Estimated Costs of Crop Production in Iowa, 2002). The assumptions are:

a. Alfalfa, birdsfoot trefoil, and red clover have a stand life of 4 years
b. Legumes are interseeded in an existing switchgrass stand in the sixth year
c. Seeding rates for alfalfa, birdsfoot trefoil and red clover are 12, 5 and 8 lbs/acre, respectively
d. No nitrogen or herbicides are applied on the mix of switchgrass and legumes
e. P and K application rates are the simple average of P and K removal rates for the mix of switchgrass and legumes
f. When switchgrass is established, from second year to sixth year only one cut harvesting system is performed while from the seventh year to tenth year, it is a two cuts harvesting system
g. The first cut corresponds to 50% of total production and is used as forage while the second cut corresponds to 50% of production and is used as biomass for bioenergy
h. Three yield levels are considered; 1.5, 3 and 4 tons/acre. From the experiments done by the team of agronomist, the yields were below 4 tons/acre.

i. From sixth year forward, production costs include not only prorated switchgrass establishment costs but also prorated legumes establishment costs. Legume establishment costs include machinery costs (no till drill) and seed costs as well as interest on operating expenses
j. Three levels of forage prices considered ($58, $75 and $85 per ton); they are used to determine biomass price levels needed to breakeven per ton production costs.

*2.3. Preliminary budgets estimations for switchgrass and perennial legumes*

The summary of the results is presented in Table 1. The details of the budgets are presented in the Appendix. The assumed yield is 4 tons/acre.

The cost of producing switchgrass alone is $65/ton and $58/ton on cropland and grassland, respectively, assuming a 4-ton yield with no reseeding.

On the year the legumes are interseeded, there is a reduction in biomass production costs that ranges from 7% up to 13% depending on the type of legume and land. This reduction is due to no nitrogen and herbicide costs when legumes are added to an existing switchgrass stand. Input cost reductions are also observed during the years when both legumes and switchgrass are harvested (seventh to tenth years). However, there is an extra cost of a second cut incurred during this period.

What is the advantage of interseeding switchgrass and those legumes in terms of biomass cost? If the produce of the first cut on cropland is sold at $75/ton (as forage), the price per ton of biomass necessary to cover (breakeven) the production cost is $53 or less depending on legume types. On grassland, the required price per ton of biomass to break even production costs will be at most $40. At $85/ton, less than $43 per ton is needed for biomass harvested on cropland and less than $30 on grassland. With the two cuts harvest system and with the possibility to sell the first harvest as forage, it is more likely that biomass will more competitive.

## C. Reed canarygrass budgets

Preliminary budgets for the establishment and production of reed canarygrass were developed last year (Table 2). The only change from the existing budgets was to update the costs using current inputs prices. The research teams indicated there was no major change in cultural practices. Production costs per ton (farm gate costs) on grassland range from $46.00 to $72 at 6 and 3 tons/acre, respectively. On cropland, costs per ton ranged from $50.00 to $80.00 at 6 and 3 tons/acre, respectively.

## D. Biomass Project Assistance

We are continuing work on estimating the cost for establishing a project similar to the Chariton Valley project. This project has involved considerable time and effort from farmers and government employees. We are trying to estimate this time and the potential cost for establishing the project.

## E. Landowner adoption of switchgrass

Work on examining farmers' motivation for adopting switchgrass is continuing. A paper, "Farmers' Motivation for Adopting Switchgrass," was presented at the Fifth National Symposium on New Crops and New Uses, Atlanta, Georgia Nov.10-13, 2001. A copy of this paper is attached in the Appendix.

Efforts are underway to expand the counties considered for biomass production. This expansion will be in a 70-mile radius of the Ottumwa power plant.

The primary focus of this analysis is the impact on profitability using CRP land with a reduced CRP payment. Under an approved plan, farmers would continue to receive 90 percent of their CRP payment and the switchgrass for biomass could still be harvested and sold.

The current switchgrass budgets include a yearly land charge. These budgets are used to estimate a cost per ton for switchgrass production. Evaluating the impact of having a CRP payment in addition to the switchgrass production requires re-estimating the budgets. The new budgets will not include a land charge because the purpose is to estimate how much would have to be received for the switchgrass in order to make the farmer indifferent between the reduced CRP payments with switchgrass and the full CRP payment. We'll estimate the impacts using a variety of yields and prices for switchgrass.

**Table 1**. Summary of production costs for switchgrass intercropped with legumes.

| | Production cost | | | Price needed to cover production costs if forage value is | |
|---|---|---|---|---|---|
| | Years 1-5[a] | Year 6 One cut | Years 7-10 Two cuts | $75/ton[b] | $85/ton[b] |
| | ($/ton) | | | | |
| **Cropland** | | | | | |
| Switchgrass | 64.98 | - | - | - | - |
| Switchgrass + alfalfa | - | 60.60 | 63.86 | 52.73 | 42.73 |
| Switchgrass + birdsfoot trefoil | - | 57.18 | 60.44 | 45.89 | 35.89 |
| Switchgrass + red clover | - | 58.68 | 61.94 | 48.89 | 38.89 |
| **Grassland** | | | | | |
| Switchgrass | 58.48 | - | - | - | - |
| Switchgrass + alfalfa | - | 54.10 | 57.37 | 39.73 | 29.73 |
| Switchgrass + birdsfoot trefoil | - | 50.68 | 53.95 | 32.89 | 22.89 |
| Switchgrass + red clover | - | 52.18 | 55.45 | 35.89 | 25.89 |

**Table 2.** Summary for reed canary grass production for two types of land (cropland, grassland) and three yield levels (3, 4 and 6 tons/acre)

| Scenarios | Yield | Prorated establishment cost | Production cost per acre | Production cost per ton |
|---|---|---|---|---|
| | tons/acre | ---------------------$--------------------- | | |
| Seeding on cropland | 3.0 | 26.43 | 239.68 | 79.89 |
| | 4.0 | 26.43 | 259.55 | 64.89 |
| | 6.0 | 26.43 | 299.30 | 49.88 |
| Seeding on grassland (1) (Burn down of grass and No till grass seed drill) | 3.0 | 26.32 | 214.57 | 71.52 |
| | 4.0 | 26.32 | 234.44 | 58.61 |
| | 6.0 | 26.32 | 274.19 | 45.70 |
| Seeding on grassland (2) (Plow and disk and grass seed drill) | 3.0 | 25.17 | 213.42 | 71.14 |
| | 4.0 | 25.17 | 232.79 | 58.20 |
| | 6.0 | 25.17 | 273.04 | 45.51 |

[a] Assuming no reseeding.

[b] Hay prices vary with the type of hay (grass hay, grass-legume hay, alfalfa hay, etc.) and its quality (premium, good, fair, low). Price per ton of fair to good quality hay ranges on average from $75-$85 in Southern Iowa. On the 1991-1999 time period, hay price ranged from $71 to $100/ton, with a national average hay price of $84/ton.

# II. SWITCHGRASS PRODUCTION IN RELATION TO SOIL VARIABILITY AND ENVIRONMENTAL QUALITY

## II.1. Fertility and Landscape Effects on Switchgrass Production and Quality

**OBJECTIVE**
The objective of this experiment is to determine the effects of locations, years, harvest dates, landscape positions, and nitrogen levels on switchgrass yield and biomass quality traits.

**METHODS**
We began field experiments in 1998 using mature, established 'Cave-In-Rock' switchgrass fields at two southern Iowa locations: near Derby in Lucas County and near Millerton in Wayne County. The experimental design was a randomized complete block design with six replications at Derby and five replications at Millerton. The replications are split across two fields in each location, which are owned and managed by the same farmer and which are adjacent to each other. We have not observed a field effect within location; the two fields were merged. One replication in Derby was dropped from data analysis because it behaved aberrantly, likely due to limestone dust from the adjacent road. Thus, five replications at each location were used for analyses. Each replication was 200' wide and between 100' and 400' long, the variable length being necessary to allow incorporation of summit, backslope, and swale landscape positions within each plot. This size plot was amenable to management by standard farm equipment. Each replication included four randomly assigned plots, representing four nitrogen fertility treatments of 0, 56, 112, and 224 kg N ha-1; each plot was 50' wide and covered all three landscape positions. In 1998 and 1999, plots were subsampled throughout the year for biomass yield and quality measurements using a 1 m2 quadrat. In autumn 1998, 1999, 2000, and 2001, total plot biomass was harvested by mowing and baling the entire plot area. Within each plot, soil samples of the 'A' horizons were taken at five points across the landscape. Additionally, 30 1-m deep cores were taken across all plots.

These fields had a history of limited management prior to our use (they were enrolled in the Conservation Reserve Program [CRP] which only mandates a good ground cover be present) and had been in continuous switchgrass for at least five years. The landscapes and soils are typical of the area with parent materials including Peorian loess, Yarmouth-Sangamon paleosol, Pre-Illinoisan till, or alluvium. The total slope range across the research plots was 0 to 14%. The soil types in the fields under investigation are shown in Table II.1.

**RESULTS AND DISCUSSION**
*Yield and plant height.*
Biomass yield showed continued improvement in 2000 over the previous years (Table II.2). The yield improvement demonstrated in these fields resulted from three years of nitrogen application and good management practices. These fields were previously enrolled in the CRP and had received very limited management. Thus, conversion of CRP switchgrass fields to biomass production will result in improved productivity, but several years may be needed to achieve maximum sustained production. The yields seen in 2000 (averaging 6 Mg $ha^{-1}$, or nearly 3 T $A^{-1}$) make the economics of biomass production much more appealing than previous yield estimates had suggested. Further gains in productivity may be possible. The 2000 growing season was not ideal, with very low soil moisture during spring and autumn, and in 2001, a wet spring delayed nitrogen application until July. Further, in 2001, an operator error resulted in application of 0, 56, 112, and 224 kg $NH_4NO_3$ rather than N $ha^{-1}$. These events likely conspired to keep yields below their potential. The observed yields, while improving, are still relatively low, likely due to a combination of weather, site limitations (e.g., the fields consist of soils with severe B horizon limitations), and fertility and/or stand problems, and inappropriate switchgrass cultivars for southern Iowa.

The two locations (Lucas and Wayne) produced similar yields in 2000 and 2001 (data not shown), although across all three years, Lucas slightly outyielded Wayne (Table II.2). The important point is that two contrasting locations in the Chariton Valley, both of which started with less than optimal switchgrass stands, could be improved over the course of three years to produce similar, and acceptable, yields of biomass. Given that some areas within the plots still have thin stands, further yield gains appear possible. The Lucas plots were rotated into row crops at the end of 2002, but we will continue to monitor yield in the Wayne plots in 2002 and beyond.

Nitrogen fertilization increased biomass both when averaged across the three years (Table II.2). A diminishing yield gain is associated with increasing levels of nitrogen; the 112 kg $ha^{-1}$ level appears to be the most efficient. Thus, the recommended fertilization rate for switchgrass biomass production in this region of southern Iowa should be between 56 and 112 kg $ha^{-1}$.

Among landscape positions, summits had higher yields (based on subsampling) than the back and footslopes, not surprising given the better soil depth and quality at this location. The end-of-year plot harvests were made across landscape positions and thus we don't have this information on specific landscape points. Except for subsample yields, differences among landscape positions were few, possibly because the size of the plots was not large enough (even though they were quite big) to represent striking differences in topography (see Tables II.5a,b in the 2000 Annual Report for more detail, which can be found at http://www.public.iastate.edu/~brummer/pubs/2000report.pdf).

Plant height appears to be related to yield from 1998 to 2001 (Table II.2). However, this relationship may not be completely accurate, as the measurements in 1998 and 1999 were made in August, about two months prior to harvest, but the 2000 and 2001 data were collected at harvest time. Heights did not differ in a meaningful manner between locations or among nitrogen treatments in 2001 (data not shown).

*Cell wall components, nitrogen content, and ash.*
Cell wall constituents differed among years (Table II.2), but the importance of these differences is not clear. Harvest in 1999 occurred at the end of September, a month or more before the other years, and that could have caused lower cell wall content values because soluble material had not been leached as severely. The most significant differences are that lignin (ADL) was lower and cellulose was higher in 2000 than in earlier years, but fibers were higher in 2001, which was harvested at relatively the same time of year. This may be related to the yield levels among the years, with the lower yield in 2001resulting in slightly improved fiber concentration. Otherwise, the differences among years followed no clear trend. Ash values, determined as a byproduct of the cell wall digestion process, were about 5%.

The two locations, Lucas and Wayne counties, were generally quite comparable for these traits, although Wayne had slightly higher levels of fiber than Lucas. Nitrogen in the plants, as determined using the Kjeldahl method, and ADL were slightly higher in Wayne, but this difference does not appear to be biologically important. Among nitrogen fertilization levels, higher N rates generally led to higher concentrations of cell wall components (except hemicellulose). No discernable trend was evident among N levels for nitrogen concentration or ash content. The main conclusion from these data is that the cell wall content of switchgrass biomass does not appear to be altered greatly due to year, location, or fertility status, and those changes that are observed are not easily explained. Certainly, increases in yield do not appear to have major effects on cell wall constituents.

*Proximate, ultimate, and elemental analyses.*
No new data are presented in this section from the 2001 annual report (http://www.public.iastate.edu/~brummer/pubs/2001BiomassReport.pdf) due to funding restrictions. However, given the breadth of data we already have in this regard, more years are unlikely to substantively change the picture presented here.

Proximate and ultimate analyses showed that differences occurred among years for all traits except sulfur (Table II.3), based on biomass samples collected at harvest time. Like the cell wall results, the differences among years do not show any clear trend. Ash was highest in 1999, nitrogen levels were highest in 2000, and BTU content was lowest in 2000; whether these results were related to environmental variation or to the higher yields obtained in 2000 is unknown. Regardless, the differences are all relatively small, and probably would have little (if any) impact on using switchgrass as a biofuel. Differences for these traits among N fertilization rates were similarly small.

Elemental analyses showed that the concentration of a number of elements differed between 1999 and 2000, but the differences are probably immaterial regarding biofuel quality (Table II.4). Neither location nor N fertilization rate had a substantial impact on composition. However, chlorine varied by location, with Wayne having roughly the levels of Lucas, but both of these levels are within acceptable ranges for power plants. The values obtained from proximate, ultimate, and elemental analyses are broadly congruent with those found previously for switchgrass by Miles (1996).

Note that the values of particular elements in Table II.4 vary between analyses because samples for the different analyses were prepared differently, being conducted on ashed samples, dry vegetation, or acid digested vegetation and because the different analysis types may result in loss or underestimation of particular elements. However, in general, the values are comparable.

Large differences for most traits were observed among sampling dates (see Tables II.6a,b in the 2000 report for details). Based on subsample yields (plot yields were not taken at multiple times), maximum dry matter yield appears to have accumulated by September (data not shown); thus, delaying harvest until frost serves only to lower the water content of the herbage. Earlier harvests, if the material was acceptably dry, would expedite work in autumn when weather is unpredictable. The leaf fraction of the harvested material declined through November. This probably helps explain why nitrogen in the plant tissue declined throughout the year, reaching its low point by November, with little additional loss over winter. Similarly, cellulose, lignin, ash, and digestibility fell as the plants matured. Perhaps most interestingly, Cl, N, P, and S ions were substantially lower in March than November, which may be important for feedstock quality.

In general, overwintering material in the field results in slightly better biofuel, from an energy standpoint per unit dry weight, but the decline in yield during that time appears to more than offset the improved energy quality (see data in 2000 annual report).

Elemental analyses are presented in Table II.8 by location and by nitrogen level. Only the September 1999 samples were analyzed due to limited samples from the 1998 growing season. In general, neither location nor nitrogen treatment affected elemental composition of biomass, with the exception of Cl, P, and Ba. Also, elemental values determined by ion chromatography corresponded very well with those determined by INAA and/or inductively coupled plasma emission spectometry (ICP). Note that the values in Table II.8 vary between analyses because they were conducted on ashed samples, dry vegetation, or acid digested vegetation and because the different analysis types may result in loss or underestimation of particular elements. However, in general, the values are comparable.

**Table II.1.** Summary of soils information available from the Lucas and Wayne County soil surveys (Prill, 1960, and Lockridge, 1971, respectively).

| Map unit | Series and great group classification | Field number* and estimated MU area (%) | | | |
|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 7 |
| ClC2, CmC3 | Clarinda, Vertic Argiaquoll | | | 70 | 20 |
| Gd | Grundy, Aquertic Argiudoll | 100 | 60 | | |
| Ha | Haig, Vertic Argiaquoll | | 10 | | |
| Oa | Omitz-Gravity-Wabash, Cumulic Mollisolls | | 10 | | |
| Sa | Shelby–Adair, Typic & Aquertic Argiudolls | | 20 | | |
| SeB, SfC2 | Seymour, Aquertic Argiudoll | | | 15 | 80 |
| ShD2 | Shelby, Typic Argiudoll | | | 15 | |

*Field numbers 1 and 2 are in Lucas County, and 3 and 4 in Wayne County.

**Table II.2.** Switchgrass yield, plant height, fiber content, nitrogen and ash for 1998, 1999, 2000, and 2001 in two southern Iowa locations and at four nitrogen fertilization rates.

| | Yield | Height | NDF | ADF | ADL | Cell | Hemi | N | Ash |
|---|---|---|---|---|---|---|---|---|---|
| | Mg/ha | cm | ------------------------------ | | | g $kg^{-1}$ | ------------------------------ | | |
| Mean | 4.6 | 161.2 | 773.5 | 456.8 | 69.1 | 387.7 | 316.7 | 4.7 | 48.3 |
| 1998 | 2.9 | 118.0 | 776.0 | 454.9 | 75.9 | 379.0 | 321.1 | 3.5 | 43.4 |
| 1999 | 3.9 | 145.0 | 710.7 | 414.1 | 70.7 | 343.4 | 296.6 | 5.5 | 56.1 |
| 2000 | 6.0 | 190.0 | 778.2 | 458.5 | 63.0 | 395.5 | 319.6 | 5.9 | 49.8 |
| 2001 | 5.6 | 191.7 | 828.9 | 499.7 | 66.7 | 433.0 | 329.2 | 4.2 | 43.9 |
| LSD (5%) | 0.3 | 3.4 | 9.9 | 11.3 | 3.3 | 8.6 | 8.0 | 0.4 | 3.1 |
| Lucas | 4.9 | 162.0 | 765.0 | 448.1 | 66.2 | 381.8 | 316.9 | 4.4 | 50.3 |
| Wayne | 4.3 | 160.3 | 782.0 | 465.6 | 72.0 | 393.6 | 316.4 | 5.1 | 46.3 |
| LSD (5%) | 0.2 | ns | 7.0 | 8.0 | 2.4 | 6.1 | ns | 0.3 | 2.2 |
| 0 | 3.9 | 154.6 | 769.1 | 446.6 | 66.0 | 380.6 | 322.5 | 4.8 | 51.2 |
| 50 | 4.5 | 160.5 | 776.8 | 458.4 | 68.7 | 389.6 | 318.4 | 4.5 | 47.8 |
| 100 | 4.9 | 164.8 | 771.3 | 453.3 | 68.8 | 384.5 | 318.0 | 4.6 | 48.1 |
| 200 | 5.2 | 164.8 | 776.7 | 469.0 | 72.9 | 396.1 | 307.7 | 5.1 | 46.0 |
| LSD (5%) | 0.3 | 3.4 | ns | 11.3 | 3.3 | 8.6 | 8.0 | 0.4 | 3.1 |

Harvest/sampling dates: November 1998, September 1999, October 2000, and October 2001.

**Table II.3.** Proximate and ultimate analyses of switchgrass biomass for 1998, 1999, and 2000 in two southern Iowa locations and at four nitrogen fertilization rates.

| | Ash | Volume matter | Fixed C | BTU | C | H | N | O | S |
|---|---|---|---|---|---|---|---|---|---|
| | -------------------- | ---------- | ---------- | ---------- | ----% Dry weight---- | ---------- | ---------- | ---------- | -------------------- |
| Year | | | | | | | | | |
| 1998 | 4.10 | 80.56 | 15.34 | 7950 | 48.25 | 5.26 | 0.25 | 42.08 | 0.062 |
| 1999 | 4.86 | 78.35 | 16.79 | 7943 | 46.94 | 5.52 | 0.25 | 42.40 | 0.063 |
| 2000 | 4.12 | 78.73 | 17.14 | 7795 | 47.56 | 5.56 | 0.68 | 42.02 | 0.063 |
| LSD (5%) | 0.34 | 0.44 | 0.29 | 52 | 0.30 | 0.10 | 0.06 | 0.31 | ns |
| Location | | | | | | | | | |
| Lucas | 4.64 | 78.87 | 16.49 | 7876 | 47.45 | 5.44 | 0.38 | 42.03 | 0.060 |
| Wayne | 4.08 | 79.55 | 16.37 | 7917 | 47.71 | 5.45 | 0.41 | 42.31 | 0.065 |
| LSD (5%) | ns | 0.36 | ns | ns | ns | ns | ns | ns | ns |
| Nitrogen Level | | | | | | | | | |
| 0 | 4.74 | 78.96 | 16.31 | 7880 | 47.37 | 5.48 | 0.38 | 42.00 | 0.071 |
| 100 | 4.41 | 79.29 | 16.30 | 7897 | 47.52 | 5.44 | 0.39 | 42.19 | 0.062 |
| 200 | 3.93 | 79.39 | 16.68 | 7911 | 47.86 | 5.42 | 0.41 | 42.32 | 0.055 |
| LSD (5%) | 0.34 | ns | 0.29 | ns | 0.30 | ns | ns | ns | 0.012 |

Harvest dates: November 1998, September 1999, and October 2000.

**Table II.4**. Elemental analysis of switchgrass biomass harvested in October 1999 and 2000 from two southern Iowa locations and at three nitrogen fertilization rates.

| | | | | | Two-year average | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | By year | | | By location | | | By nitrogen level (kg $ha^{-1}$) | | | | Overall |
| Element | Unit | 1999 | 2000 | LSD | Lucas | Wayne | LSD | 0 | 112 | 224 | LSD | mean |
| *Constituents determined using INAA on dry vegetation* | | | | | | | | | | | | |
| Au | ppb | 4.39 | 0.32 | 0.77 | 1.93 | 2.79 | ns | 2.97 | 2.32 | 1.79 | ns | 2.36 |
| Ba | ppm | 19.83 | 16.72 | 2.72 | 20.33 | 16.22 | ns | 16.00 | 16.92 | 21.92 | 3.60 | 18.28 |
| Br | ppm | 16.24 | 12.98 | 3.22 | 12.25 | 16.97 | ns | 16.61 | 16.33 | 10.89 | 4.19 | 14.61 |
| Co | ppm | 0.36 | 0.16 | 0.07 | 0.23 | 0.29 | ns | 0.25 | 0.29 | 0.23 | ns | 0.26 |
| Cl | ppm | 1003 | 767 | 190 | 1091 | 680 | ns | 928 | 877 | 850 | ns | 885 |
| Cr | ppm | 0.45 | 0.19 | 0.26 | 0.29 | 0.36 | ns | 0.39 | 0.34 | 0.23 | ns | 0.32 |
| Fe | % | 0.008 | 0.002 | 0.003 | 0.006 | 0.004 | ns | 0.004 | 0.006 | 0.004 | ns | 0.005 |
| K | % | 0.56 | 0.53 | ns | 0.57 | 0.52 | ns | 0.54 | 0.56 | 0.53 | ns | 0.54 |
| Mo | ppm | 0.61 | 0.33 | 0.15 | 0.21 | 0.74 | 0.18 | 0.54 | 0.51 | 0.37 | ns | 0.47 |
| Na | ppm | 33.37 | 30.37 | 2.46 | 32.13 | 31.61 | ns | 30.87 | 34.12 | 30.63 | ns | 31.87 |
| Zn | ppm | 18.72 | 17.11 | ns | 18.44 | 17.39 | ns | 18.42 | 17.08 | 18.25 | ns | 17.92 |
| La | ppm | 0.10 | 0.02 | 0.02 | 0.06 | 0.07 | ns | 0.07 | 0.06 | 0.06 | ns | 0.06 |
| *Constituents determined using ICP on fused and acid-digested vegetation* | | | | | | | | | | | | |
| $SiO_2$ | % | 57.97 | 54.59 | 2.57 | 55.38 | 57.18 | ns | 57.96 | 57.11 | 53.77 | 3.50 | 56.28 |
| $Al_2O_3$ | % | 0.20 | 0.24 | 0.04 | 0.24 | 0.20 | ns | 0.20 | 0.25 | 0.21 | ns | 0.22 |
| $Fe_2O_3$ | % | 0.17 | 0.14 | ns | 0.16 | 0.15 | ns | 0.13 | 0.14 | 0.19 | 0.04 | 0.15 |
| MnO | % | 0.25 | 0.20 | ns | 0.22 | 0.23 | ns | 0.22 | 0.20 | 0.26 | ns | 0.23 |
| MgO | % | 4.39 | 4.42 | ns | 3.82 | 4.99 | 0.41 | 4.29 | 4.44 | 4.50 | ns | 4.41 |
| CaO | % | 7.48 | 7.48 | ns | 6.97 | 7.99 | 0.48 | 7.01 | 7.34 | 8.09 | 0.59 | 7.48 |
| $Na_2O$ | % | 0.31 | 0.04 | 0.18 | 0.20 | 0.15 | ns | 0.10 | 0.26 | 0.16 | ns | 0.18 |
| $K_2O$ | % | 10.83 | 13.47 | 1.08 | 11.58 | 12.72 | ns | 11.47 | 12.35 | 12.63 | ns | 12.15 |
| $TiO_2$ | % | 0.009 | 0.021 | 0.003 | 0.017 | 0.013 | ns | 0.014 | 0.016 | 0.015 | ns | 0.015 |
| $P_2O_5$ | % | 3.45 | 3.33 | ns | 4.35 | 2.42 | 0.39 | 3.82 | 3.36 | 2.98 | 0.48 | 3.39 |
| LOI$^{\dagger}$ | % | 14.05 | 15.94 | ns | 16.62 | 13.38 | 2.74 | 14.29 | 13.92 | 16.78 | ns | 15.00 |
| Ba | ppm | 418.56 | 409.83 | ns | 428.28 | 400.11 | ns | 358.33 | 366.25 | 518.00 | 81.34 | 414.19 |
| Sr | ppm | 253.22 | 254.50 | ns | 276.06 | 231.67 | 20.29 | 234.08 | 250.67 | 276.83 | 24.85 | 253.86 |
| Zr | ppm | 13.22 | 14.89 | 1.18 | 13.72 | 14.39 | ns | 14.42 | 13.58 | 14.17 | ns | 14.06 |
| Ag | ppm | 0.52 | 0.00 | 0.38 | 0.18 | 0.31 | ns | 0.16 | 0.44 | 0.14 | ns | 0.25 |
| Cu | ppm | 4.67 | 68.00 | 10.02 | 27.44 | 45.22 | 10.02 | 37.17 | 35.25 | 36.58 | ns | 36.33 |
| Zn | ppm | 20.67 | 330.61 | 42.89 | 183.06 | 168.22 | ns | 162.83 | 163.33 | 200.75 | ns | 175.64 |
| *Constituents determined using INAA on ashed vegetation* | | | | | | | | | | | | |
| Au | ppb | 65.89 | 4.11 | 13.39 | 25.56 | 44.44 | ns | 38.42 | 33.50 | 33.08 | ns | 35.00 |
| Ba | ppm | 272.22 | 327.78 | 53.11 | 307.78 | 292.22 | ns | 266.67 | 256.67 | 376.67 | 69.32 | 300.00 |
| Br | ppm | 151.39 | 147.22 | ns | 115.28 | 183.33 | ns | 156.50 | 159.67 | 131.75 | ns | 149.31 |
| Ca | ppb | 5.60 | 6.59 | 0.58 | 5.72 | 6.48 | ns | 5.74 | 5.98 | 6.58 | ns | 6.10 |

*continued...*

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Two-year average | | | | | | | | |
| | | By year | | | By location | | | By nitrogen level (kg $ha^{-1}$) | | | | Overall | |
| Element | Unit | 1999 | 2000 | LSD | Lucas | Wayne | LSD | 0 | 112 | 224 | LSD | mean |
| Co | ppm | 5.67 | 5.00 | ns | 4.17 | 6.50 | 1.47 | 5.67 | 5.50 | 4.83 | ns | 5.33 |
| Cr | ppm | 7.00 | 8.22 | ns | 7.28 | 7.94 | ns | 7.92 | 8.50 | 6.42 | ns | 7.61 |
| Fe | % | 0.09 | 0.12 | 0.01 | 0.11 | 0.10 | ns | 0.10 | 0.10 | 0.11 | ns | 0.10 |
| K | % | 11.35 | 16.18 | 1.20 | 13.50 | 14.03 | ns | 12.97 | 13.75 | 14.58 | ns | 13.77 |
| Mo | ppm | 10.33 | 8.44 | ns | 2.78 | 16.00 | 3.12 | 10.00 | 10.42 | 7.75 | ns | 9.39 |
| Na | ppm | 264.61 | 311.94 | 35.68 | 308.11 | 268.44 | ns | 282.50 | 308.25 | 274.08 | ns | 288.28 |
| Rb | ppm | 53.00 | 52.94 | ns | 44.56 | 61.39 | ns | 49.83 | 55.92 | 53.17 | ns | 52.97 |
| Zn | ppm | 352.22 | 452.78 | 63.09 | 388.33 | 416.67 | ns | 380.83 | 377.50 | 449.17 | ns | 402.50 |
| La | ppm | 1.71 | 1.92 | ns | 1.73 | 1.89 | ns | 1.75 | 1.66 | 2.03 | ns | 1.81 |
| Sm | ppm | 0.22 | 0.27 | 0.04 | 0.22 | 0.27 | ns | 0.26 | 0.20 | 0.28 | 0.06 | 0.24 |

†LOI=Lost on ignition.

# II.2. ENVIRONMENTAL IMPACTS OF SWITCHGRASS PRODUCTION

## II.2.1 Summary of baseline soil properties at pertinent sites

**OBJECTIVE**
The objective of this experiment is to determine the effect of soil variability and environmental quality on switchgrass and reed canarygrass production

**METHODS**
This objective was addressed during fall 2001 field season via extensive data collection pertinent for assessing biomass production, soil suitability and environmental quality interactions. Soil data were collected from three types of sites: (1) switchgrass variety trial plots, (2) switchgrass fertility trial fields, and (3) reed canary grass fertility trial fields. Soil (epipedon) data collected for the switchgrass variety trial plots includes plant available phosphorus (P) content, plant available potassium (K) content, soil pH, soil organic carbon content (wt/wt), soil organic nitrogen content (wt/wt), bulk density and percent ground cover (Table II.5). Soil (epipedon) data collected from eight switchgrass fertility fields (four fields in Lucas County, four fields in Wayne County) and the one reed canary grass fertility field (Wayne County) includes plant available phosphorus (P) content, plant available potassium (K) content, soil pH and bulk density with a large subset of samples also being analyzed for soil organic carbon content (wt/wt), soil organic nitrogen content (wt/wt), bulk density and percent ground cover. (Tables II.6 through II.8). These samples were collected along hillslope transects that captured the soil-landscape variability designed into this experiment. In addition, plant samples adjacent to the soil samples were also collected and analyzed for biomass quality although that data is not discussed in this report.

Soil analyses for P, K, pH, SOC, and SON were completed in the ISU Soil Testing Laboratory following standard procedures. Bulk density was determined in the ISU Pedometrics Laboratory. Ground cover was determined in the field.

**RESULTS AND DISCUSSION**

Soil fertility across the switchgrass variety trail plots is good with P, K, and soil pH being generally optimal to high (Table II.5). The average SOC content of 2.4% appears to be typical for the area, with the SON contents likely being higher than found in most typical farm fields. The average SOC:SON ratio of 12:1 is ideal for microbial activity necessary for the successful decomposition and subsequent carbon sequestration of roots and leaf litter. Likewise, the average bulk density of 1.4 g/cm$^3$ is near optimal for crop production (i.e., a bulk density of 1.35 g/cm$^3$ is generally considered ideal for terrestrial crop growth). Ground cover generated by most varieties is thought to be good although more in-depth evaluation is warranted to insure that erosion and/or crusting does not become a problem in varieties such as Kanlow, NL932HC, and NU942HC.

Soil fertility across the switchgrass fields in Wayne County is likely typical for most CRP and biomass fields in the Chariton Valley (Table II.6). Plant available P generally tests low while plant available K generally tests optimal to high. Like K, pH and bulk density are generally near optimal. The average ground cover of 73% is good with respect to likely prevention of crusting and extensive sheet erosion although the presence of less than 50% ground cover on the foot- and toe-slope of transect 13 suggests this may be a prime location for rill (and ultimately gully). Interesting these two points on transect 13 do not have exceptionally low soil fertility (in fact, soil P is above average for the transects), which is speculated to indicate some other soil features are limiting ground cover development such as a root restrictive B-horizon which in turn limits plant growth. This will be investigated during the 2002-2003 field seasons.

Soil fertility across the switchgrass fields in Lucas County is likely – on average - better than many CRP and biomass fields in the Chariton Valley although the high variability found across these transects is thought to be not uncommon (Table II.7). Plant available P is on average optimal although several samples are low and numerous others are high. Plant available K generally tests high. Soil pH is generally low. Bulk density likewise can be considered generally low although even a bulk density of 1.0 g/cm-3 is not likely to limit crop growth although it might limit the load bearing capacity of the soil, which means that heavy equipment could leave ruts. Ground cover is excellent.

The reed canary grass field has overall optimal – or even excellent - soil properties with respect to crop growth (Table II.8). The average P, K, pH and bulk density soil test values are exactly what is recommended by most Midwest agronomists. Furthermore reviewing the values indicates there is little variability across the landscape.

Table II.5. Switchgrass variety trial soil data summary, ISU McNay Farm, Lucas County.

| Variety | P | K | pH | SOC | SON | BD | GC |
|---|---|---|---|---|---|---|---|
| | | | H20 | % | % | g/cm$^3$ | % |
| Alamo | 34.8 | 149.0 | 6.89 | 2.41 | 0.17 | 1.41 | 74 |
| Blackwell | 40.1 | 141.4 | 6.93 | 2.41 | 0.18 | 1.40 | 83 |
| Cave-In-Rock | 48.6 | 133.4 | 6.73 | 2.31 | 0.16 | 1.40 | 74 |
| Caddo | 28.0 | 138.1 | 7.13 | 2.32 | 0.16 | 1.44 | 83 |
| Carthage | 37.4 | 144.5 | 7.02 | 2.48 | 0.18 | 1.38 | 81 |
| Forestburg | 36.8 | 136.5 | 7.06 | 2.36 | 0.16 | 1.44 | 80 |
| HDMDC3 | 33.4 | 143.6 | 7.07 | 2.45 | 0.18 | 1.39 | 80 |
| HYLDC3 | 39.4 | 163.4 | 7.05 | 2.41 | 0.18 | 1.47 | 78 |
| IAGT | 33.8 | 135.8 | 7.19 | 2.45 | 0.17 | 1.40 | 81 |
| IALM | 36.0 | 135.0 | 6.98 | 2.46 | 0.17 | 1.38 | 77 |
| Kanlow | 40.3 | 140.4 | 7.18 | 2.67 | 0.19 | 1.39 | 61 |
| NL932HC | 27.5 | 145.1 | 7.12 | 2.33 | 0.15 | 1.46 | 67 |
| NU942HC | 58.4 | 157.1 | 6.85 | 2.20 | 0.17 | 1.42 | 69 |
| Pathfind | 63.0 | 157.9 | 6.85 | 2.21 | 0.16 | 1.37 | 76 |
| SU92ISO | 37.0 | 139.9 | 6.86 | 2.31 | 0.17 | 1.40 | 77 |
| SU942HC | 43.4 | 144.3 | 7.18 | 2.38 | 0.16 | 1.43 | 81 |
| Shawnee | 37.8 | 170.4 | 6.98 | 2.42 | 0.17 | 1.41 | 73 |
| Shelter | 30.0 | 146.5 | 7.07 | 2.46 | 0.17 | 1.42 | 77 |
| Sunburst | 56.1 | 153.1 | 6.97 | 2.21 | 0.17 | 1.43 | 85 |
| Trailblazer | 33.4 | 138.4 | 7.24 | 2.41 | 0.16 | 1.41 | 79 |
| | | | | | | | |
| AVE | 39.7 | 145.7 | 7.0 | 2.4 | 0.2 | 1.4 | 76.8 |
| p-value | 0.8263 | 0.3247 | 0.913 | 0.0432 | 0.6701 | 0.5883 | 0.0043 |
| LSD | ns | ns | ns | 0.23 | ns | ns | 11 |

Table II.6. Switchgrass field trial soil data summary, Wayne County fields.

| Transect | Landscape Position | | P | K | pH | BD | | GC |
|---|---|---|---|---|---|---|---|---|
| 3 | Summit | | 1 | 131 | 6.2 | 1.38 | . | 80 |
| 3 | Shoulder | | 2 | 145 | 6.5 | 1.34 | . | 73 |
| 3 | Backslope | | 1 | 145 | 6.5 | 1.38 | . | 76 |
| 3 | Footslope | | 1 | 137 | 6.6 | 1.52 | . | 71 |
| 3 | Toeslope | | 1 | 124 | 6.7 | 1.43 | . | 80 |
| 7 | Summit | | 1 | 147 | 6.8 | 1.33 | . | 86 |
| 7 | Shoulder | | 1 | 117 | 6.6 | 1.35 | . | 78 |
| 7 | Backslope | | 1 | 114 | 6.6 | 1.36 | . | 71 |
| 7 | Footslope | | 1 | 138 | 6.7 | 1.44 | . | 73 |
| 7 | Toeslope | | 1 | 116 | 6.6 | 1.42 | . | 73 |
| 10 | Summit | | 2 | 121 | 6.7 | 1.43 | . | 76 |
| 10 | Shoulder | | 2 | 122 | 6.6 | 1.35 | . | 76 |
| 10 | Backslope | | 1 | 130 | 6.8 | 1.43 | . | 84 |
| 10 | Footslope | | 1 | 129 | 6.7 | 1.39 | . | 78 |
| 10 | Toeslope | | 1 | 138 | 6.7 | 1.43 | . | 73 |
| 13 | Summit | | 7 | 128 | 6.7 | 1.39 | . | 63 |
| 13 | Shoulder | | 10 | 142 | 6.7 | 1.43 | . | 63 |
| 13 | Backslope | | 7 | 129 | 6.5 | 1.34 | . | 59 |
| 13 | Footslope | | 7 | 144 | 6.4 | 1.44 | . | 45 |
| 13 | Toeslope | | 3 | 155 | 6.2 | 1.33 | . | 45 |
| 18 | Summit | | 2 | 122 | 6.3 | 1.35 | . | 76 |
| 18 | Shoulder | | 2 | 131 | 6.1 | 1.40 | . | 71 |
| 18 | Backslope | | 2 | 136 | 6.2 | 1.40 | . | 80 |
| 18 | Footslope | | 2 | 132 | 6.3 | 1.33 | . | 88 |
| 18 | Toeslope | | 2 | 132 | 6.4 | 1.38 | . | 84 |
| | | AVE | 2.40 | 131.92 | 6.50 | 1.39 | . | 72.82 |
| | | MIN | 1.00 | 114.00 | 6.10 | 1.33 | . | 44.90 |
| | | MAX | 9.50 | 154.50 | 6.78 | 1.52 | . | 87.76 |

Table II.7. Switchgrass field trial soil data summary, Lucas County fields.

| Transect | Landscape Position | | P | K | pH | BD | | GC |
|---|---|---|---|---|---|---|---|---|
| 23 | Summit | | 22 | 196 | 6.1 | 1.21 | . | 78 |
| 23 | Shoulder | | 15 | 182 | 6.0 | 1.27 | . | 86 |
| 23 | Backslope | | 19 | 173 | 5.9 | 1.24 | . | 80 |
| 23 | Footslope | | 31 | 172 | 5.9 | 1.19 | . | 76 |
| 23 | Toeslope | | 32 | 171 | 5.9 | 1.35 | . | 90 |
| 28 | Summit | | 13 | 220 | 5.7 | 1.19 | . | 86 |
| 28 | Shoulder | | 17 | 222 | 5.7 | 1.18 | . | 90 |
| 28 | Backslope | | 32 | 314 | 5.8 | 1.13 | . | 84 |
| 28 | Footslope | | 28 | 279 | 5.6 | 1.11 | . | 86 |
| 28 | Toeslope | | 19 | 210 | 5.6 | 1.28 | . | 84 |
| 31 | Summit | | 22 | 297 | 5.4 | 1.24 | . | 73 |
| 31 | Shoulder | | 17 | 229 | 5.6 | 1.19 | . | 82 |
| 31 | Backslope | | 19 | 163 | 5.6 | 1.23 | . | 84 |
| 31 | Footslope | | 18 | 148 | 5.5 | 1.17 | . | 90 |
| 31 | Toeslope | | 29 | 174 | 5.5 | 1.35 | . | 71 |
| 36 | Summit | | 13 | 174 | 6.2 | 1.32 | . | 92 |
| 36 | Shoulder | | 8 | 160 | 6.3 | 1.29 | . | 94 |
| 36 | Backslope | | 7 | 161 | 6.3 | 1.33 | . | 86 |
| 36 | Footslope | | 5 | 151 | 6.3 | 1.31 | . | 90 |
| 36 | Toeslope | | 6 | 148 | 6.1 | 1.29 | . | 90 |
| 39 | Summit | | 13 | 119 | 6.8 | 1.42 | . | 92 |
| 39 | Shoulder | | 9 | 109 | 6.7 | 1.37 | . | 92 |
| 39 | Backslope | | 6 | 151 | 6.5 | 1.27 | . | 88 |
| 39 | Footslope | | 3 | 169 | 6.4 | 1.23 | . | 82 |
| 39 | Toeslope | | 12 | 153 | 6.7 | 1.34 | . | 92 |
| 44 | Summit | | 15 | 142 | 6.7 | 1.41 | . | 80 |
| 44 | Shoulder | | 9 | 146 | 6.8 | 1.41 | . | 90 |
| 44 | Backslope | | 12 | 146 | 6.5 | 1.39 | . | 86 |
| 44 | Footslope | | 13 | 163 | 6.5 | 1.31 | . | 86 |
| 44 | Toeslope | | 5 | 164 | 6.0 | 1.44 | . | 84 |
| | | AVE | 15.37 | 179.97 | 6.07 | 1.28 | . | 85.24 |
| | | MIN | 2.50 | 109.00 | 5.35 | 1.11 | . | 71.43 |
| | | MAX | 32.00 | 313.50 | 6.83 | 1.44 | . | 93.88 |

Table II.8. Reed Canary Grass field trial soil data summary, Wayne County field.

| Transcect | Landscape Position | | P | K | pH | BD | | |
|---|---|---|---|---|---|---|---|---|
| 1 | Summit | | 15 | 95 | 7.0 | 1.33 | . | . |
| 1 | Shoulder | | 16 | 99 | 6.9 | 1.19 | . | . |
| 1 | Backslope | | 15 | 97 | 7.1 | 1.30 | . | . |
| 1 | Footslope | | 13 | 90 | 6.9 | 1.25 | . | . |
| 1 | Toeslope | | 11 | 110 | 6.8 | 1.35 | . | . |
| 2 | Summit | | 17 | 115 | 7.0 | 1.33 | . | . |
| 2 | Shoulder | | 21 | 91 | 6.8 | 1.33 | . | . |
| 2 | Backslope | | 10 | 74 | 6.9 | 1.44 | . | . |
| 2 | Footslope | | 7 | 82 | 7.0 | 1.36 | . | . |
| 2 | Toeslope | | 8 | 107 | 6.8 | 1.30 | . | . |
| 3 | Summit | | 16 | 122 | 7.0 | 1.24 | . | . |
| 3 | Shoulder | | 18 | 145 | 6.8 | 1.28 | . | . |
| 3 | Backslope | | 14 | 94 | 6.9 | 1.34 | . | . |
| 3 | Footslope | | 9 | 93 | 7.1 | 1.37 | . | . |
| 3 | Toeslope | | 9 | 100 | 6.9 | 1.34 | . | . |
| | | AVE | 13.13 | 100.70 | 6.91 | 1.32 | | |
| | | MIN | 7.00 | 74.00 | 6.78 | 1.19 | . | . |
| | | MAX | 21.00 | 145.00 | 7.10 | 1.44 | . | . |

## II.2.2 ON-FARM SWITCHGRASS YIELD IN THE LOWER CHARITON RIVER WATERSHED OF IOWA, 1999-2000.

*A note being prepared for submission to the Journal of the Iowa Academy of Science*

Lee Burras[1], Charles Brummer[1], John Sellers[2,3], Martin Braster[3,4], Tyler Jacobson[3,4], Velvet Glenn[3], Mike Barker[1], and Julie McLaughlin[1]

[1]Department of Agronomy
Iowa State University
Ames, IA 50011-1010

[2]Prairie Lands Bio-Products, Inc.
Centerville, IA 52544-8922

[3]Chariton Valley RC&D
Centerville, IA 52544-8922

[4]Rathbun Regional Water Assoc., Inc.
Centerville, IA 52544-8307

### INTRODUCTION

Switchgrass *(Panicum virgatum, L.)* is a warm-season perennial that commonly grew in the native mesic prairies of central North America (Boon and Groe, 1990). It's extent and frequency in Iowa diminished dramatically between 1850 and 1930 as all but 12,000 of the state's 12,000,000 hectares of prairie was plowed and subsequently planted to introduced species of crops (see Smith, 1981; Thompson, 1992). The loss of switchgrass and the rest of the prairie flora occurred because few farmers or agronomists in Iowa perceived it, or any of the common prairie plants, as a potential valuable crop.

Only recently has this trend begun to reverse in Iowa. An important area of this reversal is the lower Chariton River Watershed where switchgrass has become an important crop in the past 15 years. It currently is grown on 10% to 15% of the land area (Cooper, 2001, Sellers, 1999). The impetus for most switchgrass production within the watershed – as well as across the USA - is the USDA's Conservation Reserve Program (CRP), which was enacted by Congress in 1985. Zinn (1997, 2001, 2002) gives two reasons for Congress's support of CRP: (a) nationwide cropland erosion rates rivaling the Dust Bowls during the late 1970's and early 1980's, and (b) widespread economic depression within the agricultural sector.

Subsequent review of CRP indicates it to be a success from a congressional perspective (Zinn, 2001). He reports Congress is satisfied with CRP because of the widespread voluntary participation of farmers and landowners, a nationwide drop of 22% in overall erosion as well as the development of 13,600 km of filter strips and about 700,000 hectares of improved wildlife habitat. Zinn (2002) estimates total annual CRP expenditures to be about $1.5 billion, with the program benefits in terms of soil and environmental quality being between about $1.0 to $1.5 billion.

The Chariton River Valley is an area where both of Congress's concerns (high erosion, agricultural-sector depression) were endemic during the 1980's because of the prevalence of marginal, low-yielding, highly erodible cropland. Thus, enaction of the CRP resulted in 50,000 hectares of switchgrass being planted in the Chariton River Watershed with almost all of it grown as soil conserving land cover with fields being located and maintained in compliance with CRP regulations (see Cooper, 2001, Sellers, 1999). It is thought three reasons motivated the 1000's of farmers and land owners in the Chariton River Watershed to participate in the early phases of CRP: (a) a desire to improve their land quality through reduced water erosion, (b) a desire to help in improving surface water quality through reduced runoff and erosion, and (c) the annual payments from the USDA in the range of $100 to $300 per hectare. Beginning about 1996, a fourth motivation occurred – farmers In the Chariton River Valley could market switchgrass, even that being grown on CRP enrolled land, as a biofuel to be mixed with coal and burned to generate electricity in the Ottumwa Generating Station.

This new motivation, which was largely driven and underwritten by a USDOE and ORNL initiative in bioenergy and biofuels, has had profound impacts in terms of agronomic research because the knowledge base necessary to successfully grow switchgrass, or any plant, as a cash crop is significantly greater than that needed to grow it as a cover crop suitable for land conservation. In the case of switchgrass production for the Chariton Valley, none of the following rudimentary agronomic knowledge bases were available in 1996:

- best establishment techniques,
- optimal fertilizer regimes,
- relative suitability of cultivars,
- likely pests and appropriate pest management,
- actual on- and off-farm environmental impacts,
- reasonable yield expectations, or
- potential profitability.

In and since 1996 research was initiated to address each of preceding issues, with most projects continuing today.

## OBJECTIVE

The objective of this note is to report field-scale switchgrass yields obtained in the Chariton River Watershed during 1999 and 2000. Secondarily this report examines whether the commonly used Corn Suitability Rating (CSR) offers promise as a tool for predicting switchgrass yields in the Chariton River Watershed.

## MATERIALS AND METHODS

Switchgrass yields were measured in 12 and 21 fields in 1999 and 2000, respectively. Each field (except 00-16 and 00-22) had been managed identically as well as in a manner consistent with what is currently thought to be best management practices. Management activities consisted of applying 160 kg ha$^{-1}$ N fertilizer prior to the growing season, use of recommended rates of atrazine and 2,4-D (i.e., 1.68 kg ha$^{-1}$ of each) for weed control, and harvesting following the first killing frost, which caused above ground growth to cease. Harvesting consisted of mowing the dry, senescent stems at about 15 cm above ground level, followed by windrowing and then baling as large square bales.

Each bale was weighed in the field. Average yields for the fields were obtained by summing the weight of individual bales and then dividing this number by the total field area.

Field and strip boundaries were determined using GPS having approximately 1-m accuracy. These boundaries were then incorporated into GIS. The GIS was then used in conjunction with the Iowa soil survey database in order to determine the area as well as selected attributes of each map unit such as slope class, erosion class, and CSR. Correlation and regression analysis was used to evaluate the relationship between switchgrass yield and selected field properties.

## RESULTS AND DISCUSSION

Within the 33 total switchgrass fields examined, yields ranged from 1.9 to 8.4 and 3.9 to 12.1 Mg ha$^{-1}$ for 1999 and 2000, respectively (Table II.9). No significant difference is apparent in yield across years, with the overall mean being about 5.5 Mg ha$^{-1}$ although "significance" is used loosely since the sets of fields used each year were different. The two sets of fields are thought to be statistically representative of the normal range of switchgrass fields present in the Chariton River Watershed.

Interestingly, the overall mean of about 5.5 Mg ha$^{-1}$ is numerically greater than the four year overall average of the nitrogen fertilization trials ( i.e., 4.6 Mg ha$^{-1}$ , see Table II.2) although they are in line with those found over the past two years. These averages are also comparable to 1996 yields found in five large CRP fields in Wisconsin (Center for Agricultural Research Systems. 2002). Returning to previous work done on this project, Brummer et al (2001) reported variety trials yields (small plots), with yields averaging 6.4, 11.8, and 9.1 Mg ha-1 for 1998, 1999, and 2000, respectively. The overall range in yields from these three years of variety trials was 4.9 to 17.5 Mg $ha^{-1}$ although it must be pointed out these values are from plots that are only a few $m^2$ in area; and, thus, probably no valid comparison can be made with the data being discussed here.

Field areas ranged from 4.3 to 22.8 hectares in 1999 and 0.6 to 60.9 hectares in 2000 (Table II.9). This range in field size is typical for the Chariton River Watershed. No correlation was found between field size and switchgrass yield for 1999, 2000, and 1999-2000 data.

The age of switchgrass stands ranged from two to 13 and one to 13 for the 1999 and 2000 fields, respectively (Table II.9). The mean stand age was greater for the 1999 fields than for the 2000 fields (6.25 versus 3.19 years) although the significance of this is difficult to interpret for two reasons. First, both data sets exhibit a high standard deviations. Second, while age of switchgrass stand is known to influence yield there is no way to effectively compare age effects given the differing distributions of ages in the 1999 and 2000 data.

The range in mean CSR values is 30 to 77 for the 33 fields studied over 1999 and 2000. These values were determined as a weighted average using each soil map unit's discrete CSR value corrected for its relative area within the field. It should be noted the 1999 mean CSR values were calculated in a less precise manner than the 2000 values. Overall there was no difference between the population of fields used in 1999 and 2000 at least in terms of CSR. Both years included fields that CSR values indicate as being very poor through good. Analysis of field yields and CSR values resulted in low correlation values for the 1999, 2000, and combined 1999-2000 data. The greatest correlation coefficient determined –0.41. It was obtained using only the 2000 data and followed exclusion of fields 00-16 and 00-22, which did not have nitrogen, fertilizer added. More typical correlation coefficients were between –0.26 and 0.10. In short, there is no meaningful correlation between CSR and a field's switchgrass yield, at least for a given year or the two-year period examined. This result is consistent with that obtained with strip yields from farmer fields in 1999 (Brummer et al., 2001). It is possible a better analysis would be between cool season grass ratings (a soil property available for Iowa soil map units) and switchgrass yield; however, this is thought to be unlikely given the approximately 0.9 correlation between that rating and CSR values.

In an attempt to explain the yield variability obtained across the fields, multiple linear regression was applied to switchgrass yield versus different combinations of CSR, stand age, and field size. These analyses were completed for 1999, 2000, and 1999-2000 combined data. No significant results were obtained. More challenging, attempts to use regression (really, best fit analysis) did not provide useful rankings of different soil map units.

It is speculated no useful results were obtained because of the number of variables involved – e.g., wide range in stand ages, large number of soil map units, large number of farmers involved (six just in 2000). It is recognized more sophisticated statistical analysis might have found some significant factors; however, it is not thought likely given the variables just described.

**CONCLUSION**

On-farm, field level switchgrass yields averaged about 5.5 Mg $ha^{-1}$ across 1999 and 2000 for the 33 fields studied. This average is thought to be reasonable for the whole of the Chariton River Watershed's switchgrass fields provided those fields are managed for weed control and have about 140 kg $ha^{-1}$ nitrogen fertilizer added.

Table II.9. Switchgrass yields from farm fields across the Chariton River Watershed, 1999-2000.

| 1999 Data | | | | | 2000 Data | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Field No.** | **Yield ($Mg\ ha^{-1}$)** | **Mean CSR** | **Age (Years)** | **Field Area (Hectares)** | **Field No.** | **Yield ($Mg\ ha^{-1}$)** | **Mean CSR** | **Age (Years)** | **Field Area (Hectares)** |
| 99-1A | 7.1 | 50 | 9 | 9.4 | 00-2 | 6.5 | 58 | 2 | 15.2 |
| 99-1E | 4.6 | 55 | 3 | 4.7 | 00-3 | 5.4 | 56 | 2 | 4.9 |
| 99-1N | 2.8 | 40 | 12 | 6.4 | 00-4 | 5.4 | 36 | 2 | 3.1 |
| 99-2A | 3.0 | 45 | 7 | 22.8 | 00-7 | 7.6 | 33 | 2 | 5.0 |
| 99-2B | 2.1 | 35 | 2 | 21.3 | 00-10 | 6.2 | 40 | 2 | 3.9 |
| 99-4 | 7.0 | 45 | 12 | 10.3 | 00-11 | 7.2 | 40 | 1 | 1.0 |
| 99-5A | 6.4 | 40 | 3 | 18.9 | 00-12 | 7.1 | 32 | 13 | 0.9 |
| 99-5B | 4.4 | 55 | 4 | 20.0 | 00-14 | 7.8 | 42 | 13 | 0.6 |
| 99-7 | 7.9 | 30 | 7 | 6.6 | 00-16 | 3.7 | 31 | 1 | 5.4 |
| 99-23 | 8.4 | 70 | 7 | 4.3 | 00-17 | 12.1 | 45 | 3 | 6.1 |
| 99-234 | 5.8 | 50 | 7 | 17.0 | 00-18 | 5.9 | 77 | 2 | 60.9 |
| 99-1315 | 1.9 | 60 | 2 | 15.0 | 00-19 | 4.7 | 63 | 2 | 9.9 |
| | | | | | 00-20 | 6.4 | 70 | 2 | 3.4 |
| | | | | | 00-21 | 5.5 | 58 | 2 | 11.0 |
| | | | | | 00-22 | 6.0 | 55 | 2 | 8.7 |
| | | | | | 00-23 | 4.3 | 47 | 2 | 3.4 |
| | | | | | 00-24 | 3.9 | 52 | 2 | 3.5 |
| | | | | | 00-25 | 5.3 | 76 | 3 | 2.9 |
| | | | | | 00-26 | 4.2 | 72 | 3 | 6.2 |
| | | | | | 00-27 | 5.2 | 62 | 3 | 8.4 |
| | | | | | 00-28 | 5.5 | 70 | 3 | 2.5 |
| mean | 5.12 | 47.92 | 6.25 | 13.07 | mean | 5.99 | 53.10 | 3.19 | 7.96 |
| st. dev | 2.31 | 11.17 | 3.55 | 6.86 | st. dev | 1.82 | 14.94 | 3.31 | 12.66 |

**BIBLIOGRAPHY**

Boon, W. and H. Groe. 1990. Nature's Heartland – Native Plant Communities of the Great Plains. Iowa State University Press, Ames.

Brummer, E.C., C.L. Burras, M.D. Duffy, and K.J. Moore. 2001. Switchgrass production in Iowa: Economic analysis, soil suitability, and varietal performance. Annual Report.

Center for Agricultural Research Systems. 2002. Switchgrass production for biomass. Research Brief 51. http://www.wisc.edu/cias/pubs/briefs/051.html (Reviewed September 10, 2002).

Cooper, J. 2001. Chariton Valley Biomass Project - Switchgrass to energy. http://www.econ.iastate.edu/outreach/agriculture/programs/2001_Renewable_Energy_Symposium/Cooper.pdf (reviewed September 10, 2002).

Smith, D.D. 1981. Iowa prairie: An endangered ecosystem. Proc. IA. Acad. Sci. 88:7-10.

Thompson, JR.R. 1992. Prairies, Forests, and Wetlands: The Restoration of Natural Landscape Communities in Iowa.

Zinn, J.A. 2002. Soil and Water Conservation Issues. Issue Brief for Congress. Congressional Research Service Report IP96030. http://www.cnie.org/nle/crsreports/agriculture/ag-18.pdf (reviewed September 10, 2002).

Zinn, J.A. 2001. Conservation Reserve Program: Status and Current Issues. CRS Report for Congress 97-673ENR. National Council for Science and the Environment. http://www.cnie.org/NLE/CRSreports/Agriculture/ag-65.pdf (reviewed September 10, 2002).

Zinn, J.A. 1997. Conservation Reserve Program: Status and Policy Issues. CRS Report for Congress 96-760ENR. National Council for Science and the Environment. http://www.cnie.org/NLE/CRSreports/Natural/nrgen-21.cfm (reviewed September 10, 2002).

# III. BIOFUEL CROP GERMPLASM EVALUATION

## III.1. Switchgrass Germplasm Yield and Quality

**OBJECTIVE**
The objective of this experiment is to determine the biofuel potential of a diverse set of switchgrass cultivars and germplasm in the Chariton Valley, and specifically, to determine if any of them has more potential as a biofuel crop than the standard cultivar 'Cave-In-Rock.'

**STATUS**
This study is in press at *Biomass and Bioenergy*. A copy of the proofs of the article follow this page.

JBB 880
pp: 1--10 (col.fig.: Nil)
PROD. TYPE: COM
ED: EM
PAGN: Suresh – SCAN: Nil



PERGAMON

Biomass and Bioenergy ▮▮▮ (▮▮▮▮) ▮▮▮–▮▮▮

BIOMASS & BIOENERGY

www.elsevier.com/locate/biombioe

# Biomass yield and quality of 20 switchgrass populations in southern Iowa, USA ☆

Roque Lemus[a], E. Charles Brummer[b,*], Kenneth J. Moore[b], Neil E. Molstad[c], C. Lee Burras[b], Michael F. Barker[b]

[a]*Department of Crop and Soil Environmental Sciences, Virginia Tech University, Blacksburg, VA 24061, USA*
[b]*Department of Agronomy, Iowa State University, Ames, IA 50011, USA*
[c]*SDI Consultants Ltd. Oak Brook, IL 60523, USA*

Received 7 May 2002; accepted 5 June 2002

**Abstract**

Renewable bioenergy could be supplied by high yielding grass crops, such as switchgrass (*Panicum virgatum* L.). Successful development of a bioenergy industry will depend on identifying cultivars with high yield potential and acceptable biofuel quality. The objective of this study was to evaluate 20 switchgrass populations in a field study planted in May 1997 in southern Iowa, USA. The populations included released cultivars and experimental germplasm of both upland and lowland ecotypes. Yield, plant height, stand, lodging, leaf:stem ratio, cell wall fiber, total plant nitrogen, and ash were determined on all entries between 1998 and 2001. Ultimate and proximate analyses together with chlorine and major oxide determinations were made on three cultivars in 2000 and 2001. Biomass yield was determined from a single autumn harvest each year. The lowland cultivars 'Alamo' and 'Kanlow' produced the most biomass, exceeding the production of the widely recommended upland cultivar 'Cave-In-Rock'. Other traits differed among the cultivars, although the range was less than that for yield. The differences among years were substantially greater for the ultimate, proximate, and major oxide analyses than differences among cultivars. The highest yielding cultivars had low ash, slightly lower fiber concentrations, and moderate levels of important minerals, suggesting that excellent germplasm is available for biofuel production. The persistence of the lowland cultivars in southern Iowa may need more research because the winters during the experiment were mild.


*Keywords:* Biomass; Yield; Switchgrass; Biofuel quality; Mineral content



## 1. Introduction

Perennial, herbaceous energy crops offer a significant opportunity to improve agricultural sustainability through crop diversification, decreased erosion, and improved water quality compared with a traditional annual row crop system [1]. The perennial nature of these crops makes their cultivation desirable on highly erosive land, particularly if they can produce acceptable yields on poor quality soils. In order to be profitably grown, energy crops need to produce high yields of biomass, low concentrations of water, nitrogen, and ash, and high concentrations of lignin and cellulose [2]. Switchgrass, a warm-season ($C_4$) grass native to

☆ Journal Paper No. J-19831 of the Iowa Agric. and Home Econ. Exp. Stn., Ames, IA 50011, Project No. 2569, supported by Hatch Act and State of Iowa Funds.

* Corresponding author. Tel.: +1-515-294-1415; fax: +1-515-294-6505.
*E-mail address:* brummer@iastate.edu (E.C. Brummer).

0961-9534/02/$ - see front matter © 2002 Published by Elsevier Science Ltd.
PII: S0961-9534(02)00073-9

much of the central, midwestern, and southeastern United States, has been proposed as the herbaceous perennial plant most suitable for biofuel production in these regions [3].

Across its wide native geographic range, switchgrass has evolved into two types: (i) lowland ecotypes, which are vigorous, tall, thick-stemmed, and adapted to wet conditions, and (ii) upland ecotypes, which are short, rhizomatous, thin-stemmed, and adapted to drier conditions [4]. Lowland ecotypes are predominantly tetraploid ($2n{=}4\times{=}36$); upland ecotypes are typically hexaploid ($2n = 6\times = 54$) or octaploid ($2n = 8\times = 72$) [5,6]. Switchgrass is photoperiod sensitive, and flowering is related to the latitude at which a particular germplasm evolved, with northern populations flowering earlier than southern populations [7]. Selection of late flowering genotypes originating at lower latitudes under northern conditions has resulted in switchgrass yield improvements for the Great Plains and Upper Midwestern US [8].

Switchgrass grown for biofuel can either be used directly to generate power by cofiring with coal or indirectly as a fuel by fermentation to ethanol [9]. The quality of switchgrass for fuel depends on the concentration of energy, primarily derived from the cell walls and particularly from lignin and cellulose. In addition, certain elements and minerals, including potassium, sodium, chlorine, silica, and others could cause corrosion, slagging, and fouling of the boilers and other components of the power plant, decreasing efficiency and increasing maintenance costs [10]. A switchgrass of ideal quality for co-firing would contain a high concentration of lignin and cellulose while minimizing total ash, chloride, and other undesirable elements.

Cultivar selection can have a major impact on the ultimate productivity, persistence, and profitability of a forage crop [11,12]. By extension, we might expect that cultivars differ for biofuel traits, and the optimum forage cultivar may not be the same as the most desirable biofuel cultivar, given the contrasting needs of the two uses. The switchgrass cultivar Cave-In-Rock (CIR) is widely recommended for forage in Iowa and other upper Midwestern US states because of its persistence, high dry matter yield, and superior nutritive value. However, a thorough examination of CIR and other cultivars for biofuel characteristics has not been conducted in the region.

The objective of this experiment was to test the hypothesis that Cave-in-Rock was the best switchgrass cultivar for biofuel production in southern Iowa by evaluating the biomass yield and quality of a diverse assemblage of 20 cultivars and germplasms.

## 2. Materials and methods

### 2.1. Plant materials

Twenty cultivars and experimental populations of switchgrass were included in the study. The cultivars included in the study were 'Alamo', 'Blackwell', 'Caddo', 'Carthage', Cave-in-Rock (CIR), 'Forestburg', 'Kanlow', 'Pathfinder', 'Shawnee', 'Shelter', 'Sunburst', and 'Traiblazer'. In addition, eight experimental populations were included: two selected by Drs. E.C. Brummer and K.J. Moore at Iowa State University from CIR for grazing tolerance (IA-GT) and late maturity (IA-LM); four developed by Dr. C. Taliaferro at Oklahoma State University (NL93-2CH, NU94-2CH, SU92-ISO, and SU94-2CH); and two from Dr. K.P. Vogel at University of Nebraska (HDMD-C3 and HYLD-C3).

### 2.2. Field design and data collection

All entries were seeded on 13 May 1997 at the McNay Memorial Research Farm (40°58′N, 93°26′W), 5 miles south of Chariton, IA. Experimental plots were established on a Grundy silty clay loam soil (fine, smectitic, superactive, mesic Aquertic Argiudoll) in a randomized complete block design with four replications and a plot size of $3\times4.6$ m. Nitrogen was applied as urea at a rate of 56 kg N ha$^{-1}$ in June 1998, and as ammonium nitrate at a rate of 112 kg N ha$^{-1}$ in June 1999, April 2000, and April 2001. For weed control, Atrazine (2-chloro-4-ethylamino-6-isopropyl amino-s-atrazine) was applied at a rate of 2.24 kg active ingredient ha$^{-1}$ in June 1998 and 1999.

Plots were harvested for dry matter yield on 13 November 1998, 30 September 1999, and 15 October 2001. Wet autumn conditions and an early snowfall prevented us from harvesting biomass in 2000. In 1998 and 1999, a 1 m wide strip was harvested from the center of each plot at a height of approximately 7.5 cm using a flail-type forage harvester (Carter Manufacturing Co., Brookston, IN); in 2001, the entire plot area was harvested using a commercial mower-conditioner. The harvested plant material was weighed using a 12 kg scale. Sub-samples for fiber and mineral content determination were taken at harvest, dried at 60°C for 4 days, and ground to pass a 1-mm mesh screen (Cyclone Mill, UDY Mfg., Fort Collins, CO 80524). Plot samples from the 2000 growing season were taken in early January 2001 (for convenience, we will refer to these as '2000' samples). Samples collected in November 1998 were hand separated into leaf (leaf blade only) and stem (leaf sheath, stem, and inflorescence) fractions and a leaf:stem ratio, based on mass, was determined.

Canopy height was measured in August 1998 and 1999, October 2000, and November 2001 at two random locations per plot. Stand scores, based on ground cover, were taken in June 1998 and 1999, using a scale of 0= no stand to 5= excellent. Stand scores were multiplied by 20 to convert them to percentages. In October 2001, stand was measured immediately after harvest using a 0.84 $m^2$ frame cross-gridded with wire to produce 50 intersection points. The number of points which fell on a switchgrass plant was counted, and stand percentage calculated by multiplying the count by two. Lodging was scored in July 1998 and August 1999 as the percentage of the plants within the whole plot that were lodged past a 35° angle perpendicular to the ground.

### 2.3. Fiber, ash, and nitrogen determinations

In 1998 and 1999, neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL) concentrations were determined using an ANKOM 200 Fiber Analyzer (ANKOM Technology Corp., Fairport, NY 14450), as described previously [13]. Hemicellulose was calculated as NDF–ADF and cellulose as ADF–ADL. Nitrogen was determined using the micro-Kjeldahl procedure [14] and ash content (g $kg^{-1}$) was determined by combustion of 1 g of plant tissue in a muffle furnace at 550°C for 4 h.

For samples collected in 2000, fiber, ash, and N concentrations were based on near infra-red spectroscopy calibrated with wet chemistry. All samples from this trial were scanned as part of a larger set of switchgrass samples from another experiment, using a Pacific Scientific 6250 scanning monochromator to collect reflectance measurements (log $1/R$) between 1100 and 2500 nm, recorded at 4-nm intervals (NIRS Systems, Silver Springs, MD 20910). A subset of 40 samples was identified for wet chemistry analyses as described previously for calibration of spectra [15]. Calibration equations were calculated using modified partial least squares regression [16]. Coefficients of determination ($R^2$) and standard errors of the calibration and cross validation were 0.99, 0.21, and 0.86 for NDF; 0.97, 0.44, and 0.89 for ADF; 0.91, 0.24, and 0.39 for ADL; 0.97, 0.16, and 0.35 for ash; and 0.99, 0.01, and 0.03 for N.

### 2.4. Ultimate, proximate, and elemental analyses

The samples from CIR, Kanlow, and Alamo collected in 2000 and 2001 were used for ultimate, proximate, and elemental analyses. Ultimate and proximate analyses were performed by Hazen Research, Inc. (Golden, CO) using ASTM D3176 for the ultimate analysis and evaluating O by difference, and ASTM D3172 for the proximate analysis and determining fixed C by difference. In both cases, ashing was done at 600°C instead of 800°C. Energy density was determined using ASTM D3286. Analysis of major oxides was performed by Activation Labs Ltd. (Ancaster, Ontario, Canada). Ash, produced by combustion at 475°C, was mixed with a flux of lithium metaborate and lithium tetraborate, fused at 1050°C in an induction furnace, poured into a 5% nitric acid solution, mixed for 30 min to dissolve, and analyzed on a Thermo Jarell–Ash ENVIRO II inductively coupled plasma (ICP) emission spectroscope. Chloride was determined on ash prepared at 475°C using instrumental neutron activation analysis (INAA).

### 2.5. Data analysis

Data were analyzed using the GLM and CORR procedures of the SAS statistical software program (SAS, Inc., Cary, NC 1996). Entries were considered to be fixed effects; years were considered random. Mean separations were based on Fisher's protected LSD [17]. Unless otherwise indicated, differences were considered to be significant at the 5% probability level.

## 3. Results and discussion

### 3.1. Biomass yield

Biomass dry matter yield averaged across all entries and years was 9.0 Mg ha$^{-1}$. Substantial variability was evident among years, with the average yield ranging from 6.4 Mg ha$^{-1}$ in 1998 to 11.8 Mg ha$^{-1}$ in 1999 (Table 1). The improvement in yield between 1998 and 1999 was concurrent with an increased stand percentage (Table 1) and a higher nitrogen fertilization rate. Germplasms varied widely for biomass yield (Table 2), but no cultivar by year interaction was present. Two lowland cultivars, Kanlow and Alamo, whose later maturity give them a longer period of vegetative growth compared with upland ecotypes [18], produced the most biomass (Table 2). Two experimental populations, NU94 and HDMDC3, had yields similar to Alamo. The comparative performance of HDMD-C3 and HYLD-C3 contrasted with their ranking when grown previously in other locations (Dr. K. Vogel, pers. comm.). Although these data suggest a genotype by environment interaction for biomass yield of these populations, we cannot rule out a seed labeling or planting error. The maximum single year yield was 17.5 Mg ha$^{-1}$ for Alamo in 1999 (data not shown). Cave-In-Rock, the most widely recommended cultivar for Iowa, had an average yield of 9.3 Mg ha$^{-1}$, which was considerably lower than the top producing varieties (Table 2). In a previous report from Iowa, CIR had a yield of 14 Mg ha$^{-1}$ [19]; the disparity in yield reflects the superior soil in central compared with southern Iowa. CIR performed as well as or better than all other released upland cultivars, as has been observed in other experiments in the Great Plains, USA [19], Quebec, Canada [20], and southern England [21].

Not surprisingly, the yield advantage of lowland ecotypes in southern Iowa is not as great as that seen in some locations in Texas [22]. Although the lowland ecotypes have survived in southern Iowa since 1997, several of the subsequent winters were relatively mild and during the most severe winter of 2000–2001, the plots were covered by snow from mid-November through mid-March. Thus, continued evaluation of their adaptation to this region is warranted.

### 3.2. Agronomic traits

Stand density differences occurred among years (Table 1). Some entries had weak stands in 1998, but all had roughly complete stands by 1999. Some stand thinning occurred by 2001, with fewer, but larger plants in each plot. The mean differences among entries are attributable primarily to the poor initial stands in 1998 (Table 2). Low stands of some populations in 1998 resulted from a combination of poor seed germination and weed competition during the planting season in summer 1997. The stand variability likely lowered total yield in 1998 and consequently, the 3 year average yield. Ground cover estimated in 2001 indicated that most entries were similar (data not shown). However, Kanlow, the highest yielding variety, had substantial open areas within the plot, suggesting that if Kanlow were planted across an entire field, its lower ground cover could lead to higher erosion rates than many other cultivars.

Canopy height differences were evident among years, which can be partially attributed to the date of measurement (Table 1). However, height was measured in mid-August in both 1998 and 1999, so differences between those years clearly was due to environmental factors, possibly because the more fully established plants in 1999 could withstand stress better than they could in 1998. Similar heights were observed in 2000 and 2001 when the measurement was made in late autumn. Height differences existed among cultivars, with the highest yielding cultivars being considerably taller than the others (Table 2). CIR was substantially shorter than the tallest entries. These results are consistent with reports indicating that late-maturing cultivars produce taller canopies [20]. Despite the differences in plant height, no differences in lodging were observed among entries. Overall, although lodging was higher in 1998 (5.5%) than in 1999 (2.2%), it was not at a level that would hamper normal harvesting operations in either year (Table 1).

Separation of plant parts showed that, on average, 65% of the total aboveground biomass was in the stem (stem, leaf sheath, and inflorescence) fraction. The leaf:stem ratios among the entries ranging from

Table 1
Biomass yield, agronomic traits, cell wall constituents, ash, and nitrogen determinations averaged across 20 switchgrass cultivars grown in southern Iowa and harvested in autumn 1998, 1999, 2000, and 2001

| Variable[a] | Units | 1998 | 1999 | 2000 | 2001 | Mean | LSD (5%) |
|---|---|---|---|---|---|---|---|
| Biomass yield | Mg $ha^{-1}$ | 6.4 | 11.8 | —[b] | 8.7 | 9.0 | 0.8 |
| Plant height | cm | 85 | 121 | 175 | 180 | 140 | 4 |
| Stand | % | 75 | 98 | — | 77 | 83 | 5 |
| Lodging | % | 2.2 | 5.5 | — | — | 3.8 | 1.8 |
| NDF | g $kg^{-1}$ | 764 | 698 | 804 | — | 737 | 2 |
| ADF | g $kg^{-1}$ | 432 | 402 | 469 | — | 421 | 7 |
| ADL | g $kg^{-1}$ | 70 | 62 | 57 | — | 61 | 2 |
| Hemicellulose | g $kg^{-1}$ | 332 | 296 | 336 | — | 316 | 5 |
| Cellulose | g $kg^{-1}$ | 361 | 340 | 411 | — | 361 | 5 |
| Ash | g $kg^{-1}$ | 63 | 72 | 52 | — | 61 | 2 |
| N | g $kg^{-1}$ | 4.0 | 6.9 | 5.3 | — | 5.4 | 0.2 |

[a]NDF = neutral detergent fiber; ADF = acid detergent fiber; ADL = acid detergent lignin; N = total nitrogen.
[b]Years for which no data were taken for a particular trait are indicated by '—'.

Table 2
Biomass yield, plant height, leaf:stem ratio, lodging, and stand of 20 switchgrass cultivars grown in southern Iowa from 1998 to 2001.

| Entry | Ecotype[a] | Yield[b] | Height | Leaf:stem | Lodging (%) | Stand (%) |
|---|---|---|---|---|---|---|
| | | Mg $ha^{-1}$ | cm | Ratio | | |
| Alamo | L | 12.1 | 178 | 0.53 | 2.0 | 88 |
| Blackwell | U | 8.3 | 128 | 0.39 | 9.0 | 91 |
| CIR | U | 9.3 | 151 | 0.51 | 3.8 | 91 |
| Caddo | U | 7.8 | 131 | 0.63 | 2.6 | 88 |
| Carthage | L | 9.9 | 139 | 0.74 | 4.6 | 87 |
| Forestburg | U | 6.9 | 118 | 0.49 | 3.0 | 67 |
| HDMDC3 | U | 10.5 | 128 | 0.58 | 2.8 | 87 |
| HYLDC3 | U | 8.6 | 133 | 0.49 | 3.0 | 89 |
| IAGT | U | 8.3 | 143 | 0.48 | 3.8 | 94 |
| IALM | U | 8.7 | 141 | 0.45 | 3.3 | 92 |
| Kanlow | L | 13.1 | 177 | 0.46 | 13.8 | 84 |
| NL93 | L | 9.0 | 158 | 0.79 | 1.9 | 76 |
| NU94 | U | 11.2 | 162 | 0.46 | 1.3 | 83 |
| Pathfinder | U | 7.3 | 125 | 0.66 | 2.6 | 62 |
| SU92ISO | U | 8.3 | 131 | 0.42 | 6.3 | 76 |
| SU94 | U | 8.5 | 133 | 0.58 | 2.6 | 90 |
| Shawnee | U | 8.8 | 146 | 0.52 | 4.1 | 88 |
| Shelter | U | 8.3 | 136 | 0.63 | 2.1 | 76 |
| Sunburst | U | 6.8 | 126 | 0.44 | 2.0 | 75 |
| Trailblazer | U | 7.9 | 123 | 0.47 | 2.5 | 83 |
| Mean | | 9.0 | 140 | 0.54 | 3.8 | 83 |
| LSD (5%) | | 1.8 | 8 | 0.17 | 5.7 | 13 |

[a]Ecotype designations based on Gunter et al. [5] and Wullschelger et al. [6], or on personal communications with the developers of the germplasm.
[b]Trait data are means across the years indicated in Table 1; Leaf:stem ratio based on November 1998 harvest only.

0.39 to 0.79. A decrease in leaf:stem ratio may lead to improved biomass quality because stems have a higher fiber content; hence, the proportion of stem tissue could be one of the key determinants of the biofuel quality of switchgrass. The range of values among cultivars indicates that lowering leaf:stem ratios could be a feasible breeding goal.

Disease ratings indicated that all entries expressed some disease symptoms in 1998, but little disease was noted in 1999 (data not shown). No substantial susceptibility differences were observed among entries. Stem rust (*Puccinia* spp.) and smut (*Tilletia maclaganii* (Berk.) G.P. Clinton) were the predominant diseases present. The smut symptoms, including stunted, early flowering plants, were not as severe as those documented previously [23]. The diseases might have reduced yield in 1998.

### 3.3. Cell wall components (CWC)

All cell wall components differed among the 3 years (Table 1). The samples were harvested in November 1998, September 1999, and January 2001, and the results are consistent with this timeline: cell wall components increase in later harvests as the more easily degraded plant components are lost. The lack of any significant entry by year interaction (data not shown) indicates that while the cell wall composition may change at different times during the year (and in different years), all varieties responded similarly. Analyses of cell wall components often find no or small genotype by environment interactions [24], although both genotype by year and genotype by location interactions have been found in switchgrass grown in Iowa, Indiana, and Nebraska [19].

The 3-year average values of NDF, ADL, and hemicellulose differed among the entries, but ADF and cellulose did not (Table 3). The magnitude of differences was not large: NDF ranged from 741 to 774 g kg$^{-1}$, ADL from 53 to 69 g kg$^{-1}$, and hemicellulose from 308 to 336 g kg$^{-1}$ (Table 3). The lowland cultivars, Alamo and Kanlow, had among the highest yields but also had among the lowest lignin content.

### 3.4. Ash, nitrogen, and elemental analysis

Total ash content of biomass combusted at 550°C, averaged across years, was 6.2%, and ranged from about 5% in 2000 to slightly more than 7% in 1999 (Table 1). The years differed from each other. These ash results slightly lower than those reported previously for switchgrass [10]. Although differences in ash content were present among entries (Table 3), no entry by year interaction was noted. The high biomass producers Alamo and Kanlow had among the lowest ash levels suggesting that both high yield and low ash are mutually compatible.

Total N content of biomass also differed across years, paralleling the ash values (Table 1). Undoubtedly, the higher N and ash levels in 1999 reflected the earlier harvest (September) compared to the other years. Averaged across the three harvests, total N varied among entries from 4.6 g kg$^{-1}$ (Kanlow) to 6.2 g kg$^{-1}$ (SU94), but most entries had values similar to the mean of 5.4 g kg$^{-1}$.

### 3.5. Ultimate and proximate analyses

For both the ultimate and proximate analyses, few differences were noted among the three cultivars, although CIR had slightly more ash and lower C than the other two, which were similar (Table 4). However, most components varied between years, a result confounded by the interactions of different harvest dates and different climatic conditions. The energy concentration did not change among cultivars, despite lower lignin in the lowland cultivars, or over years, averaging 16.4 kJ g$^{-1}$ on a dry matter basis, somewhat lower than other reported values [10,20]. Thus, when yield differences are taken into account, Kanlow would produce 215 GJ ha$^{-1}$ compared with 152 GJ for CIR.

Chlorine levels were higher than those found in a test in southern England [21], which could have resulted from differences in analysis method (they used water extractable Cl, which represents about 80% of total Cl [10]), soil Cl concentrations, or environmental variables. However, in our experiment, Kanlow and Alamo both had approximately twice as much Cl as CIR, congruent with Christian et al. [21].

Analysis of major oxides indicated few differences among cultivars (Table 4). CIR had lower MgO, $Na_2O$ and $K_2O$ than the upland cultivars; the latter two oxides represent alkali that can have a deleterious effect on biomass plants through slagging and fouling the reactor [10]. CIR has a slight advantage over the

Table 3
Mean cell wall components, nitrogen, and ash of switchgrass biomass harvested in 1998, 1999, and 2000 in southern Iowa (in g $kg^{-1}$)

| Entry | NDF[a] | ADF | ADL | Hemicell. | Cellulose | N | Ash |
|---|---|---|---|---|---|---|---|
| Alamo | 767 | 438 | 57 | 328 | 381 | 4.9 | 52 |
| Blackwell | 763 | 443 | 67 | 319 | 375 | 5.2 | 62 |
| Cave-In-Rock | 766 | 446 | 67 | 320 | 378 | 5.1 | 60 |
| Caddo | 753 | 434 | 62 | 318 | 371 | 5.5 | 61 |
| Carthage | 748 | 428 | 63 | 319 | 365 | 5.5 | 64 |
| Forestburg | 755 | 428 | 62 | 326 | 366 | 5.7 | 67 |
| HDMDC3 | 750 | 427 | 63 | 322 | 364 | 5.7 | 70 |
| HYLDC3 | 748 | 429 | 64 | 319 | 364 | 5.7 | 62 |
| IAGT | 741 | 433 | 68 | 307 | 364 | 5.1 | 63 |
| IALM | 742 | 431 | 64 | 311 | 367 | 4.8 | 63 |
| Kanlow | 774 | 445 | 60 | 328 | 385 | 4.6 | 54 |
| NL932 | 750 | 422 | 53 | 327 | 369 | 5.1 | 61 |
| NU942 | 755 | 419 | 54 | 335 | 364 | 5.4 | 62 |
| Pathfinder | 758 | 433 | 62 | 324 | 371 | 5.4 | 63 |
| SU92ISO | 760 | 441 | 66 | 319 | 375 | 5.4 | 66 |
| SU94 | 756 | 436 | 66 | 320 | 369 | 6.2 | 59 |
| Shawnee | 751 | 439 | 67 | 311 | 372 | 5.5 | 60 |
| Shelter | 750 | 436 | 64 | 314 | 372 | 5.1 | 66 |
| Sunburst | 759 | 436 | 64 | 323 | 371 | 5.5 | 65 |
| Trailblazer | 757 | 431 | 63 | 325 | 368 | 5.9 | 64 |
| Mean | 755 | 434 | 63 | 321 | 371 | 5.4 | 62 |
| LSD (5%) | 16 | ns | 6 | 12 | ns | 0.6 | 7 |

[a]NDF = neutral detergent fiber; ADF = acid detergent fiber; ADL = acid detergent lignin; Hemicell. = hemicellulose; N = total nitrogen.

upland cultivars in this regard. Large differences between years were observed for most oxides, most importantly for $SiO_2$ and $K_2O$ (Table 4). This variation could have a significant impact on fuel quality and probably reflects differences in harvest timing; the 2001 data represent a more realistic harvest period (October) than the 2000 sampling (January).

The risk of slagging and fouling can be based upon the amount of alkali per heat unit. The value for these cultivars averaged across years is approximately 0.28 kg $GJ^{-1}$, which should not result in excessive problems at the boiler [10]. However, the year differences are less benign. Biomass sampled in October 2001 averaged across cultivars had 0.55 kg alkali $GJ^{-1}$, versus the later sampling from the 2000 growing season, which only had 0.10 kg alkali $GJ^{-1}$. Thus, year-to-year differences, and perhaps even differences among harvest periods within a growing season can greatly affect the amount of alkali present in the feedstock.

### 3.6. *Correlations among traits*

Correlations were calculated based on the mean values over years for the traits that were measured on all cultivars (Table 5). Total seasonal yield was positively correlated with canopy height and negatively correlated with ash content, N concentration, and ADL (Table 5). No significant correlation was observed between yield and the other traits. These results suggest that yield increases could be effected by selection for taller plants, although this clearly needs to be demonstrated experimentally, and that higher yield has the desirable effect of lowering ash concentration. A slight decline in lignin may result from increased yield, but the effect of this on energy production appears to be slight (Table 4).

Height has stronger negative correlations with ash, N, and ADL than does yield, and is also positively correlated with increased cellulose, an important trait for biofuels being used to produce ethanol via

Table 4
Proximate, ultimate, chlorine, and major oxide analyses of switchgrass biomass harvested from three cultivars in 2000 and 2001 in southern Iowa

| Component | Mean | By entry | | | | By year | | |
|---|---|---|---|---|---|---|---|---|
| | | Alamo | CIR[a] | Kanlow | LSD (5%) | 2000 | 2001 | LSD (5%) |
| | $g\,kg^{-1}$ dry matter[b] | | | | | | | |
| Ash | 48 | 44 | 56 | 46 | 7 | 38 | 59 | 5 |
| Volatile Matter | 816 | 815 | 817 | 815 | ns | 823 | 808 | ns |
| Fixed Carbon | 136 | 142 | 127 | 139 | ns | 139 | 133 | ns |
| Energy Conc.[b] | 16.40 | 16.40 | 16.37 | 16.43 | ns | 16.45 | 16.35 | ns |
| C | 478 | 480 | 473 | 480 | 5 | 470 | 485 | 4 |
| H | 54 | 54 | 53 | 54 | ns | 56 | 51 | 1 |
| N | 4.6 | 4.2 | 5.4 | 4.1 | ns | 3.5 | 5.6 | 0.9 |
| O | 414 | 417 | 411 | 414 | ns | 430 | 398 | 5 |
| S | 1.4 | 1.4 | 1.3 | 1.6 | ns | 2.0 | 0.9 | 0.2 |
| | % of ash | | | | | | | |
| Cl | 0.50 | 0.59 | 0.28 | 0.63 | 0.20 | 0.48 | 0.51 | ns |
| $SiO_2$ | 57.2 | 55.4 | 58.8 | 57.3 | ns | 62.8 | 51.5 | 3.1 |
| $Al_2O_3$ | 0.8 | 0.8 | 0.7 | 0.8 | ns | 0.7 | 0.9 | 0.2 |
| $Fe_2O_3$ | 0.37 | 0.36 | 0.35 | 0.40 | ns | 0.41 | 0.32 | ns |
| MgO | 4.8 | 5.8 | 3.5 | 5.2 | 0.6 | 4.6 | 5.1 | 0.5 |
| CaO | 11.1 | 10.2 | 12.1 | 10.8 | ns | 13.1 | 9.0 | 1.2 |
| $Na_2O$ | 0.3 | 0.5 | 0.1 | 0.4 | 0.2 | 0.4 | 0.3 | ns |
| $K_2O$ | 9.1 | 10.1 | 8.1 | 9.1 | 1.3 | 3.9 | 14.3 | 1.0 |
| $P_2O_5$ | 5.5 | 5.7 | 5.6 | 5.1 | ns | 4.3 | 6.6 | 0.8 |
| Lost on ignition | 10.8 | 11.0 | 10.6 | 10.8 | ns | 10.0 | 11.7 | 1.4 |

[a]CIR = Cave-In-Rock.
[b]Units for energy concentration are $kJ\,g^{-1}$.

Table 5
Correlations among traits measured on 20 switchgrass populations over 4 years in southern Iowa

| | Yield | Height | Lodging | LSR[a] | Stand | Ash | N | NDF | ADF | ADL | Hemi. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Height | 0.85**** | | | | | | | | | | |
| Lodging | 0.40 | 0.27 | | | | | | | | | |
| LSR | 0.00 | 0.05 | 0.35 | | | | | | | | |
| Stand | 0.37 | 0.30 | 0.17 | −0.24 | | | | | | | |
| Ash | −0.60** | −0.80**** | −0.32 | 0.03 | −0.31 | | | | | | |
| N | −0.47* | −0.66*** | −0.44 | 0.09 | −0.11 | 0.44 | | | | | |
| NDF | 0.40 | 0.37 | 0.52* | −0.29 | −0.15 | −0.55* | −0.23 | | | | |
| ADF | 0.07 | 0.12 | 0.60** | −0.39 | 0.19 | −0.38 | −0.32 | 0.63** | | | |
| ADL | −0.47* | −0.52* | 0.19 | −0.38 | 0.31 | 0.30 | 0.22 | −0.13 | 0.57*** | | |
| Hemi. | 0.41 | 0.33 | 0.00 | 0.05 | −0.38 | −0.28 | 0.05 | 0.56** | −0.29 | −0.77*** | |
| Cell. | 0.42 | 0.52* | 0.60** | −0.20 | 0.01 | −0.67** | −0.55* | 0.86*** | 0.81*** | −0.02 | 0.20 |

[a]LSR = leaf : stem ratio; NDF = neutral detergent fiber; ADF = acid detergent fiber; ADL = acid detergent lignin; Hemi. = hemicellulose; Cell = Cellulose; N = total nitrogen.



fermentation. Lodging increased with increasing cellulose, ADF, and NDF (all three of which are positively correlated among themselves), but whether this correlation is biologically meaningful is unclear given the small differences among cultivars for lodging. Leaf:stem ratio did not correlate to any other traits. This desirable result means that high yields of stem can be achieved regardless of yield level; however, since LSR was only measured in 1998, these correlations may be spurious. Stand also did not correlate with the other traits. A few other correlations were noted among the remaining traits, but they were either expected (as among the CWCs [e.g., [25]]) or difficult to interpret biologically (e.g., the negative correlation between ash and NDF, for instance). In summary, the correlations among traits measured in this experiment suggest that high biomass production can be realized with no adverse connections to other traits, other than a slight reduction in lignin.

## 4. Conclusions

Differences in yield among cultivars were greater than differences in biomass quality and mineral composition. Thus, selection of appropriate cultivars, at least for southern Iowa, can be based primarily on biomass production. Cave-in-Rock, although widely grown, does not appear to have the maximum biomass potential for southern Iowa. Several cultivars and populations developed from lowland ecotypes had better yield than CIR, but their adaptability to southern Iowa is uncertain. Cultivar adaptability is an important factor for biomass yield and a long-term winter hardiness study will be necessary to assure stand survival. Future testing of these varieties should also be conducted under different N fertilization rates, which may affect their development and persistence. Wider testing in the area to ascertain performance under a variety of stress situations, such as low water availability and marginal soil conditions, is currently being conducted. Among the upland cultivars, CIR was superior or equal to all others except NU95-2CH. This experimental variety was selected from a population derived from Pathfinder and CIR. Its performance suggests that selection within upland cultivars, particularly if done in the area of intended use, could improve biomass yield. Breeding programs for improved biomass should probably take a two track approach in southern Iowa, selecting both for superior yield and winter survival in lowland types and for superior yield in upland types. Selection based on plant height and/or delayed maturity could be an effective means to improve biomass yield in these populations.

The results in this experiment show that variability among populations exists for most important biofuel traits, such that the development of an ideal biofuel cultivar—one having high yield, high lignocellulose, low nitrogen, low ash, and minimal undesirable mineral concentrations—could be possible. The phenotypic correlations among these variables suggest that optimal genotypes could be developed. However, specific differences among entries exist that may limit the optimization of all the parameters; for example, Kanlow and Alamo had high yield, but low lignocellulose content. This experiment provides support for planting varieties other than CIR in southern Iowa for maximum biomass productivity.

## Acknowledgements

This Research was funded by the Department of Energy's Bioenergy Feedstock Development Program at Oak Ridge National Laboratory under subcontract 90X-SY510V with Iowa State University, Ames, Iowa. The authors would like to thank Mark Downing, Sandy McLaughlin, Mark Smith, Trish Patrick, Jim Secor, John Sellers, Marty Braster, Jim Cooper, and the Chariton Valley RC&D for their assistance with this project.

## References

[1] Tolbert VR, Wright LL. Environmental enhancement of US biomass crop technologies: research results to date. Biomass and Bioenergy 1998;15:93–100.

[2] McKendry P. Energy production from biomass (part 1): overview of biomass. Bioresearch Technology 2002;83:37–46.

[3] McLaughlin SB, Walsh ME. Evaluating environmental consequences of producing herbaceous crops for bioenergy. Biomass and Bioenergy 1998;14:317–24.

[4] Moser LE, Vogel KP. Switchgrass, big bluestem, and indiangrass. In: Barnes RF, Miller DA, Nelson CJ, editors. Forages, vol. 1: An introduction to grassland agriculture. Ames, IA: Iowa State University, 1995. p. 409–20.

[5] Gunter LE, Tuskan GA, Wullschleger SD. Diversity among populations of switchgrass based on RAPD markers. Crop Science 1996;36:1017–22.

[6] Wullschleger SD, Sanderson MA, McLaughlin SB, Biradir DP, Rayburn AL. Photosynthetic rates and ploidy levels among populations of switchgrass. Crop Science 1996;36:306–12.

[7] Sanderson MA, Reed RL, McLaughlin SB, Wullschleger SD, Conger BV, Parrish DJ, Wolf DD, Taliaferro C, Hopkins AA, Ocumpaugh WR, Hussey MA, Read JC, Tischler C. Switchgrass as a sustainable bioenergy crop. Bioresearch Technology 1996;56:83–93.

[8] Vogel KP, Jung HG. Genetic modification of herbaceous plants for feed and fuel. Critical Reviews in Plant Science 2001;20:15–49.

[9] Tolbert V. Guest editorial. Biomass and Bioenergy 1998;14:301–6.

[10] Miles TR, Miles Jr. TR, Baxter LL, Bryers RW, Jenkins BM, Oden LL. Alkali deposits found in biomass power plants: a preliminary investigation of their extent and nature. National Technical Information Service, Springfield, VA, 1996.

[11] Anderson B, Ward JK, Vogel KP, Ward MG, Gorz HJ, Haskins FA. Forage quality and performance of yearlings grazing switchgrass strains selected for differing digestibility. Journal of Agricultural Science 1988;66:2239–44.

[12] Vogel KP, Haskins FA, Gorz HJ, Anderson BA, Ward JK. Registration of 'Trailblazer' switchgrass. Crop Science 1991;31:1388.

[13] Riday H, Brummer EC. Heterosis of forage quality in alfalfa. Crop Science 2002; 42, in press.

[14] Bremner JM, Breitenbeck GA. A simple method for determination of ammonium in semimicro-Kjeldahl analysis for soils and plant materials using a block digester. Communications in Soil Science and Plant Analysis 1983;14:905–13.

[15] Windham WR, Mertens DR, Barton FE II. Protocol for NIRS calibration: sample selection and equation development and validation. In: Marten GC, Shenk JS, Barton FE II, editors. Near Infrared Reflectance Spectroscopy (NIRS): analysis of forage quality. Washington, DC: USDA, 1989. p. 97–103.

[16] Shenk JS, Westerhaus MO. Population structure of near infrared spectra and modified partial least squares regression. Crop Science 1991;31:1548–55.

[17] Steel RGD, Torrie JH. Principles and procedures of statistics. New York: McGraw-Hill, 1980.

[18] Van Esbroeck GA, Hussey MA, Sanderson MA. Leaf appearance rate and final leaf number of switchgrass cultivars. Crop Science 1997;37:864–70.

[19] Hopkins AA, Vogel KP, Moore KJ, Johnson KD, Carlson IT. Genotype effects and genotype by environment interactions for traits of elite switchgrass populations. Crop Science 1995;35:125–32.

[20] Madakadze IC, Stewart K, Peterson PR, Coulman BE, Samson R, Smith DL. Light interception, use-efficiency and energy yield of switchgrass (*Panicum virgatum* L.) grown in a short season area. Biomass and Bioenergy 1998;15: 475–82.

[21] Christian DG, Riche AB, Yates NE. The yield and composition of switchgrass and coastal panic grass grown as a biofuel in Southern England. Bioresearch Technology 2002;83:115–24.

[22] Sanderson MA, Reed RL, Ocumpaugh WR, Hussey MA, Van Esbroeck G, Read JC, Tischler CR, Hons FM. Switchgrass cultivars and germplasm for biomass feedstock production in Texas. Bioresearch Technology 1999;67: 209–19.

[23] Gravert CE, Tiffany LH, Munkvold GP. Outbreak of smut caused by *Tilletia maclaganii* on cultivated switchgrass in Iowa. Plant Diseases 2000;84:596.

[24] Buxton DR, Casler MD. Environmental and genetic effects on cell wall composition and digestibility. In: Jung HG, Buxton DR, Hatfield RD, Ralph J, editors. Forage cell wall structure and digestibility. Madison: ASA-CSSA-SSSA, 1993. p. 685–714.

[25] Jung HG, Sheaffer CC, Barnes DK, Halgerson JL. Forage quality variation in the U.S. alfalfa core collection. Crop Science 1997;37:1361–6.

## III.2. REED CANARYGRASS BREEDING AND EVALUATION

(Dr. Michael Casler, University of Wisconsin, cooperating)

**Biofuel Potential of Reed Canarygrass: A Literature Review**

Perennial herbaceous crops contribute a number of desirable attributes to cropping systems: limiting soil erosion, improving water quality, diversifying salable farm products, and, when grown in rotation, breaking pest cycles endemic to annual grain crop production systems. On marginal crop land, the effect of returning to perennial plants has an even greater positive effect on erosion control. Costanza et al. (1997) indicate that grasslands provide more valuable ecosystem services than crop land, but that value is often overlooked in traditional commodity-driven economics. However, given the increasing importance given to environmental issues at the national level, perennial grass crops may play an increasing role in agricultural systems. Certainly, enhancing the production and/or quality of grasses will further their adoption and integration.

In addition to forage uses, perennial herbaceous crops can be grown for other reasons, such as biomass for energy. Conversion of plant biomass to fuel, either through fermentation to ethanol (Lynd et al., 1991) or via direct burning to generate electricity (McLaughlin, 1993), has a number of desirable attributes, including a reduced dependance on foreign fossil fuels and stabilizing greenhouse gasses in the atmosphere through carbon and nitrogen cycling. Other uses of these crops include paper pulp, hardboard for building construction, and pellets for use in home heating (Thons and Prufer, 1991; A. Teel, pers. comm.). Unfortunately, little effort has been directed toward the genetic characterization and improvement of most grasses for these varied uses.

Switchgrass has been identified as a model plant for biomass production based on its productivity in various environments in the United States (Cushman and Turhollow, 1991; Sanderson et al., 1996). Though switchgrass clearly represents an important biofuels crop, it does have limitations. Being a C4 species, switchgrass performs particularly well in hot environments. It does not produce as well relative to cool-season grasses in cooler climates typical of the upper Midwest as it does at lower latitudes; switchgrass also performs poorly on wet soils (Cushman and Turhollow, 1991; Wright, 1988).

The reliance on a single species of herbaceous crops for biomass production is risky. Abundant ecological literature suggests that increasing the diversity of species in a given area improves the temporal and spatial yield stability of the system (e.g. Tilman et al., 1996). Further, functional diversity and composition (i.e. types of species--warm-season, cool-season, legume, etc.) appear to be particularly important in developing these stable systems (Tilman et al., 1997). Crop monocultures may have higher productivity than a diverse system under uniform, highly-managed conditions, but the marginal lands on which many biomass crops will be grown, with heterogeneous soils, slopes, and productive capacities (Brummer et al., 1997), intimate that diversifying biomass species, at least on a field scale, could have a positive impact on overall productivity. Cushman and Turhollow (1991) note that an ideal biomass system would consist of one warm-season and one cool-season perennial grass, a legume, and an annual warm-season grass. Despite such ecologically sound advice, virtually all work in the past decade has emphasized switchgrass alone (McLaughlin et al., 1997).

The most promising cool-season grass for biofuel production is reed canarygrass. Because the most important restriction on cropland use in the Midwest after erosion is wet soils (USDA, 1987), reed canarygrass appears to be an ideal species. Reed canarygrass grows extremely well in wet soils, even withstanding inundation for long periods (Carlson et al., 1996). Its wet soil tolerance often overshadows its excellent drought tolerance, which makes it relatively more productive in the summer relative to other cool-season species (Carlson et al., 1996). Biomass productivity of reed canarygrass exceeded that of switchgrass in northern Ohio (Wright, 1988) and occasionally in southern Iowa (Anderson et al., 1991). Numerous other studies have also indicated that reed canarygrass produces excellent yields of total biomass (e.g. Smith et al., 1984; Cherney et al., 1986; Marten et al., 1980).

Reed canarygrass makes an appealing biomass crop for several reasons in addition to its yield. As a cool-season grass, it can be harvested in early summer when warm-season grass biomass is not available, facilitating a constant feedstock flow to the bioreactor (Cushman and Turhollow, 1991). Secondly, reed canarygrass biomass increases linearly with applied nitrogen (Anderson et al., 1991; Cherney et al., 1991). Though fertilization with high levels of nitrogen is generally undesirable, disposal of manure from intensive, industrial livestock and poultry farms or of municipal wastewater presents situations where the ability to take up high nutrient levels is necessary (Carlson et al., 1996). Finally, reed canarygrass has been reported to improve the structure of clay-based soils in Ontario, Canada (Drury et al., 1991).

An important consideration in evaluating reed canarygrass yield data is that the variety tested may not represent the best type for biomass production. Cherney et al. (1991) included 'Venture' in their trials; Iowa State University yield tests indicate that Venture yields 98% of 'Vantage' (Carlson et al., 1991). Work in Sweden (Landström et al., 1997; Burvall, 1997) used 'Palaton,' an improved U.S. variety similar to Venture. All three of these varieties were selected for lower alkaloid levels to alleviate palatability and animal health problems. Thus, higher yielding varieties or germplasm containing the anti-quality factors may have been discarded in forage improvement programs. Their inclusion in a biomass breeding program would further boost the possibilities of using reed canarygrass as a biofuel.

Success as a biofuel crop requires several traits. First, yields need to be maximized. Harvest management has a large impact on the total biomass realized from a planting. Wright (1988) showed that in northern Ohio two harvests (one late May and the other after frost) yielded 130% of that produced under a single harvest system. Several other characteristics are concurrently important. Ash needs to be minimized to avoid fouling the bioreactor and to limit the disposal problem. Likewise, several mineral constituents, including nitrogen, sulfur, and chlorine, have negative emissions or corrosion qualities and need to be minimized (Landström et al., 1997). Preliminary evidence indicates that reed canarygrass has higher than desirable levels of silica (Cherney et al., 1991), chlorine, and nitrogen (Burvall, 1997). However, delaying harvest of material from fall to early spring before regrowth begins can significantly depress the levels of undesirable constituents (Landström et al., 1996; Burvall, 1997; Hadders and Olsson, 1997). Further, Burvall (1997) showed that soil type dramatically affects all of these traits. Genetic variation for ash content and mineral composition has not been evaluated. Generally, high levels of hemicellulose and cellulose are desirable attributes of a biofuel, particularly in fermentation, but levels of these constituents is not as high in reed canarygrass as in switchgrass (Cherney et al., 1991).

Despite the obvious potential of reed canarygrass as a biofuel, no evaluations of reed canarygrass germplasm have been undertaken to assess biofuel characteristics. All breeding research on reed canarygrass to this point have focused on forage traits-palatability, seed retention, disease resistance, persistence, leafiness, etc. (Carlson et al., 1996). Maximum biomass per se has not been evaluated in available germplasm. Likewise, chemical constituents such as chlorine and sulfur have not been important in the past. Characterization of biofuel traits, under a harvesting regime designed for biofuel production, will improve our ability to breed distinctive, enhanced cultivars for this use.

## III.2.1. Reed Canarygrass Variety And Harvest Management Evaluation

**OBJECTIVE**

The objectives of this experiment are to determine if differences for biomass yield and biofuel quality exist among currently available reed canarygrass cultivars and to determine the optimal harvest management for reed canarygrass when grown as a biofuel crop.

**METHODS**

Seven cultivars were included in the trial (Palaton, Venture, Vantage, PSC1142, Rival, Bellevue, and Common). Palaton, Venture, and Vantage originated in Iowa, PSC1142 in Wisconsin, Rival and Bellevue in Canada, and Common may be derived from an old cultivar named Iowa Common. No other reed canarygrass cultivars were available in North America at the start of the experiment.

Trials were seeded at the Iowa State Agronomy and Agricultural Engineering Research Farm west of Ames, IA in August 1997, at the University of Wisconsin Agronomy Farm near Arlington, WI in May 1998, and at the McNay Research Farm near Lucas, IA in April 1999. Five harvest treatments were included in the experiment: spring + fall (SF), spring + winter (SW), fall only (F), winter only (W), and hay (H), which typically would include three harvests (spring, summer, and fall). The W and H treatments were not included at Ames. In all cases, the experiment was a randomized complete block design with four replications. Treatments were planted in a split-block arrangement, with harvest dates being main plots and cultivars sub-plots within each main plot. Plot size was 3' x 12' except at Ames, where it was 3' x 20'. A 3' border surrounded each plot.

Nitrogen was applied at 112 kg N $ha^{-1}$ in early April. In 2000 and 2001, spring harvest treatments had nitrogen application split between early April and after the spring harvest. Harvest dates were typically mid June, mid-October, and mid-March for spring, fall, and winter, respectively. The hay harvest was taken in July or August if sufficient growth was available. No data were taken in establishment year.

**RESULTS AND DISCUSSION**

Averaged across harvest treatments and varieties, dry matter biomass yields ranged considerably, both within and among locations. Ames produced the highest average yield in 1998 but the lowest in 2000 (Table III.1). This low level was partially the result of no yield from the winter 2001 harvest (Table III.2) due to excessive lodging. Average yield across the years of evaluation was highest at Ames, intermediate at Arlington, and lowest at Chariton.

The SF harvest management was superior to the others in most years and locations, although H at Arlington equaled its performance in 1999 and exceeded it in 2001 (Table III.2). However, for biofuel purposes, such a regime would probably be too expensive–necessitating another harvest–and produce too much biomass with a high moisture content to be useful for this project. As alluded to above, treatments containing the winter harvest typically had the lowest yields of any system. A major problem with overwintering reed canarygrass is lodging; the winter of 2000-01 produced a nearly four month snowpack in Iowa, resulting in severe lodging. Plots were not harvestable with our sickle-type harvester. Yields were measured in Wisconsin, but they were quite low.

The yield distribution in the SF management system showed that the F harvest was on average 67% of the spring harvest (Table III.4); height of the regrowth was about half of the spring growth (Table III.5). Height did not increase from spring to fall in unharvested material (Table III.5).

Dry matter content of biomass declined from ~30% in June to ~60% in October and overwintered material was ~90% dry matter(data not shown). A disadvantage of spring/early summer harvesting is a high water content in the biomass. Delaying this harvest to the latter part of June, as we have done here, helps to dry the material to an extent (dry matter in late May is around 20%, based on the germplasm evaluation III.2.2).

Few differences in biomass production or plant height were noted among the varieties tested (Tables III.3, III.4, and III.5). The major consistent differences were that PSC1142 had higher yield than the others and Rival was lower yielding. The yield advantage of PSC1142, though repeatable across locations and years, was not especially large, averaging 0.5 Mg $ha^{-1}$ (Table III.3). PSC1142 also tended to be taller than other cultivars, though this was not seen at all harvest dates (Table III.5).

Biofuel quality, as assessed by cell wall content, did not differ among varieties, but was influenced by location (which could be confounded by year/harvest date) and by harvest management (Table III.6). In general, biomass from the F treatment had more cell wall content than SF, due to the lower fiber in the spring harvest. However, overwintering material greatly increased the fiber in the biomass, but the lower yields remaining in the field, and the possibility that no yield at all can be harvested, suggest that this quality improvement is not worth pursuing.

Analysis of the biomass produced at Ames in 1999 and 2000 and Chariton in 2000 and pooled across cultivars shows that reed canarygrass has a fairly high ash content of about 11% on average (Table III.6). Interestingly, ash content determined during the proximate analysis (conducted by a different laboratory) was lower (Table III.7); the reason for the disparity could be due to slightly different ashing temperatures, but regardless, the ash value is at least twice as high as switchgrass grown in the same general location. The high ash content doesn't necessarily mean that reed canarygrass is not a viable fuel–it could be used in fuel mixtures, formulated in a manner analogous to livestock rations to have specified properties.

Harvest timing had no effect on energy concentration, but Ames had slightly more kJ $g^{-1}$ than did Chariton (Table III.7). Ultimate analysis indicated that N content was much higher in the spring harvested material (Table III.7), not surprising since fertilizer was applied in April and no leaves had senesced to return N to the soil. Winter harvests had slightly lower N than autumn harvests. Sulfur, an important element for co-firing, did not differ among the harvests or locations.

Chloride concentration was higher at Ames than at Chariton, and on average, its concentration fell from spring to winter, with a precipitous decline in the overwintered material (Table III.7). These levels of chloride are higher than those seen with switchgrass (Table II.4). Silica is an important element in co-firing operations, and reed canarygrass has relatively high levels when harvested in the fall, in either the one or two cut systems (Table III.8). Silica levels were higher in Ames than Chariton. Many major oxides and elements differed between locations, and a considerable number differed among the harvest dates averaged across locations. $K_2O$ and CaO declined after spring. Most other elements differed between the harvest managements.

In summary, reed canarygrass can produce acceptable biomass yields, though two harvests are desirable to maximize productivity. Several chemical constituents are higher in reed canarygrass than desirable, including silicon, chlorine, and total ash, as discussed in the literature review, suggesting that the best way to incorporate reed canarygrass biomass into a co-firing operation is to mix it with other material, such as switchgrass, to minimize its potential impact on boiler operation.

## III.2.2. Reed Canarygrass Germplasm Evaluation

**OBJECTIVE**

The objective of this experiment is to determine the biofuel potential of a diverse set of reed canarygrass germplasm from which new breeding germplasm can be developed. Much of this material is high in alkaloids, an anti-quality component for animal feed. Since all breeding to date has focussed on animal forage, many high yielding germplasms may have been overlooked.

**METHODS**

The entire reed canarygrass germplasm collection in the United States was acquired from the National Plant Introduction Station in Pullman, WA. (For a complete list of accessions and their origin, see Appendix III.1.) Several accessions had poor germination and were not included in the study. In addition, a number of germplasms and cultivars were included in the evaluation. In total 121 entries were included in the experiment at Ames, IA and 100 at Arlington, WI. The seeds were germinated in the greenhouse and transplanted to the field in mid-July 1998. Each plot consisted of 20 plants spaced 30 cm apart in two rows 30 cm apart. Approximately 1.2 m was left between plots. Plots were harvested twice in 1999 and in 2000, in late May or early June and in October using a flail-type or a sickle-type harvester. Nitrogen was applied at 112 kg N $ha^{-1}$ in early April in 1999 and split applied between early April and after the first harvest in 2000.

**RESULTS AND DISCUSSION**

An impressive range of variation is present among the accessions tested for virtually all traits related to biomass crops, including yield and height (Tables III.9-III.12). Most importantly, numerous accessions show yields as high as, or higher than, the elite cultivars, such as 'Palaton,' suggesting that this collection can be used to develop higher yielding cultivars. In addition, the entry 'Fraser', entered only at Ames, represented a collection of wild material along the roadside in Boone County, IA. It has high yields and appears generally useful (Table III.10). A broader and more representative set of collections should be made throughout the upper Midwest and North America in general (I have begun this in my spare time, and will become a regional evaluation in 2004) to adequately represent wild material. Height doesn't appear to be essential for high yields, but again, as the stands thicken over time, the yield potential may change. Some accessions did not survive the winter in 1998-9 (Brummer et al., 2000), but in general, reed canarygrass is well adapted to severe winter weather.

Biomass quality, as measured by cell-wall constituents, varied among the accessions although some constituents were not significant when averaged over years (Table III.12; complete data in the Appendix). Arlington samples have not yet been tested for quality components; they will be completed by December 2001. This suggests that quality, as measured by fiber content, does not differ substantially among the germplasm tested. Therefore, these results suggest that high yielding biomass cultivars can be developed that will have sufficient fiber for biofuel use.

**Table III.1.** Reed canarygrass biomass yields averaged across harvest treatments and varieties at Ames and Chariton (McNay), IA and Arlington, WI between 1998 and 2001.

| Location | Biomass (dry matter) Yield 1998 | 1999 | 2000 | 2001 | Avg |
|---|---|---|---|---|---|
| | ----------------------------Mg ha$^{-1}$ ------------------------------------ | | | | |
| Ames | 8.6 | 8.0 | 2.7 | - | 6.4 |
| Arlington | - | 5.4 | 4.6 | 7.0 | 5.6 |
| Chariton | - | - | 3.6 | 3.7 | 3.6 |
| Mean | 8.6 | 6.7 | 3.6 | 5.3 | 5.2 |
| LSD (5%) | - | 0.3 | 0.2 | 0.3 | 0.2 |

"-" No data collected in these years at specified location.

**Table III.2.** Reed canarygrass biomass yields averaged across varieties for several harvest managements at Ames and Chariton (McNay), IA and Arlington, WI between 1998 and 2001.

| Harvest Schedule | Ames 1998 | Ames 1999 | Ames 2000 | Ames Avg | Arlington 1999 | Arlington 2000 | Arlington 2001 | Arlington Avg | Chariton 2000 | Chariton 2001 | Chariton Avg | All Avg[1] | Ar-C Avg[2] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | --------------------------------------Mg ha$^{-1}$ ------------------------------------------------------ | | | | | | | | | | | | |
| Fall | 8.6 | 8.8 | 3.2 | 6.9 | 6.5 | 5.1 | 5.2 | 5.6 | 3.3 | 5.0 | 4.1 | 5.5 | 4.9 |
| Spr + Fall | 12.5 | 11.1 | 4.9 | 9.5 | 7.5 | 4.2 | 8.8 | 6.8 | 6.5 | 4.4 | 5.5 | 7.3 | 6.2 |
| Winter | 4.6 | 4.1 | 0.0 | 2.9 | 0.0 | 3.8 | 3.0 | 2.3 | 0.0 | 2.6 | 1.3 | 2.2 | 1.8 |
| Spr + Win | - | - | - | - | 5.2 | 3.8 | 7.3 | 5.5 | 2.5 | 2.9 | 2.7 | - | 4.1 |
| Hay | - | - | - | - | 7.6 | 5.8 | 10.6 | 8.0 | 5.6 | 3.4 | 4.5 | - | 6.2 |
| Mean | 8.6 | 8.0 | 2.7 | 6.4 | 5.4 | 4.6 | 7.0 | 5.6 | 3.6 | 3.7 | 3.6 | 5.0 | 4.6 |
| LSD (5%) | 0.5 | 0.6 | 0.3 | 0.3 | 0.3 | 0.4 | 0.7 | 0.3 | 0.4 | 0.3 | 0.3 | 0.3 | 0.2 |

[1]Averaged across all three locations.
[2]Averaged across Arlington and Chariton only.

**Table III.3.** Reed canarygrass total varietal dry matter yields by year, location, or harvest management. Only data from the Fall, Spring + Fall, and Winter managements were included.

| | Year | | | | Location | | | Harvest Mgmt. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Variety | 1998 | 1999 | 2000 | 2001 | Ames | Arl | Char | F | SF | W | Avg. |
| | | | | | Mg ha$^{-1}$ | | | | | | |
| Bellevue | 8.6 | 6.1 | 3.4 | 4.6 | 6.4 | 4.6 | 3.5 | 5.6 | 7.0 | 2.0 | 4.9 |
| Common | 8.6 | 6.2 | 3.4 | 5.1 | 6.4 | 5.0 | 3.6 | 5.6 | 7.3 | 2.2 | 5.0 |
| PSC1142 | 8.3 | 6.8 | 3.9 | 5.9 | 6.4 | 5.9 | 4.2 | 6.1 | 8.1 | 2.4 | 5.5 |
| Palaton | 8.9 | 6.4 | 3.6 | 4.5 | 6.6 | 4.7 | 3.8 | 5.4 | 7.4 | 2.2 | 5.0 |
| Rival | 8.7 | 5.9 | 3.0 | 4.2 | 6.1 | 4.5 | 3.1 | 5.2 | 6.6 | 1.9 | 4.6 |
| Vantage | 8.4 | 6.5 | 3.3 | 5.0 | 6.4 | 5.0 | 3.5 | 5.6 | 7.2 | 2.1 | 5.0 |
| Venture | 8.5 | 6.5 | 3.5 | 4.6 | 6.6 | 4.7 | 3.7 | 5.4 | 7.3 | 2.3 | 5.0 |
| Mean | 8.6 | 6.3 | 3.5 | 4.8 | 6.4 | 4.9 | 3.6 | 5.5 | 7.3 | 2.2 | 5.0 |
| LSD (5%) | NS | 0.5 | 0.3 | 0.5 | NS | 0.5 | 0.4 | 0.4 | 0.4 | 0.3 | 0.3 |

**Table III.4.** Reed canarygrass dry matter yields by variety and by location at three harvest dates, averaged across locations and years. Only data from the Fall, Spring + Fall, and Winter managements were included.

| | Spring | Fall Harvest | | | Winter |
|---|---|---|---|---|---|
| Harvest mgmt: | Spr + Fall | Average | Fall only | Spr + Fall | Winter only |
| | | | Mg ha$^{-1}$ | | |
| Mean | 4.3 | 4.2 | 5.5 | 2.9 | 2.5 |
| *By Variety* | | | | | |
| Bellevue | 4.2 | 4.2 | 5.6 | 2.8 | 2.4 |
| Common | 4.3 | 4.3 | 5.6 | 2.9 | 2.6 |
| PSC1142 | 4.7 | 4.7 | 6.0 | 3.4 | 2.8 |
| Palaton | 4.4 | 4.2 | 5.4 | 3.0 | 2.6 |
| Rival | 4.0 | 3.9 | 5.2 | 2.5 | 2.2 |
| Vantage | 4.2 | 4.3 | 5.6 | 2.9 | 2.5 |
| Venture | 4.4 | 4.2 | 5.4 | 2.9 | 2.6 |
| LSD (5%) | 0.3 | 0.2 | 0.4 | 0.2 | 0.3 |
| *By Location* | | | | | |
| Ames | 5.6 | 5.4 | 6.9 | 3.8 | 2.9 |
| Arlington | 4.6 | 4.0 | 5.6 | 2.3 | 3.4 |
| McNay | 2.8 | 3.4 | 4.1 | 2.6 | 1.3 |
| LSD (5%) | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |

**Table III.5.** Reed canarygrass heights by variety and by location at three harvest dates, averaged across locations and years. Only data from the Fall, Spring + Fall, and Winter managements were included. Ames heights for 1999 only. No height measurements were taken at Chariton.

| | Spring | Fall Harvest | | | Winter |
|---|---|---|---|---|---|
| Harvest mgmt: | Spr + Fall | Average | Fall only | Spr + Fall | Winter only |
| | -------------------- | -------------------- | cm | -------------------- | -------------------- |
| Mean | 126 | 91 | 129 | 53 | 107 |
| *By Variety* | | | | | |
| Common | 127 | 91 | 130 | 52 | 104 |
| PSC1142 | 130 | 94 | 133 | 55 | 112 |
| Palaton | 125 | 90 | 125 | 54 | 113 |
| Rival | 125 | 89 | 128 | 50 | 106 |
| Vantage | 127 | 93 | 133 | 54 | 94 |
| Venture | 125 | 91 | 127 | 55 | 110 |
| LSD (5%) | NS | 3 | 5 | NS | NS |
| *By Location* | | | | | |
| Ames | 118 | 82 | 119 | 45 | ND |
| Arlington | 134 | 101 | 139 | 62 | 106 |
| Contrast | * | * | * | * | - |

ND = not determined.
* = Locations are significantly different at P<0.05.

**Table III.6.** Reed canarygrass biofuel quality by variety, by location, and by harvest date, averaged across locations and years. Only data from the Fall, Spring + Fall, and Winter managements were included. No quality measurements are presented from Arlington, WI.

| | IVDMD[1] | NDF | ADF | ADL | CP | Ash (11/00) |
|---|---|---|---|---|---|---|
| | ------------------------------------------------% | ------------------------------------------------ | | | | |
| Mean | 33.9 | 58.9 | 40.6 | 8.0 | 4.4 | 11.3 |
| *By Variety* | | | | | | |
| Bellevue | 33.5 | 58.8 | 40.4 | 7.9 | 4.49 | 11.3 |
| Common | 34.4 | 58.7 | 40.2 | 7.9 | 4.31 | 11.3 |
| PSC1142 | 33.8 | 58.6 | 40.5 | 8.0 | 4.07 | 11.9 |
| Palaton | 33.9 | 59.5 | 41.0 | 8.0 | 4.35 | 11.1 |
| Rival | 34.3 | 58.9 | 40.5 | 7.9 | 4.58 | 11.2 |
| Vantage | 33.7 | 58.7 | 40.4 | 8.0 | 4.61 | 11.4 |
| Venture | 34.0 | 59.2 | 40.9 | 8.0 | 4.43 | 10.9 |
| LSD (5%) | NS | NS | NS | NS | 0.33 | 0.7 |
| *By Location* | | | | | | |
| Ames | 37.8 | 51.6 | 43.8 | 12.1 | 3.6 | 10.9 |
| McNay | 30.1 | 66.3 | 37.4 | 3.8 | 5.2 | 11.7 |
| Contrast | * | * | * | * | * | * |
| *By Harvest Management* | | | | | | |
| Fall | 33.6 | 54.9 | 40.1 | 8.8 | 4.8 | 11.9 |
| SprFall | 48.2 | 45.9 | 37.0 | 9.2 | 5.8 | 10.7 |
| Winter | 20.0 | 75.9 | 44.6 | 5.9 | 2.6 | NA |
| LSD (5%) | 0.5 | 0.53 | 0.5 | 0.1 | 0.2 | 0.4 |

[1]IVDMD–*in vitro* dry matter digestibility; NDF–neutral detergent fiber; ADF–acid detergent fiber; ADL–acid detergent lignin; CP–crude protein.
Note: Hemicellulose = NDF-ADF; Cellulose = ADF-ADL.

**Table III.7.** Proximate, ultimate, and chloride analyses of reed canarygrass biofuel by harvest management and by location. Only data from the Fall, Spring + Fall, and Winter managements were included. No measurements are presented from Arlington, WI.

| | Ash | Vol Mat | Fixed C | Energy | C | H | N | O | S | Cl |
|---|---|---|---|---|---|---|---|---|---|---|
| | ---------------%--------------- | | | kJ g-1 | ---------------------------%--------------------------- | | | | | ppm |
| Mean | 10.4 | 72.2 | 17.4 | 17.47 | 43.5 | 5.31 | 0.97 | 39.7 | 0.15 | 5494 |
| *By Harvest Management* | | | | | | | | | | |
| F | 11.0 | 72.5 | 16.6 | 17.35 | 43.0 | 5.23 | 0.86 | 39.8 | 0.14 | 3876 |
| SF–Fall | 10.4 | 72.0 | 17.6 | 17.47 | 43.5 | 5.40 | 0.89 | 39.7 | 0.16 | 5746 |
| SF–Spring | 9.9 | 72.1 | 18.1 | 17.60 | 43.9 | 5.30 | 1.17 | 39.6 | 0.16 | 6861 |
| W (A99) | 10.7 | 75.3 | 15.6 | 17.57 | 43.9 | 5.08 | 0.65 | 39.6 | 0.08 | 292 |
| LSD (5%) | NS | NS | 0.4 | NS | 0.6 | NS | 0.10 | NS | NS | 1378 |
| *By Location* | | | | | | | | | | |
| Ames | 10.2 | 72.3 | 17.5 | 17.63 | 43.6 | 5.30 | 1.06 | 39.7 | 0.13 | 6674 |
| McNay | 10.6 | 72.1 | 17.3 | 17.31 | 43.3 | 5.32 | 0.88 | 39.7 | 0.17 | 4315 |
| Contrast | NS | NS | NS | * | NS | NS | * | NS | NS | * |

**Table III.8.** Elemental and major oxide analyses of reed canarygrass biofuel by harvest management and by location. Only data from the Fall and Spring + Fall managements were included; all analyses were averaged across varieties. No data were taken from Arlington, WI.

| | | | | | By Harvest Date | | | |
|---|---|---|---|---|---|---|---|---|
| | | By Location | | | | Fall Harvest | | |
| Element | | Ames | McNay | Contrast | Spring | S + F | F only | LSD |
| *Constituents determined using INAA on dry vegetation* | | | | | | | | |
| As | ppm | 0.06 | 0.05 | | 0.04 | 0.03 | 0.08 | 0.29 |
| Au | ppb | 1.75 | 0.12 | * | 2.03 | 0.24 | 0.54 | NS |
| Ba | ppm | 19.00 | 28.67 | * | 24.75 | 22.75 | 24.00 | NS |
| Br | ppm | 5.46 | 7.72 | * | 7.13 | 7.62 | 5.03 | 1.07 |
| Ca | % | 0.34 | 0.38 | | 0.37 | 0.38 | 0.34 | NS |
| Co | ppm | 0.12 | 0.19 | | 0.14 | 0.18 | 0.14 | NS |
| Cr | ppm | 0.21 | 0.47 | * | 0.26 | 0.23 | 0.52 | 0.29 |
| Fe | ppm | 0.02 | 0.01 | | 0.01 | 0.01 | 0.02 | 0.003 |
| K | % | 1.24 | 0.96 | * | 1.50 | 1.15 | 0.66 | 0.13 |
| La | ppm | 0.11 | 0.15 | * | 0.12 | 0.10 | 0.16 | 0.036 |
| Mo | ppm | 1.70 | 0.96 | * | 0.91 | 1.77 | 1.32 | 0.54 |
| Na | ppm | 49.82 | 48.23 | | 47.08 | 42.37 | 57.63 | 11.07 |
| Rb | ppm | 7.61 | 16.33 | * | 14.17 | 13.92 | 7.83 | 1.75 |
| Sb | ppm | 0.01 | 0.02 | * | 0.01 | 0.01 | 0.01 | 0.008 |
| Sc | ppm | 0.02 | 0.04 | * | 0.03 | 0.03 | 0.04 | 0.011 |
| Se | ppm | 0.44 | 0.59 | * | 0.50 | 0.55 | 0.50 | NS |
| Sm | ppm | 0.01 | 0.02 | * | 0.01 | 0.01 | 0.02 | 0.28 |
| W | ppm | 0.15 | 0.44 | * | 0.39 | 0.31 | 0.18 | NS |
| Yb | ppm | 0.01 | 0.01 | | 0.01 | 0.00 | 0.01 | NS |
| Zn | ppm | 28.56 | 43.78 | * | 30.75 | 34.92 | 42.83 | 5.79 |
| *Constituents determined using ICP on fused and acid-digested vegetation* | | | | | | | | |
| $Al_2O_3$ | % | 0.40 | 0.42 | * | 0.43 | 0.33 | 0.48 | 0.16 |
| CaO | % | 4.25 | 3.22 | * | 3.74 | 4.14 | 3.32 | 0.54 |
| $Fe_2O_3$ | % | 0.21 | 0.14 | | 0.18 | 0.14 | 0.21 | 0.057 |
| $K_2O$ | % | 13.85 | 6.58 | * | 13.81 | 9.91 | 6.93 | 3.38 |
| MgO | % | 2.39 | 1.43 | * | 2.19 | 2.15 | 1.38 | 0.24 |
| MnO | % | 0.10 | 0.06 | * | 0.06 | 0.08 | 0.10 | 0.019 |
| $Na_2O$ | % | 0.21 | 0.22 | | 0.48 | 0.11 | 0.06 | NS |
| $P_2O_5$ | % | 5.05 | 3.06 | * | 4.27 | 4.59 | 3.30 | 0.59 |
| $SiO_2$ | % | 64.46 | 48.95 | * | 49.99 | 55.98 | 64.15 | 3.88 |
| $TiO_2$ | % | 0.02 | 0.03 | * | 0.02 | 0.02 | 0.03 | 0.0072 |
| LOI | % | 9.34 | 35.63 | * | 24.90 | 22.44 | 20.11 | 4.02 |
| Ba | ppm | 207.44 | 214.44 | | 224.33 | 198.92 | 209.58 | NS |
| Sr | ppm | 57.50 | 113.78 | * | 91.50 | 89.75 | 75.67 | 8.7 |
| Zr | ppm | 16.67 | 11.33 | * | 13.33 | 11.92 | 16.75 | 4.87 |

*continued...*

| Element | | By Location | | | By Harvest Date | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | Fall Harvest | | |
| | | Ames | McNay | Contrast | Spring | S + F | F only | LSD |
| *Constituents determined using ICP on aqua-regia digested vegetation* | | | | | | | | |
| Al | ppm | 0.06 | 0.10 | | 0.09 | 0.07 | 0.08 | NS |
| Ba | ppm | 108.11 | 242.56 | * | 190.58 | 162.42 | 173.00 | NS |
| Ca | ppm | 1.90 | 2.62 | | 2.37 | 2.42 | 1.99 | NS |
| Cr | ppm | 1.17 | 0.33 | | 0.92 | 1.00 | 0.33 | NS |
| Cu | ppm | 31.28 | 38.44 | | 31.25 | 36.25 | 37.08 | NS |
| Fe | ppm | 0.06 | 0.08 | | 0.06 | 0.05 | 0.08 | NS |
| K | ppm | 3.71 | 3.99 | | 5.13 | 4.26 | 2.16 | 2.84 |
| Mg | ppm | 0.78 | 0.92 | | 0.94 | 1.02 | 0.58 | NS |
| Mn | ppm | 308.33 | 435.44 | | 290.08 | 363.75 | 461.83 | NS |
| Mo | ppm | 9.83 | 6.67 | | 5.08 | 11.83 | 7.83 | NS |
| Na | ppm | 0.04 | 0.00 | * | 0.03 | 0.01 | 0.02 | NS |
| Ni | ppm | 6.67 | 10.67 | | 10.83 | 7.58 | 7.58 | NS |
| P | ppm | 937.16 | 1.36 | * | 449.97 | 595.53 | 362.30 | NS |
| S | ppm | 650.56 | 638.33 | | 636.58 | 749.33 | 547.42 | 134.8 |
| Sr | ppm | 29.56 | 107.78 | * | 75.42 | 72.42 | 58.17 | NS |
| Zn | ppm | 143.61 | 267.33 | * | 173.92 | 202.25 | 240.25 | NS |
| *Constituents determined using INAA on ashed vegetation* | | | | | | | | |
| As | ppm | 1.29 | 1.58 | | 1.48 | 1.37 | 1.47 | NS |
| Au | ppb | 15.22 | -3.67 | * | 14.25 | -1.08 | 4.17 | 12.63 |
| Ba | ppm | 143.28 | 153.33 | | 160.00 | 132.42 | 152.50 | NS |
| Br | ppm | 56.89 | 27.67 | * | 59.58 | 40.92 | 26.33 | 30.7 |
| Ca | % | 3.14 | 2.19 | * | 2.67 | 3.00 | 2.33 | 0.61 |
| Co | ppm | 2.61 | 2.00 | | 2.67 | 2.17 | 2.08 | NS |
| Cr | ppm | 2.44 | 1.78 | | 1.83 | 2.50 | 2.00 | NS |
| Cs | ppm | 1.10 | 0.60 | | 1.27 | 0.63 | 0.65 | NS |
| Fe | % | 0.12 | 0.11 | | 0.10 | 0.10 | 0.14 | 0.03 |
| K | % | 14.66 | 8.89 | * | 16.13 | 11.52 | 7.68 | 2.6 |
| La | ppm | 0.98 | 1.10 | | 0.96 | 0.84 | 1.33 | 0.35 |
| Mo | ppm | 17.61 | 7.56 | * | 7.42 | 16.92 | 13.42 | 2.11 |
| Na | ppm | 354.67 | 258.00 | | 265.00 | 226.17 | 427.83 | 156.5 |
| Rb | ppm | 65.39 | 100.67 | * | 103.17 | 95.58 | 50.33 | 16.1 |
| Sb | ppm | 0.12 | 0.09 | | 0.11 | 0.08 | 0.13 | NS |
| Sc | ppm | 0.18 | 0.26 | | 0.17 | 0.19 | 0.30 | 0.11 |
| Sm | ppm | 0.11 | 0.19 | * | 0.10 | 0.13 | 0.21 | 0.089 |
| Th | ppm | 0.07 | 0.14 | | 0.05 | 0.01 | 0.26 | 0.14 |
| Zn | ppm | 311.67 | 316.67 | | 265.00 | 309.17 | 368.33 | 69.8 |

**Table III.9.** Descriptive data for yield, height, and biomass quality averaged over 100 reed canarygrass accessions grown in Ames, IA and Arlington, WI in 1999 and 2000.

| | Total yield | Avg Ht | IVDMD[1] | NDF | ADF | ADL | CP | Ash |
|---|---|---|---|---|---|---|---|---|
| | g plant$^{-1}$ | cm | ------------- | ------------- | -----%----- | ------------- | ------------- | ------------- |
| Overall | 243 | 102 | 54.30 | 57.62 | 30.95 | 2.92 | 11.50 | 10.30 |
| 1st cut | 120 | 122 | 62.18 | 57.35 | 31.17 | 2.35 | 17.02 | 6.64 |
| 2nd cut | 120 | 81 | 46.52 | 57.84 | 30.68 | 3.49 | 6.05 | 13.96 |
| 1999 | 261 | 98 | 56.68 | 55.64 | 29.49 | 2.75 | 14.34 | 9.83 |
| 2000 | 223 | 105 | 52.01 | 59.54 | 32.38 | 3.08 | 8.74 | 11.26 |
| 1999 1st cut | 88 | 115 | 67.64 | 53.10 | 28.57 | 1.93 | 21.32 | 6.75 |
| 2000 1st cut | 152 | 128 | 56.75 | 61.57 | 33.75 | 2.77 | 12.70 | 7.52 |
| 1999 2nd cut | 173 | 79 | 45.68 | 58.29 | 30.46 | 3.60 | 7.32 | 12.86 |
| 2000 2nd cut | 69 | 83 | 47.34 | 57.45 | 30.97 | 3.38 | 4.81 | 15.03 |
| Ames | 296 | 94 | 58.49 | 57.21 | 31.06 | 3.44 | 11.95 | 10.83 |
| Arlington | 194 | 109 | 50.45 | 57.75 | 30.64 | 2.36 | 11.18 | 10.76 |
| Ames 1st cut | 139 | 102 | 67.80 | 56.72 | 31.07 | 2.60 | 18.19 | 6.60 |
| Arlington 1st cut | 101 | 141 | 56.58 | 57.95 | 31.24 | 2.09 | 15.86 | 7.60 |
| Ames 2nd cut | 152 | 85 | 49.11 | 57.90 | 31.16 | 4.30 | 5.63 | 15.07 |
| Arlington 2nd cut | 92 | 77 | 44.33 | 57.55 | 30.04 | 2.63 | 6.54 | 13.88 |
| Ames 1999 | 318 | 95 | 61.29 | 54.54 | 29.59 | 3.18 | 13.96 | nd |
| Ames 2000 | 275 | 94 | 55.62 | 59.95 | 32.57 | 3.72 | 9.89 | 10.83 |
| Arlington 1999 | 213 | 102 | 52.25 | 56.58 | 29.24 | 2.31 | 14.70 | 9.83 |
| Arlington 2000 | 175 | 116 | 48.66 | 58.91 | 32.05 | 2.42 | 7.66 | 11.71 |
| Ames 1999 1st cut | 92 | 103 | 72.60 | 52.53 | 29.03 | 2.21 | 21.04 | nd |
| Ames 2000 1st cut | 190 | 102 | 63.07 | 60.85 | 33.08 | 2.99 | 15.36 | 6.60 |
| Ames 1999 2nd cut | 223 | 84 | 49.97 | 56.67 | 30.22 | 4.16 | 6.83 | nd |
| Ames 2000 2nd cut | 84 | 87 | 48.20 | 59.06 | 32.06 | 4.44 | 4.43 | 15.07 |
| Arlington 1999 1st cut | 84 | 128 | 62.69 | 53.67 | 28.09 | 1.64 | 21.58 | 6.75 |
| Arlington 2000 1st cut | 118 | 154 | 50.52 | 62.22 | 34.36 | 2.55 | 10.14 | 8.43 |
| Arlington 1999 2nd cut | 129 | 75 | 41.85 | 59.47 | 30.37 | 2.97 | 7.84 | 12.86 |
| Arlington 2000 2nd cut | 56 | 79 | 46.85 | 55.60 | 29.72 | 2.29 | 5.18 | 14.97 |

[1]IVDMD–*in vitro* dry matter digestibility; NDF–neutral detergent fiber; ADF–acid detergent fiber; ADL–acid detergent lignin; CP–crude protein.

**Table III.10.** Biomass yield, plant height, spring vigor, winterkill, and maturity of 100 reed canarygrass accessions grown in Ames, IA and Arlington, WI in 1999 and 2000. Data are averaged across locations and years.

| Accession | Biomass yield | | | Plant height | | | Spring Vigor | Winter Kill | Maturity |
|---|---|---|---|---|---|---|---|---|---|
| | Total | Cut 1 | Cut 2 | Avg | Cut 1 | Cut 2 | | | |
| | -------g $plant^{-1}$--------- | | | ---------cm--------- | | | Score | % | Score |
| **Mean** | **243** | **123** | **120** | **102** | **123** | **81** | **5.8** | **5.7** | **3.3** |
| **Max** | **345** | **171** | **182** | **122** | **141** | **105** | **8.5** | **99.5** | **5.3** |
| **Min** | **169** | **64** | **80** | **79** | **92** | **61** | **0.9** | **0.0** | **1.0** |
| 172443 | 227 | 129 | 96 | 106 | 132 | 80 | 6.7 | 5.8 | 3.8 |
| 206463 | | | | | | | 4.9 | 95.4 | 3.1 |
| 209979 | 260 | 132 | 127 | 107 | 132 | 82 | 7.5 | 0.0 | 3.3 |
| 225116 | 263 | 132 | 132 | 112 | 138 | 86 | 6.8 | 0.0 | 3.1 |
| 227670 | 237 | 125 | 113 | 94 | 116 | 72 | 5.8 | 0.0 | 4.5 |
| 234694 | 205 | 94 | 112 | 80 | 100 | 61 | 3.8 | 0.0 | 1.6 |
| 234695 | 257 | 127 | 131 | 108 | 130 | 85 | 5.6 | 0.0 | 3.5 |
| 234696 | 301 | 140 | 159 | 97 | 116 | 78 | 4.8 | 4.5 | 2.6 |
| 234698 | 251 | 133 | 118 | 106 | 127 | 85 | 5.6 | 3.7 | 3.1 |
| 234780 | 268 | 140 | 128 | 104 | 123 | 85 | 6.5 | 2.0 | 3.3 |
| 234790 | 259 | 131 | 128 | 103 | 127 | 79 | 4.9 | 4.5 | 3.4 |
| 235023 | 259 | 132 | 129 | 97 | 118 | 77 | 5.0 | 0.0 | 3.6 |
| 235482 | 296 | 114 | 182 | 96 | 114 | 78 | 4.4 | 4.0 | 2.5 |
| 235484 | 270 | 137 | 134 | 99 | 117 | 80 | 6.1 | 0.0 | 3.3 |
| 235485 | 262 | 136 | 126 | 112 | 133 | 90 | 7.0 | 2.6 | 3.6 |
| 235546 | 286 | 147 | 138 | 105 | 123 | 87 | 7.0 | 7.2 | 4.0 |
| 236525 | 199 | 75 | 124 | 86 | 102 | 70 | 1.4 | 7.3 | 1.5 |
| 251426 | 278 | 135 | 141 | 105 | 127 | 84 | 5.3 | 0.0 | 3.6 |
| 251531 | 345 | 171 | 177 | 104 | 121 | 86 | 6.9 | 0.0 | 4.0 |
| 251841 | 268 | 135 | 132 | 106 | 129 | 83 | 6.5 | 0.0 | 3.8 |
| 251842 | 262 | 121 | 142 | 105 | 126 | 83 | 5.7 | 0.0 | 3.4 |
| 253317 | 279 | 143 | 136 | 108 | 128 | 89 | 8.0 | 0.0 | 4.1 |
| 255887 | 265 | 132 | 134 | 111 | 132 | 90 | 6.1 | 0.0 | 3.9 |
| 269728 | 286 | 135 | 149 | 100 | 114 | 86 | 5.0 | 0.0 | 2.5 |
| 272122 | 287 | 145 | 142 | 104 | 123 | 85 | 6.2 | 2.0 | 3.6 |
| 272123 | 252 | 137 | 114 | 107 | 131 | 82 | 5.8 | 0.0 | 4.3 |
| 284179 | 205 | 71 | 135 | 82 | 96 | 69 | 1.0 | 20.4 | 1.0 |
| 297362 | 178 | 93 | 85 | 80 | 92 | 67 | 4.0 | 2.3 | 1.5 |
| 314102 | 225 | 118 | 107 | 115 | 137 | 94 | 7.5 | 0.0 | 4.0 |
| 314581 | 205 | 106 | 102 | 99 | 119 | 78 | 4.9 | 0.0 | 2.3 |
| 314726 | 231 | 122 | 108 | 119 | 139 | 99 | 8.5 | 0.0 | 4.3 |
| 314727 | 232 | 124 | 108 | 102 | 122 | 81 | 7.4 | 0.0 | 3.0 |
| 314728 | 260 | 136 | 124 | 105 | 126 | 84 | 7.9 | 0.0 | 3.6 |
| 315486 | 267 | 142 | 123 | 114 | 140 | 87 | 7.2 | 0.0 | 4.4 |
| 315487 | 177 | 90 | 87 | 101 | 115 | 87 | 5.3 | 0.0 | 2.6 |
| 316329 | | | | | | | 1.0 | 69.7 | 1.3 |
| 316330 | 179 | 67 | 111 | 85 | 105 | 66 | 1.5 | 9.2 | 1.4 |
| 319825 | 235 | 123 | 112 | 89 | 116 | 63 | 5.2 | 0.0 | 3.3 |

*continued...*

| | Biomass yield | | | Plant height | | | Spring | Winter | |
|---|---|---|---|---|---|---|---|---|---|
| Accession | Total | Cut 1 | Cut 2 | Avg | Cut 1 | Cut 2 | Vigor | Kill | Maturity |
| | -------g plant$^{-1}$--------- | | | ---------cm--------- | | | Score | % | Score |
| 329243 | | | | | | | 0.9 | 96.2 | |
| 337718 | 236 | 121 | 116 | 110 | 139 | 82 | 8.0 | 0.0 | 4.9 |
| 338666 | . | . | . | . | . | . | . | 99.5 | . |
| 344557 | 275 | 124 | 153 | 98 | 115 | 81 | 6.2 | 2.7 | 3.5 |
| 345662 | 225 | 119 | 106 | 109 | 129 | 89 | 7.0 | 0.0 | 4.4 |
| 346015 | 258 | 121 | 142 | 101 | 120 | 82 | 4.7 | 0.0 | 2.5 |
| 357645 | 260 | 136 | 124 | 103 | 120 | 86 | 6.5 | 0.0 | 2.9 |
| 368980 | 252 | 126 | 125 | 114 | 141 | 88 | 6.7 | 0.0 | 4.5 |
| 369290 | 193 | 110 | 84 | 97 | 117 | 77 | 5.7 | 0.0 | 2.9 |
| 369291 | 248 | 133 | 115 | 107 | 132 | 81 | 6.5 | 0.0 | 2.8 |
| 369292 | 209 | 114 | 94 | 106 | 127 | 86 | 7.5 | 0.0 | 3.3 |
| 371754 | 248 | 123 | 123 | 103 | 125 | 81 | 6.3 | 0.0 | 3.5 |
| 372558 | 292 | 143 | 150 | 102 | 124 | 80 | 5.6 | 0.0 | 3.5 |
| 380963 | 190 | 100 | 89 | 95 | 111 | 78 | 5.7 | 0.0 | 2.6 |
| 380965 | 258 | 120 | 138 | 98 | 119 | 76 | 4.5 | 4.6 | 3.3 |
| 383726 | 200 | 101 | 98 | 94 | 112 | 76 | 6.2 | 0.0 | 2.8 |
| 387928 | 227 | 120 | 106 | 95 | 113 | 76 | 5.2 | 0.0 | 3.0 |
| 387929 | 169 | 89 | 80 | 96 | 117 | 75 | 5.5 | 0.0 | 3.1 |
| 392389 | 214 | 124 | 90 | 104 | 127 | 81 | 8.2 | 0.0 | 3.8 |
| 406316 | 230 | 119 | 113 | 98 | 119 | 77 | 6.5 | 0.0 | 3.3 |
| 422030 | 284 | 132 | 154 | 113 | 132 | 94 | 6.1 | 2.4 | 4.0 |
| 422031 | 224 | 90 | 134 | 93 | 107 | 80 | 2.3 | 17.7 | 2.0 |
| 433725 | 287 | 143 | 144 | 103 | 126 | 80 | 6.3 | 0.0 | 3.4 |
| 435294 | 222 | 117 | 106 | 107 | 128 | 86 | 5.7 | 0.0 | 3.1 |
| 435295 | 241 | 123 | 118 | 99 | 120 | 77 | 6.1 | 5.5 | 2.1 |
| 435296 | 250 | 127 | 124 | 95 | 116 | 74 | 6.2 | 3.1 | 2.5 |
| 435297 | 214 | 118 | 100 | 99 | 123 | 76 | 6.4 | 0.0 | 3.3 |
| 435298 | 241 | 125 | 116 | 98 | 119 | 78 | 5.5 | 3.8 | 3.5 |
| 435299 | 219 | 109 | 108 | 94 | 115 | 74 | 6.5 | 0.0 | 2.3 |
| 435300 | 248 | 133 | 116 | 104 | 128 | 80 | 7.1 | 0.0 | 4.0 |
| 435301 | 258 | 139 | 120 | 106 | 131 | 82 | 7.9 | 0.0 | 4.1 |
| 435302 | 229 | 130 | 100 | 105 | 130 | 79 | 8.3 | 0.0 | 3.5 |
| 435303 | 222 | 130 | 93 | 111 | 135 | 87 | 7.8 | 0.0 | 3.5 |
| 435304 | 224 | 117 | 105 | 97 | 114 | 80 | 4.8 | 0.0 | 2.8 |
| 435305 | 237 | 131 | 106 | 106 | 126 | 86 | 7.5 | 0.0 | 3.3 |
| 435307 | 208 | 104 | 106 | 89 | 105 | 74 | 5.8 | 0.0 | 2.0 |
| 435308 | 224 | 111 | 113 | 96 | 113 | 80 | 5.7 | 0.0 | 3.1 |
| 435309 | 220 | 112 | 107 | 97 | 124 | 70 | 5.5 | 0.0 | 2.9 |
| 435311 | 222 | 119 | 102 | 101 | 123 | 79 | 6.2 | 0.0 | 3.1 |
| 435312 | 284 | 147 | 138 | 98 | 114 | 82 | 7.1 | 0.0 | 2.4 |
| 440584 | 201 | 114 | 90 | 95 | 114 | 75 | 7.1 | 0.0 | 3.3 |
| 440585 | 197 | 105 | 92 | 95 | 121 | 69 | 5.7 | 0.0 | 4.0 |
| 505892 | 242 | 128 | 114 | 102 | 127 | 77 | 6.2 | 0.0 | 3.4 |
| 505893 | 268 | 132 | 135 | 106 | 129 | 83 | 6.2 | 0.0 | 4.4 |
| 539029 | 228 | 125 | 104 | 107 | 130 | 84 | 6.3 | 0.0 | 3.6 |
| 539030 | 262 | 133 | 129 | 106 | 129 | 83 | 6.7 | 0.0 | 4.3 |

*continued...*

| | Biomass yield | | | Plant height | | | Spring | Winter | |
|---|---|---|---|---|---|---|---|---|---|
| Accession | Total | Cut 1 | Cut 2 | Avg | Cut 1 | Cut 2 | Vigor | Kill | Maturity |
| | -------g plant$^{-1}$--------- | | | ---------cm--------- | | | Score | % | Score |
| 557461 | 203 | 104 | 100 | 93 | 112 | 75 | 4.5 | 0.0 | 3.8 |
| 578789 | 251 | 128 | 124 | 108 | 128 | 88 | 6.2 | 0.0 | 3.8 |
| 578790 | 169 | 64 | 100 | 79 | 102 | 63 | 1.0 | 20.6 | 1.6 |
| 578791 | 284 | 131 | 153 | 107 | 126 | 89 | 6.4 | 0.0 | 3.8 |
| 578792 | | | | | | | 1.2 | 41.6 | 1.5 |
| 578793 | 282 | 141 | 140 | 112 | 137 | 87 | 7.0 | 0.0 | 3.6 |
| 578795 | | | | | | | 1.0 | 25.1 | 1.3 |
| 578796 | 247 | 127 | 119 | 110 | 133 | 87 | 6.9 | 0.0 | 3.5 |
| 578797 | 290 | 149 | 141 | 122 | 139 | 105 | 6.8 | 0.0 | 5.0 |
| 597488 | 198 | 101 | 97 | 108 | 131 | 87 | 4.7 | 0.0 | 4.0 |
| Bellevue | 252 | 126 | 126 | 104 | 124 | 83 | 6.2 | 0.0 | 3.6 |
| PSC_1142 | 260 | 131 | 127 | 108 | 125 | 92 | 7.2 | 0.0 | 5.3 |
| Palaton | 306 | 149 | 155 | 112 | 136 | 89 | 6.8 | 0.0 | 4.1 |
| Rival | 252 | 128 | 123 | 105 | 126 | 85 | 5.2 | 0.0 | 3.9 |
| Vantage | 229 | 116 | 111 | 107 | 128 | 86 | 6.2 | 0.0 | 3.5 |
| Venture | 248 | 131 | 117 | 111 | 130 | 91 | 6.9 | 0.0 | 4.3 |

**Table III.11.** Biomass yield, plant height, spring vigor, winterkill, and maturity of 121 reed canarygrass accessions grown in Ames, IA in 1999 and 2000. Data are averaged across years.

| Accession | Biomass yield | | | Plant height | | | Spring Vigor | Winter Kill | Maturity |
|---|---|---|---|---|---|---|---|---|---|
| | Total | Cut 1 | Cut 2 | Avg | Cut 1 | Cut 2 | | | |
| | -------g $plant^{-1}$--------- | | | ---------cm--------- | | | Score | % | Score |
| **Mean** | **296** | **139** | **152** | **94** | **102** | **85** | **94.4** | **101.6** | **85.5** |
| **Max** | **446** | **204** | **243** | **113** | **123** | **111** | **99.0** | **8.1** | **4.0** |
| **Min** | **131** | **3** | **50** | **58** | **31** | **52** | **0.0** | **0.8** | **1.0** |
| 172443 | 276 | 166 | 133 | 97 | 109 | 86 | 12.1 | 6.9 | 2.5 |
| 206463 | . | 108 | . | 78 | 89 | 66 | 90.7 | 5.0 | 2.5 |
| 209979 | 307 | 153 | 173 | 99 | 107 | 90 | 0.0 | 7.0 | 2.5 |
| 225116 | 330 | 154 | 164 | 105 | 118 | 92 | 0.0 | 6.6 | 2.8 |
| 227670 | 255 | 137 | 108 | 92 | 108 | 75 | 2.6 | 5.6 | 4.0 |
| 234694 | 267 | 127 | 151 | 76 | 83 | 69 | 2.6 | 4.6 | 1.3 |
| 234695 | 321 | 150 | 169 | 98 | 106 | 91 | 0.0 | 5.3 | 2.5 |
| 234696 | 377 | 167 | 221 | 88 | 93 | 82 | 6.4 | 5.1 | 2.3 |
| 234698 | 300 | 153 | 143 | 96 | 106 | 86 | 2.5 | 6.3 | 2.3 |
| 234780 | 316 | 147 | 146 | 97 | 106 | 89 | 0.0 | 6.0 | 3.0 |
| 234790 | 307 | 141 | 137 | 93 | 104 | 83 | 4.1 | 5.3 | 2.8 |
| 235023 | 325 | 142 | 147 | 89 | 96 | 81 | 2.7 | 5.5 | 2.3 |
| 235482 | 356 | 154 | 223 | 90 | 102 | 79 | 0.0 | 4.8 | 3.0 |
| 235484 | 339 | 173 | 173 | 95 | 100 | 91 | 2.9 | 5.6 | 3.0 |
| 235485 | 296 | 155 | 145 | 102 | 110 | 94 | 0.0 | 6.5 | 2.8 |
| 235546 | 352 | 176 | 189 | 101 | 107 | 94 | 14.4 | 7.1 | 3.0 |
| 235547 | 360 | 167 | 217 | 91 | 98 | 83 | 6.7 | 6.4 | 2.5 |
| 235551 | 307 | 146 | 140 | 91 | 103 | 79 | 6.1 | 6.0 | 3.0 |
| 236525 | 226 | 78 | 141 | 72 | 78 | 67 | 5.4 | 0.8 | 1.0 |
| 241064 | 330 | 149 | 195 | 97 | 98 | 96 | 14.9 | 6.5 | 2.5 |
| 241065 | 285 | 131 | 162 | 91 | 100 | 83 | 53.2 | 5.8 | 3.0 |
| 251426 | 351 | 169 | 195 | 100 | 114 | 87 | 0.0 | 6.0 | 3.3 |
| 251531 | 338 | 148 | 164 | 98 | 108 | 88 | 0.0 | 5.9 | 3.0 |
| 251841 | 303 | 155 | 150 | 98 | 105 | 90 | 0.0 | 5.9 | 3.0 |
| 251842 | 366 | 157 | 206 | 100 | 109 | 90 | 3.0 | 6.4 | 2.8 |
| 253315 | 380 | 179 | 202 | 103 | 110 | 97 | 0.0 | 7.0 | 3.0 |
| 253316 | 446 | 204 | 243 | 100 | 103 | 97 | 3.3 | 7.0 | 3.0 |
| 253317 | 304 | 159 | 150 | 102 | 114 | 90 | 0.0 | 7.5 | 3.3 |
| 255887 | 309 | 151 | 171 | 98 | 103 | 92 | 0.0 | 5.8 | 2.8 |
| 269728 | 344 | 155 | 206 | 97 | 104 | 90 | 0.0 | 5.0 | 2.5 |
| 272122 | 331 | 167 | 163 | 97 | 103 | 92 | 0.0 | 6.4 | 2.8 |
| 272123 | 272 | 158 | 118 | 97 | 106 | 89 | 0.0 | 6.0 | 3.0 |
| 278706 | 332 | 158 | 193 | 101 | 106 | 95 | 0.0 | 6.0 | 2.8 |
| 284179 | 231 | 73 | 142 | 71 | 69 | 72 | 25.9 | 1.0 | 1.0 |
| 297362 | 193 | 91 | 96 | 80 | 79 | 81 | 0.0 | 5.1 | 1.5 |
| 314102 | 279 | 140 | 121 | 108 | 121 | 95 | 0.0 | 7.1 | 3.5 |
| 314581 | 258 | 119 | 119 | 90 | 101 | 79 | 0.0 | 5.8 | 2.5 |
| 314726 | 287 | 149 | 139 | 113 | 123 | 103 | 0.0 | 8.0 | 3.5 |
| 314727 | 262 | 153 | 143 | 101 | 110 | 91 | 0.0 | 7.4 | 3.0 |
| 314728 | 324 | 157 | 157 | 100 | 114 | 86 | 0.0 | 7.9 | 3.3 |
| 315486 | 308 | 164 | 150 | 106 | 119 | 92 | 0.0 | 7.0 | 3.3 |
| 315487 | 190 | 96 | 92 | 94 | 100 | 88 | 2.7 | 5.1 | 2.8 |

*continued...*

| Accession | Biomass yield Total | Biomass yield Cut 1 | Biomass yield Cut 2 | Plant height Avg | Plant height Cut 1 | Plant height Cut 2 | Spring Vigor | Winter Kill | Maturity |
|---|---|---|---|---|---|---|---|---|---|
| | -------g plant$^{-1}$--------- | | | ---------cm--------- | | | Score | % | Score |
| 316329 | . | 30 | . | . | 72. | | 72.6 | 0.9 | 1.0 |
| 316330 | 152 | 55 | 124 | 70 | 79 | 61 | 6.1 | 1.0 | 1.3 |
| 319825 | 267 | 135 | 143 | 79 | 96 | 63 | 0.0 | 5.3 | 2.5 |
| 329243 | . | . | . | . | 31. | | 97.0 | 0.9 | |
| 337718 | 280 | 141 | 145 | 106 | 119 | 92 | 0.0 | 7.0 | 3.8 |
| 338666 | | | | | | | 99.0 | | |
| 344557 | 355 | 155 | 190 | 92 | 95 | 89 | 5.9 | 5.9 | 3.0 |
| 345662 | 263 | 132 | 128 | 101 | 111 | 90 | 0.0 | 7.0 | 3.3 |
| 346015 | 314 | 133 | 163 | 94 | 102 | 86 | 3.2 | 5.3 | 2.5 |
| 357645 | 334 | 170 | 157 | 101 | 113 | 89 | 0.0 | 6.9 | 2.8 |
| 368980 | 298 | 150 | 151 | 108 | 121 | 95 | 0.0 | 5.9 | 3.5 |
| 369290 | 233 | 125 | 96 | 88 | 101 | 76 | 0.0 | 6.4 | 2.3 |
| 369291 | 317 | 170 | 168 | 98 | 109 | 87 | 3.1 | 6.9 | 2.5 |
| 369292 | 225 | 129 | 121 | 97 | 106 | 88 | 0.0 | 6.4 | 2.5 |
| 371754 | 301 | 146 | 169 | 100 | 111 | 88 | 0.0 | 6.5 | 3.0 |
| 372558 | 369 | 178 | 200 | 98 | 106 | 90 | 0.0 | 6.5 | 3.0 |
| 380963 | 245 | 144 | 123 | 95 | 110 | 80 | 0.0 | 5.5 | 3.3 |
| 380965 | 350 | 149 | 185 | 96 | 108 | 84 | 8.7 | 4.5 | 3.0 |
| 383726 | 222 | 117 | 116 | 91 | 100 | 82 | 0.0 | 6.4 | 2.5 |
| 387928 | 244 | 136 | 122 | 88 | 97 | 80 | 2.2 | 5.9 | 2.5 |
| 387929 | 188 | 99 | 90 | 88 | 97 | 79 | 0.0 | 5.4 | 2.8 |
| 392389 | 262 | 150 | 121 | 94 | 108 | 79 | 0.0 | 7.9 | 3.0 |
| 406316 | 294 | 142 | 141 | 91 | 101 | 80 | 0.0 | 7.0 | 3.0 |
| 422030 | 365 | 156 | 209 | 105 | 107 | 102 | 5.0 | 5.3 | 3.0 |
| 422031 | 272 | 109 | 158 | 88 | 89 | 88 | 15.6 | 3.6 | 2.0 |
| 433725 | 325 | 150 | 166 | 95 | 106 | 84 | 0.0 | 7.0 | 2.8 |
| 435294 | 268 | 128 | 133 | 95 | 104 | 86 | 0.0 | 5.9 | 2.8 |
| 435295 | 301 | 148 | 155 | 90 | 100 | 80 | 11.2 | 6.8 | 1.8 |
| 435296 | 326 | 149 | 176 | 89 | 98 | 80 | 5.6 | 5.8 | 2.0 |
| 435297 | 288 | 134 | 121 | 92 | 106 | 79 | 0.0 | 6.3 | 2.5 |
| 435298 | 293 | 144 | 164 | 96 | 103 | 88 | 7.4 | 6.0 | 2.5 |
| 435299 | 259 | 117 | 140 | 89 | 101 | 76 | 0.0 | 5.9 | 2.0 |
| 435300 | 285 | 143 | 137 | 95 | 111 | 80 | 0.0 | 6.6 | 2.5 |
| 435301 | 315 | 155 | 143 | 100 | 112 | 87 | 0.0 | 7.8 | 3.3 |
| 435302 | 290 | 149 | 119 | 96 | 114 | 78 | 0.0 | 8.1 | 3.0 |
| 435303 | 255 | 138 | 100 | 108 | 120 | 95 | 0.0 | 7.6 | 3.0 |
| 435304 | 264 | 137 | 139 | 94 | 101 | 86 | 0.0 | 4.5 | 2.5 |
| 435305 | 265 | 140 | 127 | 96 | 103 | 88 | 0.0 | 7.1 | 2.5 |
| 435307 | 269 | 115 | 138 | 83 | 94 | 72 | 0.0 | 6.0 | 2.0 |
| 435308 | 263 | 138 | 136 | 90 | 99 | 80 | 0.0 | 5.9 | 2.3 |
| 435309 | 255 | 122 | 132 | 83 | 104 | 62 | 0.0 | 6.0 | 2.3 |
| 435311 | 261 | 135 | 114 | 94 | 108 | 81 | 0.0 | 5.9 | 2.8 |
| 435312 | 389 | 181 | 192 | 87 | 98 | 76 | 0.0 | 6.8 | 2.3 |
| 440584 | 236 | 122 | 111 | 88 | 99 | 77 | 0.0 | 7.1 | 2.5 |
| 440585 | 249 | 122 | 112 | 87 | 102 | 71 | 0.0 | 5.9 | 3.0 |
| 505892 | 291 | 143 | 146 | 95 | 110 | 80 | 0.0 | 7.0 | 2.8 |
| 505893 | 322 | 149 | 181 | 97 | 106 | 88 | 2.8 | 5.5 | 3.3 |
| 539029 | 271 | 134 | 119 | 95 | 105 | 87 | 0.0 | 6.1 | 2.8 |
| 539030 | 330 | 152 | 171 | 98 | 108 | 88 | 0.0 | 7.1 | 3.0 |

*continued...*

| Accession | Biomass yield Total | Biomass yield Cut 1 | Biomass yield Cut 2 | Plant height Avg | Plant height Cut 1 | Plant height Cut 2 | Spring Vigor | Winter Kill | Maturity |
|---|---|---|---|---|---|---|---|---|---|
| | -------g plant$^{-1}$--------- | | | ---------cm--------- | | | Score | % | Score |
| 557461 | 247 | 110 | 125 | 88 | 96 | 79 | 0.0 | 4.9 | 3.0 |
| 578789 | 308 | 150 | 155 | 102 | 109 | 95 | 0.0 | 6.3 | 3.0 |
| 578790 | 162 | 60 | 50 | 89 | 77 | 77 | 14.9 | 1.0 | 1.3 |
| 578791 | 366 | 158 | 194 | 99 | 104 | 95 | 0.0 | 6.8 | 3.0 |
| 578792 | . | 3 | . | . | 41. | | 67.7 | 1.4 | 1.0 |
| 578793 | 348 | 163 | 177 | 103 | 116 | 90 | 0.0 | 7.1 | 2.8 |
| 578795 | . | 3 | . | 69 | 53 | 85 | 28.2 | 1.0 | 1.0 |
| 578796 | 298 | 150 | 154 | 102 | 113 | 91 | 0.0 | 7.3 | 3.0 |
| 578797 | 330 | 172 | 167 | 113 | 116 | 111 | 0.0 | 6.6 | 4.0 |
| 597488 | 223 | 114 | 108 | 101 | 109 | 93 | 0.0 | 5.5 | 3.0 |
| Bellevue | 303 | 142 | 147 | 93 | 105 | 81 | 0.0 | 6.3 | 2.8 |
| Flare | 308 | 140 | 177 | 102 | 107 | 97 | 0.0 | 5.3 | 2.8 |
| Fraser | 342 | 158 | 180 | 101 | 110 | 92 | 4.0 | 6.3 | 3.0 |
| High_SLW | 380 | 164 | 218 | 105 | 113 | 96 | 0.0 | 6.9 | 2.3 |
| Lo_SLW | 303 | 147 | 173 | 98 | 103 | 94 | 0.0 | 6.1 | 2.8 |
| PS-3 | 313 | 154 | 147 | 101 | 106 | 96 | 0.0 | 6.6 | 3.0 |
| PSC_1142 | 371 | 177 | 203 | 102 | 108 | 96 | 3.3 | 6.5 | 3.5 |
| Palaton | 300 | 154 | 158 | 104 | 107 | 101 | 0.0 | 6.5 | 3.3 |
| RC-11 | 333 | 163 | 182 | 96 | 104 | 89 | 0.0 | 5.6 | 2.8 |
| RC-5 | 353 | 168 | 181 | 97 | 105 | 89 | 0.0 | 6.4 | 2.8 |
| RC-6 | 363 | 158 | 190 | 103 | 112 | 94 | 0.0 | 6.0 | 2.8 |
| RC-7 | 306 | 155 | 165 | 94 | 98 | 91 | 7.3 | 6.5 | 2.8 |
| RH33 | 339 | 137 | 171 | 84 | 88 | 80 | 4.3 | 5.0 | 1.8 |
| RH47 | 293 | 143 | 153 | 101 | 109 | 93 | 2.6 | 5.0 | 2.8 |
| RH50 | 181 | 79 | 86 | 66 | 80 | 52 | 0.0 | 4.8 | 1.5 |
| RH78 | 131 | 50 | 93 | 58 | 58 | 57 | 2.6 | 4.1 | 1.5 |
| RH85 | 246 | 109 | 128 | 80 | 86 | 73 | 0.0 | 3.1 | 1.5 |
| Rival | 322 | 158 | 160 | 98 | 101 | 95 | 3.8 | 5.9 | 2.8 |
| Vantage | 254 | 141 | 135 | 95 | 102 | 87 | 0.0 | 6.5 | 3.0 |
| Venture | 305 | 159 | 138 | 105 | 113 | 97 | 0.0 | 7.4 | 3.0 |

**Table III.12.** Fiber, protein, and ash concentration of 100 reed canarygrass accessions grown in Ames, IA and Arlington, WI in 1999 and 2000. Data are averaged across locations and years.

| | *In Vitro* Dry Matter Digestibility (IVDMD) | | | Neutral Detergent Fiber (NDF) | | | Acid Detergent Fiber (ADF) | | | Acid Detergent Lignin (ADL) | | | Crude Protein | | | Ash | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Accession | Avg | 1st | 2nd | Avg | 1st | 2nd | Avg | 1st | 2nd | Avg | 1st | 2nd | Avg | 1st | 2nd | Avg | 1st | 2nd |
| | % | | | | | | | | | | | | | | | | | |
| **Mean** | **54.3** | **62.2** | **46.5** | **57.6** | **57.4** | **57.8** | **31.0** | **31.2** | **30.7** | **2.9** | **2.4** | **3.5** | **11.5** | **17.0** | **6.0** | **10.3** | **7.6** | **14.0** |
| **Max** | **57.3** | **67.7** | **51.8** | **60.4** | **61.0** | **62.5** | **33.0** | **34.0** | **33.8** | **3.3** | **2.8** | **4.3** | **14.7** | **21.9** | **8.9** | **12.3** | **10.1** | **17.1** |
| **Min** | **50.9** | **58.1** | **39.3** | **54.6** | **51.9** | **54.4** | **28.1** | **26.8** | **28.2** | **2.5** | **1.7** | **3.2** | **9.5** | **13.5** | **4.6** | **7.8** | **5.8** | **10.8** |
| 172443 | 50.9 | 58.6 | 43.1 | 60.4 | 60.2 | 60.5 | 33.0 | 33.4 | 32.5 | 3.3 | 2.8 | 3.8 | 10.5 | 14.9 | 6.0 | 9.1 | 6.5 | 13.3 |
| 206463 | . | . | 47.2 | . | . | 56.6 | . | . | 29.8 | . | . | 3.5 | . | . | 6.6 | . | . | 12.9 |
| 209979 | 54.6 | 59.8 | 49.1 | 57.8 | 59.7 | 55.9 | 30.9 | 32.6 | 29.0 | 2.9 | 2.6 | 3.3 | 10.3 | 15.2 | 5.3 | 9.9 | 6.6 | 13.9 |
| 225116 | 54.0 | 61.3 | 47.1 | 57.6 | 58.2 | 56.9 | 31.2 | 32.2 | 30.1 | 3.0 | 2.5 | 3.6 | 10.4 | 15.9 | 5.1 | 10.3 | 6.2 | 14.3 |
| 227670 | 51.2 | 59.9 | 42.6 | 59.7 | 59.2 | 60.2 | 32.3 | 32.6 | 32.3 | 3.2 | 2.5 | 3.9 | 11.7 | 15.7 | 7.7 | 10.6 | 8.6 | 13.6 |
| 234694 | 56.1 | 65.5 | 46.6 | 55.1 | 53.1 | 57.2 | 28.3 | 27.7 | 29.0 | 2.6 | 1.9 | 3.3 | 14.7 | 21.2 | 8.2 | 10.5 | 6.9 | 13.8 |
| 234695 | 54.7 | 61.5 | 48.0 | 57.0 | 57.4 | 56.6 | 31.1 | 31.9 | 30.2 | 2.9 | 2.5 | 3.4 | 11.3 | 16.7 | 6.0 | 10.4 | 7.3 | 13.5 |
| 234696 | 55.0 | 63.9 | 45.9 | 56.1 | 55.8 | 56.2 | 30.5 | 30.7 | 30.2 | 2.8 | 2.1 | 3.5 | 12.3 | 18.5 | 6.0 | 10.3 | 9.1 | 13.9 |
| 234698 | 55.8 | 61.7 | 49.9 | 56.7 | 58.2 | 55.1 | 30.5 | 31.9 | 29.2 | 2.8 | 2.4 | 3.2 | 11.5 | 17.0 | 6.0 | 10.9 | 7.7 | 15.1 |
| 234780 | 55.6 | 62.2 | 49.1 | 57.1 | 58.4 | 55.6 | 30.8 | 31.6 | 29.9 | 2.8 | 2.3 | 3.3 | 11.1 | 16.8 | 5.2 | 11.1 | 7.1 | 14.9 |
| 234790 | 53.5 | 60.3 | 46.5 | 57.9 | 58.6 | 57.4 | 31.2 | 32.5 | 30.1 | 3.1 | 2.6 | 3.5 | 11.2 | 16.3 | 6.0 | 9.8 | 7.6 | 14.8 |
| 235023 | 54.7 | 62.6 | 47.3 | 56.1 | 55.8 | 56.3 | 30.0 | 30.2 | 29.8 | 2.8 | 2.3 | 3.4 | 12.4 | 18.4 | 6.4 | 11.2 | 9.3 | 15.0 |
| 235482 | 56.7 | 64.4 | 49.1 | 55.8 | 55.4 | 56.3 | 29.7 | 29.9 | 29.5 | 2.7 | 2.1 | 3.4 | 13.0 | 19.5 | 6.5 | 10.8 | 8.0 | 14.4 |
| 235484 | 56.3 | 61.9 | 50.4 | 55.5 | 56.6 | 54.4 | 29.7 | 30.8 | 28.6 | 2.8 | 2.3 | 3.3 | 11.9 | 18.1 | 5.7 | 10.7 | 7.7 | 14.2 |
| 235485 | 55.2 | 60.9 | 49.4 | 56.6 | 57.8 | 55.3 | 30.4 | 31.7 | 29.1 | 2.8 | 2.5 | 3.2 | 11.1 | 16.3 | 5.9 | 11.5 | 8.6 | 15.0 |
| 235546 | 55.4 | 61.9 | 48.8 | 56.5 | 57.7 | 55.3 | 30.3 | 31.7 | 29.1 | 2.8 | 2.4 | 3.3 | 11.3 | 16.7 | 5.7 | 10.6 | 9.1 | 14.3 |
| 236525 | 55.6 | 62.3 | 49.1 | 57.6 | 57.7 | 57.2 | 31.4 | 31.7 | 30.9 | 2.9 | 2.3 | 3.4 | 12.4 | 17.8 | 6.9 | 10.4 | 7.5 | 14.2 |
| 251426 | 55.4 | 62.8 | 47.8 | 57.3 | 57.5 | 57.1 | 31.6 | 32.3 | 30.9 | 2.9 | 2.4 | 3.5 | 11.2 | 17.1 | 5.2 | 9.9 | 9.3 | 12.0 |
| 251531 | 53.0 | 60.0 | 46.0 | 58.0 | 58.6 | 57.5 | 31.5 | 32.4 | 30.6 | 3.1 | 2.5 | 3.7 | 10.2 | 15.9 | 4.6 | 10.5 | 7.3 | 14.1 |
| 251841 | 55.3 | 63.2 | 47.4 | 57.0 | 55.9 | 57.7 | 30.6 | 30.0 | 31.0 | 2.9 | 2.3 | 3.5 | 11.7 | 17.8 | 5.5 | 9.4 | 7.6 | 11.7 |
| 251842 | 54.4 | 62.1 | 46.5 | 57.4 | 56.7 | 58.5 | 30.5 | 30.6 | 30.6 | 2.9 | 2.3 | 3.4 | 11.6 | 17.0 | 6.3 | 10.2 | 7.7 | 13.8 |
| 253317 | 55.4 | 61.5 | 49.2 | 57.3 | 58.4 | 56.3 | 31.1 | 32.4 | 29.8 | 2.9 | 2.5 | 3.2 | 10.8 | 16.2 | 5.5 | 9.9 | 7.5 | 12.5 |
| 255887 | 56.0 | 62.7 | 49.1 | 56.4 | 57.6 | 55.4 | 30.1 | 31.2 | 29.0 | 2.9 | 2.3 | 3.5 | 10.6 | 15.9 | 5.3 | 8.7 | 7.0 | 11.0 |
| 269728 | 54.7 | 62.1 | 46.9 | 56.7 | 58.4 | 55.1 | 31.0 | 32.0 | 29.9 | 3.0 | 2.4 | 3.5 | 10.9 | 16.9 | 4.7 | 9.2 | 7.2 | 12.9 |
| 272122 | 56.1 | 61.4 | 50.5 | 56.4 | 57.5 | 55.6 | 30.1 | 31.3 | 28.9 | 2.8 | 2.5 | 3.2 | 11.7 | 16.3 | 7.0 | 8.7 | 7.6 | 10.8 |

*continued...*

| Accession | *In Vitro* Dry Matter Digestibility (IVDMD) | | | Neutral Detergent Fiber (NDF) | | | Acid Detergent Fiber (ADF) | | | Acid Detergent Lignin (ADL) | | | Crude Protein | | | Ash | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Avg | 1st | 2nd | Avg | 1st | 2nd | Avg | 1st | 2nd | Avg | 1st | 2nd | Avg | 1st | 2nd | Avg | 1st | 2nd |
| | % | | | | | | | | | | | | | | | | | |
| 272123 | 56.2 | 62.0 | 50.3 | 56.9 | 58.6 | 55.1 | 30.7 | 32.5 | 28.8 | 2.9 | 2.4 | 3.3 | 11.2 | 16.7 | 5.5 | 9.4 | 7.8 | 12.3 |
| 284179 | 57.2 | 64.7 | 49.8 | 56.7 | 56.3 | 57.0 | 30.5 | 30.2 | 30.7 | 2.8 | 2.1 | 3.4 | 13.1 | 19.1 | 7.1 | 10.5 | 6.8 | 14.3 |
| 297362 | 56.7 | 67.7 | 46.0 | 54.6 | 51.9 | 57.3 | 28.1 | 26.8 | 29.4 | 2.5 | 1.7 | 3.3 | 14.5 | 21.6 | 7.4 | 11.8 | 7.2 | 16.8 |
| 314102 | 53.7 | 60.6 | 46.9 | 59.3 | 59.5 | 59.3 | 32.0 | 32.6 | 31.4 | 3.1 | 2.6 | 3.6 | 10.5 | 15.1 | 6.0 | 9.0 | 7.5 | 11.5 |
| 314581 | 53.4 | 64.5 | 42.3 | 57.8 | 54.4 | 61.4 | 30.1 | 28.4 | 31.8 | 2.9 | 2.0 | 3.8 | 12.6 | 18.9 | 6.4 | 10.3 | 6.1 | 13.6 |
| 314726 | 51.6 | 60.2 | 43.2 | 60.1 | 59.2 | 60.9 | 32.5 | 32.6 | 32.3 | 3.1 | 2.6 | 3.7 | 10.2 | 14.4 | 6.1 | 10.6 | 8.0 | 14.1 |
| 314727 | 54.9 | 63.4 | 46.3 | 56.7 | 55.7 | 57.9 | 30.3 | 29.9 | 30.9 | 2.8 | 2.3 | 3.4 | 11.9 | 17.5 | 6.2 | 11.9 | 10.1 | 16.3 |
| 314728 | 51.6 | 61.4 | 42.1 | 58.6 | 56.7 | 60.3 | 31.9 | 31.2 | 32.5 | 3.1 | 2.5 | 3.8 | 11.7 | 16.8 | 6.9 | 11.7 | 8.2 | 15.8 |
| 315486 | 54.6 | 60.9 | 48.4 | 57.8 | 59.2 | 56.3 | 31.4 | 32.7 | 30.1 | 3.0 | 2.5 | 3.4 | 10.3 | 15.6 | 5.0 | 8.9 | 6.7 | 12.7 |
| 315487 | 52.5 | 62.6 | 42.4 | 58.8 | 56.0 | 61.5 | 31.7 | 30.6 | 32.6 | 3.0 | 2.3 | 3.7 | 11.7 | 17.3 | 6.1 | 10.0 | 7.0 | 13.0 |
| 316329 | 57.3 | 64.4 | 50.5 | 56.0 | 54.3 | 57.6 | 30.4 | 29.1 | 31.7 | 2.7 | 2.1 | 3.3 | 12.2 | 18.8 | 5.7 | 11.3 | 7.5 | 14.7 |
| 316330 | 56.0 | 64.4 | 47.2 | 57.1 | 56.9 | 57.4 | 31.0 | 30.7 | 31.4 | 2.9 | 2.2 | 3.6 | 13.8 | 18.6 | 8.7 | 10.2 | 7.9 | 14.5 |
| 319825 | 54.5 | 62.6 | 46.3 | 57.7 | 56.9 | 58.5 | 30.7 | 30.8 | 30.6 | 2.8 | 2.3 | 3.4 | 11.9 | 17.1 | 6.6 | 10.8 | 7.8 | 15.0 |
| 329243 | . | . | 47.8 | . | . | 58.7 | . | . | 31.2 | . | . | 3.5 | . | . | 6.2 | . | 9.3 | . |
| 337718 | 54.2 | 60.1 | 47.9 | 58.8 | 59.7 | 57.6 | 31.4 | 32.5 | 30.2 | 3.0 | 2.7 | 3.4 | 10.8 | 15.1 | 6.3 | 9.7 | 7.4 | 12.0 |
| 338666 | | | | | | | | | | | | | | | | | | |
| 344557 | 56.9 | 62.0 | 51.8 | 56.3 | 58.1 | 54.5 | 29.8 | 31.5 | 28.2 | 2.8 | 2.4 | 3.2 | 10.9 | 16.7 | 5.3 | 9.9 | 6.7 | 13.5 |
| 345662 | 53.6 | 61.7 | 45.3 | 58.7 | 58.1 | 59.5 | 31.8 | 31.6 | 32.1 | 3.0 | 2.4 | 3.7 | 11.0 | 16.8 | 5.2 | 7.8 | 6.9 | 11.5 |
| 346015 | 56.5 | 63.7 | 49.6 | 55.5 | 55.8 | 55.3 | 29.4 | 30.1 | 28.8 | 2.7 | 2.2 | 3.3 | 12.5 | 18.2 | 6.9 | 9.7 | 6.4 | 13.3 |
| 357645 | 54.2 | 61.6 | 46.6 | 57.6 | 57.4 | 58.0 | 30.9 | 31.2 | 30.7 | 3.0 | 2.4 | 3.6 | 11.1 | 16.8 | 5.4 | 10.6 | 8.2 | 14.2 |
| 368980 | 53.1 | 59.0 | 47.4 | 59.3 | 61.0 | 57.7 | 32.3 | 34.0 | 30.5 | 3.0 | 2.7 | 3.4 | 9.9 | 13.5 | 6.2 | 10.6 | 7.5 | 14.8 |
| 369290 | 53.3 | 64.4 | 42.3 | 59.1 | 56.2 | 62.2 | 31.4 | 30.0 | 32.9 | 3.0 | 2.2 | 3.8 | 11.5 | 17.8 | 5.2 | 9.5 | 7.9 | 12.6 |
| 369291 | 52.7 | 60.9 | 44.5 | 59.0 | 57.9 | 60.2 | 31.9 | 31.5 | 32.3 | 3.0 | 2.4 | 3.6 | 11.4 | 17.2 | 5.5 | 10.0 | 8.3 | 14.6 |
| 369292 | 51.9 | 60.1 | 43.9 | 60.0 | 59.4 | 60.7 | 32.6 | 32.8 | 32.3 | 3.2 | 2.6 | 3.7 | 11.2 | 16.0 | 6.4 | 10.5 | 7.3 | 13.4 |
| 371754 | 54.7 | 61.6 | 47.4 | 56.3 | 57.2 | 55.5 | 30.0 | 30.8 | 29.3 | 2.8 | 2.4 | 3.2 | 10.5 | 16.0 | 4.8 | 10.9 | 8.1 | 15.5 |
| 372558 | 55.2 | 62.4 | 47.8 | 56.4 | 56.8 | 56.1 | 30.4 | 30.8 | 30.0 | 2.9 | 2.4 | 3.4 | 11.3 | 17.4 | 5.2 | 10.3 | 6.9 | 13.5 |
| 380963 | 51.6 | 63.9 | 39.3 | 60.0 | 57.4 | 62.5 | 32.5 | 31.3 | 33.8 | 3.3 | 2.3 | 4.3 | 13.2 | 18.4 | 7.9 | 9.4 | 7.8 | 11.7 |
| 380965 | 53.3 | 63.7 | 42.8 | 58.8 | 57.2 | 60.3 | 31.0 | 30.4 | 31.5 | 3.1 | 2.3 | 4.0 | 13.8 | 18.7 | 8.9 | 10.5 | 7.6 | 14.8 |
| 383726 | 52.3 | 63.2 | 41.4 | 60.1 | 58.4 | 61.7 | 31.5 | 31.0 | 32.0 | 3.1 | 2.2 | 4.0 | 12.7 | 17.2 | 8.1 | 9.4 | 5.8 | 13.8 |
| 387928 | 54.5 | 63.8 | 45.5 | 57.4 | 56.1 | 58.7 | 30.5 | 29.7 | 31.3 | 2.8 | 2.1 | 3.6 | 11.6 | 18.1 | 5.2 | 9.6 | 7.6 | 13.4 |
| 387929 | 53.9 | 63.7 | 44.3 | 58.2 | 56.8 | 59.6 | 30.4 | 29.8 | 31.0 | 2.8 | 2.1 | 3.5 | 12.3 | 18.1 | 6.5 | 9.0 | 6.9 | 12.9 |
| 392389 | 52.2 | 62.8 | 41.8 | 59.6 | 58.8 | 60.7 | 31.9 | 31.7 | 32.2 | 3.1 | 2.3 | 3.9 | 11.6 | 16.3 | 7.1 | 10.4 | 6.8 | 15.3 |

*continued...*

| Accession | *In Vitro* Dry Matter Digestibility (IVDMD) | | | Neutral Detergent Fiber (NDF) | | | Acid Detergent Fiber (ADF) | | | Acid Detergent Lignin (ADL) | | | Crude Protein | | | Ash | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Avg | 1st | 2nd | Avg | 1st | 2nd | Avg | 1st | 2nd | Avg | 1st | 2nd | Avg | 1st | 2nd | Avg | 1st | 2nd |
| | % | | | | | | | | | | | | | | | | | |
| 406316 | 53.6 | 60.1 | 47.4 | 58.0 | 58.8 | 57.1 | 31.3 | 32.3 | 30.3 | 3.0 | 2.6 | 3.4 | 10.5 | 15.1 | 6.0 | 10.1 | 7.9 | 13.3 |
| 422030 | 54.1 | 59.6 | 48.5 | 57.6 | 59.1 | 56.3 | 31.7 | 33.2 | 30.3 | 3.0 | 2.6 | 3.4 | 9.8 | 14.8 | 4.8 | 11.6 | 8.6 | 14.5 |
| 422031 | 53.7 | 59.7 | 47.9 | 58.9 | 60.0 | 57.8 | 31.9 | 32.8 | 31.1 | 3.0 | 2.6 | 3.5 | 11.8 | 16.5 | 7.3 | 10.3 | 7.1 | 13.7 |
| 433725 | 56.1 | 63.1 | 48.8 | 55.8 | 57.1 | 54.4 | 30.0 | 31.2 | 28.8 | 2.9 | 2.4 | 3.4 | 10.7 | 16.7 | 4.6 | 10.2 | 6.0 | 14.1 |
| 435294 | 53.1 | 63.4 | 43.0 | 59.4 | 57.4 | 61.4 | 32.0 | 30.9 | 33.1 | 2.9 | 2.2 | 3.5 | 11.4 | 17.3 | 5.5 | 9.6 | 6.3 | 13.1 |
| 435295 | 55.4 | 64.7 | 46.2 | 55.6 | 54.3 | 56.9 | 29.5 | 28.7 | 30.1 | 2.8 | 2.1 | 3.5 | 11.9 | 18.7 | 5.1 | 11.4 | 8.8 | 15.9 |
| 435296 | 55.0 | 64.3 | 45.8 | 56.2 | 54.5 | 57.9 | 29.6 | 28.8 | 30.4 | 2.7 | 2.1 | 3.3 | 11.2 | 17.1 | 5.3 | 9.6 | 6.8 | 13.3 |
| 435297 | 53.8 | 63.1 | 44.6 | 58.0 | 56.6 | 59.3 | 31.2 | 30.8 | 31.7 | 2.8 | 2.2 | 3.5 | 11.4 | 17.4 | 5.5 | 10.7 | 7.2 | 15.3 |
| 435298 | 54.3 | 62.0 | 46.3 | 57.0 | 56.7 | 57.2 | 30.7 | 31.0 | 30.3 | 2.8 | 2.4 | 3.2 | 11.7 | 17.1 | 6.1 | 11.6 | 7.0 | 15.9 |
| 435299 | 54.4 | 63.7 | 45.3 | 57.0 | 55.2 | 58.7 | 30.5 | 29.6 | 31.3 | 2.8 | 2.2 | 3.5 | 12.4 | 18.4 | 6.3 | 12.0 | 7.8 | 16.9 |
| 435300 | 54.4 | 61.6 | 47.4 | 57.5 | 58.0 | 57.0 | 31.0 | 31.7 | 30.3 | 2.8 | 2.3 | 3.2 | 10.7 | 16.4 | 4.9 | 12.3 | 8.5 | 17.1 |
| 435301 | 52.9 | 61.7 | 44.1 | 59.2 | 58.5 | 59.5 | 31.8 | 31.8 | 31.7 | 3.1 | 2.4 | 3.8 | 12.2 | 16.7 | 7.6 | 9.8 | 8.4 | 12.9 |
| 435302 | 51.8 | 61.2 | 42.7 | 60.2 | 59.6 | 60.7 | 32.0 | 32.1 | 32.0 | 3.2 | 2.5 | 4.0 | 11.7 | 15.5 | 7.9 | 9.8 | 7.9 | 13.3 |
| 435303 | 51.5 | 61.8 | 41.6 | 60.3 | 58.4 | 62.2 | 32.8 | 32.2 | 33.4 | 3.2 | 2.4 | 3.9 | 11.0 | 16.3 | 5.9 | 10.9 | 6.7 | 14.7 |
| 435304 | 54.3 | 63.7 | 44.9 | 57.5 | 55.4 | 59.5 | 31.1 | 30.1 | 32.0 | 2.8 | 2.1 | 3.4 | 11.9 | 17.9 | 5.8 | 10.9 | 7.4 | 15.3 |
| 435305 | 54.6 | 62.7 | 46.5 | 57.9 | 56.7 | 59.0 | 30.8 | 30.3 | 31.2 | 2.9 | 2.3 | 3.4 | 11.6 | 17.3 | 6.0 | 9.3 | 7.5 | 12.5 |
| 435307 | 55.3 | 65.5 | 44.7 | 55.7 | 53.1 | 58.3 | 28.9 | 27.5 | 30.2 | 2.7 | 1.9 | 3.4 | 13.2 | 19.1 | 7.2 | 10.2 | 6.8 | 14.3 |
| 435308 | 55.3 | 63.4 | 47.4 | 55.3 | 53.9 | 56.6 | 29.3 | 28.6 | 29.9 | 2.8 | 2.4 | 3.3 | 12.7 | 18.6 | 6.7 | 11.2 | 8.8 | 15.0 |
| 435309 | 54.6 | 63.0 | 46.2 | 57.1 | 55.9 | 58.3 | 30.0 | 29.7 | 30.3 | 2.9 | 2.3 | 3.5 | 12.2 | 17.3 | 7.2 | 10.4 | 6.5 | 14.3 |
| 435311 | 53.4 | 62.0 | 44.9 | 58.0 | 56.7 | 59.3 | 30.8 | 30.4 | 31.2 | 3.0 | 2.4 | 3.6 | 11.7 | 17.5 | 6.0 | 10.9 | 8.3 | 15.4 |
| 435312 | 54.6 | 64.0 | 45.2 | 57.0 | 55.3 | 58.8 | 30.0 | 29.2 | 30.7 | 2.8 | 2.1 | 3.5 | 12.2 | 17.7 | 6.7 | 11.9 | 6.8 | 16.6 |
| 440584 | 52.3 | 62.8 | 41.8 | 59.1 | 56.6 | 62.0 | 31.7 | 30.6 | 33.1 | 3.1 | 2.3 | 3.9 | 11.9 | 17.5 | 6.3 | 10.3 | 7.7 | 13.7 |
| 440585 | 52.1 | 64.3 | 39.8 | 58.6 | 55.4 | 61.6 | 30.9 | 29.4 | 32.2 | 3.0 | 2.1 | 3.8 | 12.4 | 17.9 | 6.9 | 11.2 | 8.1 | 14.5 |
| 505892 | 54.7 | 62.4 | 46.8 | 57.2 | 57.3 | 57.2 | 30.3 | 30.8 | 29.7 | 2.8 | 2.4 | 3.2 | 12.0 | 17.3 | 6.6 | 10.3 | 5.9 | 14.9 |
| 505893 | 54.2 | 61.2 | 47.1 | 57.0 | 57.8 | 56.2 | 30.5 | 31.5 | 29.5 | 2.9 | 2.5 | 3.4 | 10.9 | 15.8 | 5.9 | 11.5 | 8.1 | 15.1 |
| 539029 | 53.8 | 62.1 | 45.6 | 58.2 | 57.4 | 59.2 | 31.4 | 31.8 | 31.2 | 2.8 | 2.2 | 3.4 | 11.4 | 17.0 | 5.7 | 10.8 | 7.0 | 13.8 |
| 539030 | 52.7 | 59.5 | 46.1 | 57.6 | 57.0 | 58.3 | 31.0 | 31.6 | 30.4 | 3.0 | 2.6 | 3.3 | 11.0 | 16.5 | 5.6 | 10.4 | 7.4 | 14.0 |
| 557461 | 53.9 | 61.0 | 46.9 | 58.2 | 58.5 | 57.9 | 31.5 | 32.2 | 30.8 | 2.9 | 2.4 | 3.4 | 11.4 | 16.9 | 6.1 | 9.1 | 7.7 | 12.2 |
| 578789 | 54.1 | 61.5 | 46.8 | 57.9 | 58.6 | 57.5 | 31.5 | 32.3 | 30.8 | 2.9 | 2.3 | 3.5 | 10.6 | 16.1 | 5.4 | 9.8 | 6.7 | 13.7 |
| 578790 | 55.1 | 61.9 | 48.1 | 57.2 | 56.5 | 57.9 | 31.2 | 31.0 | 31.3 | 3.0 | 2.4 | 3.6 | 12.7 | 18.2 | 7.1 | 9.9 | 7.8 | 12.8 |
| 578791 | 54.7 | 60.4 | 48.9 | 57.4 | 59.1 | 55.7 | 31.0 | 32.3 | 29.7 | 3.0 | 2.6 | 3.4 | 10.3 | 15.4 | 5.1 | 10.8 | 8.1 | 15.8 |
| 578792 | . | 66.8 | . | . | 55.4 | . | . | 28.5 | . | . | 1.9 | . | . | 21.9 | . | . | 6.9 | . |

*continued...*

| Accession | *In Vitro* Dry Matter Digestibility (IVDMD) | | | Neutral Detergent Fiber (NDF) | | | Acid Detergent Fiber (ADF) | | | Acid Detergent Lignin (ADL) | | | Crude Protein | | | Ash | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Avg | 1st | 2nd | Avg | 1st | 2nd | Avg | 1st | 2nd | Avg | 1st | 2nd | Avg | 1st | 2nd | Avg | 1st | 2nd |
| | % | | | | | | | | | | | | | | | | | |
| 578793 | 54.9 | 61.3 | 48.7 | 57.5 | 57.9 | 56.9 | 31.2 | 32.2 | 30.2 | 2.9 | 2.5 | 3.4 | 10.3 | 15.5 | 5.0 | 10.1 | 7.3 | 13.0 |
| 578795 | 56.1 | 62.7 | 51.5 | 57.6 | 57.2 | 56.4 | 31.8 | 31.0 | 31.0 | 2.8 | 2.2 | 3.2 | 11.6 | 18.5 | 6.2 | . | 7.9 | . |
| 578796 | 53.9 | 59.8 | 48.1 | 58.2 | 59.9 | 56.5 | 31.1 | 32.7 | 29.5 | 2.9 | 2.6 | 3.3 | 10.0 | 14.9 | 5.1 | 9.9 | 6.7 | 14.6 |
| 578797 | 55.7 | 61.3 | 49.9 | 57.6 | 59.6 | 55.7 | 31.7 | 33.0 | 30.4 | 3.0 | 2.6 | 3.4 | 10.8 | 15.8 | 5.6 | 9.5 | 7.3 | 13.2 |
| 597488 | 54.1 | 61.4 | 46.6 | 57.9 | 58.1 | 57.4 | 31.4 | 31.9 | 30.7 | 3.0 | 2.4 | 3.6 | 11.2 | 16.9 | 5.4 | 10.2 | 8.5 | 12.8 |
| Bellevue | 53.1 | 60.1 | 46.3 | 58.3 | 58.6 | 57.9 | 31.7 | 32.2 | 31.4 | 3.0 | 2.5 | 3.6 | 10.7 | 16.1 | 5.3 | 10.8 | 9.4 | 14.5 |
| PSC_1142 | 55.2 | 61.3 | 49.0 | 58.1 | 59.5 | 56.5 | 31.4 | 32.5 | 30.2 | 2.9 | 2.5 | 3.3 | 10.4 | 15.7 | 5.1 | 10.0 | 7.8 | 14.3 |
| Palaton | 53.4 | 58.1 | 48.5 | 57.5 | 60.1 | 54.8 | 31.4 | 33.3 | 29.4 | 3.1 | 2.8 | 3.5 | 9.5 | 14.2 | 4.6 | 9.9 | 8.8 | 14.3 |
| Rival | 55.0 | 63.1 | 46.9 | 57.5 | 57.8 | 57.0 | 31.3 | 31.9 | 30.6 | 2.9 | 2.3 | 3.6 | 11.1 | 17.1 | 5.1 | 10.3 | 9.5 | 13.1 |
| Vantage | 54.2 | 60.0 | 48.5 | 57.7 | 59.1 | 56.3 | 31.4 | 32.5 | 30.3 | 2.9 | 2.4 | 3.3 | 10.3 | 15.6 | 5.0 | 10.4 | 9.1 | 13.4 |
| Venture | 53.7 | 60.5 | 47.2 | 59.0 | 60.3 | 57.7 | 32.1 | 33.4 | 30.7 | 3.0 | 2.5 | 3.4 | 10.1 | 15.0 | 5.3 | 10.1 | 7.1 | 13.6 |

**BIBLIOGRAPHY**


Amezketa, E. 1999. Soil aggregate stability: A review. J. Sustain. Agric. 14:83-151.

Anderson, I.C., D.R. Buxton, and P.A. Lawlor. 1991. Yield and chemical composition of perennial grasses and alfalfa grown for maximum biomass. p. 128-132. Proc. 1991 Forage and Grasslands Conf. AFGC, Georgetown, TX.

Boeckman, L.E. 1999. Soil Survey of Lucas County, Iowa. USDA-NRCS Washington, DC.

Brummer, E.C., C.L. Burras, M.D. Duffy, and K.J. Moore. 2000. Switchgrass Production in Iowa: Economic analysis, soil suitability, and varietal performance. Annual Report.

Brummer, C., L. Burras, M. Duffy, K. Moore, M. Downing, and S. McLaughlin. 1997. Integration of technical aspects of switchgrass production in Iowa. p. 1445-1454. In: Making a business from biomass. Vol. 2. R.P. Overend and E. Chornet (eds.) Proc.3rd Biomass Conf. of the Americas. Pergamon, Oxford, UK.

Burvall, J. 1997. Influence of harvest time and soil type on fuel quality in reed canarygrass (*Phalaris arundinacea* L.). Biomass and Bioenergy 12:149-154.

Carlson, I.T., D.E. Doty, and S.K. Barnhart. 1991. Iowa orchardgrass, tall fescue, smooth bromegrass, and reed canarygrass variety tests. Iowa State Ext. Bull. Pm-1434. Iowa State University, Ames.

Carlson, I.T., R.N. Oram, and J. Surprenant. 1996. Reed canarygrass and other Phalaris species. p. 569-604. In: Cool-season forage grasses. L.E. Moser, D.R. Buxton, and M.D. Casler (eds.) Agron. Monogr. 34. ASA, CSSA, and SSSA, Madison, WI.

Cherney, J.H., K.D. Johnson, V.L. Lechtenberg, and J.M. Hertel. 1986. Biomass yield, fiber composition, and persistence of cool-season forage grasses. Agric. Biomass 10:175-86.

Cherney, J.H., K.D. Johnson, J.J. Volenec, and D.K. Greene. 1991. Biomass potential of selected grass and legume crops. Energy Sources 13:283-292.

Costanza, R., R. d'Arge, R. de Groot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R.V. O'Neill, J. Paruelo, R.G. Raskin, P. Sutton, and M. van den Belt. 1997. The value of the world's ecosystem services and natural capital. Nature 387:253-260.

Cushman, J.H. and A.F. Truhollow. 1991. Selecting herbaceous energy crops for the Southeast and Midwest/Lake States. p. 465-480. In: D.L. Klass (ed.) Energy from biomass and waste, XIV. Institute of Gas Technol., Chicago, IL.

Daniels, R.B. and R.D. Hammer. 1992. Soil Geomorphology. John Wiley & Sons, Inc. NY.

Drury, C.F., J.A. Stone, W.I. Findlay. 1991. Microbial biomass and soil structure associated with corn, grasses, and legumes. Soil Sci. Soc. Am. J. 55:805-811.

EPA. 2001. Upper Chariton USGS Cataloging Unit: 10280201 . http://www.epa.gov/surf3/hucs/10280201/ (reviewed June 07, 2001).

Hadders, G. and R. Olsson. 1997. Harvest of grass for combustion in late summer and in spring. Biomass and Bioenergy 12:171-175.

Hillel, D. 1982. Introduction to soil physics. Academic Press, Inc. Orlando, FL.

Hintz, R.L., K.R. Harmoney, K.J. Moore, J.R. George, and E.C. Brummer. 1998. Establishment of switchgrass and big bluestem in corn with atrazine. Agron. J. 90:591-596.

Jenny, H. 1941. Factors of soil formation, a system of quantitative pedology. MacGraw-Hill Book Company, Inc., New York, NY.

Jenny, H. 1980. The soil resource, origin and behavior. Springer-Verlag, New York, NY.

Jordahl, J.L. and D.L. Karlen. 1993. Comparison of alternative farming systems III. Soil aggregate stability. J. Altern. Agric. 8:27-33.

Kemper, W.D. and R.C. Rosenau. 1986. Aggregate stability and size distribution. In A. Klute (ed) Methods of soil analysis. Part 1. Physical and mineralogical methods. 2nd ed. Soil Science Society of America, Madison, WI.

Killham, K. 1994. Soil ecology. Cambridge University Press, Cambridge, England.

Laird, D.A., T.E. Fenton, and A.D. Scott. 1988. Layer charge of smectites in an Argialboll-Argiaquoll sequence. Soil Sci. Soc. Am. J. 52:463:467.

Landström, S., L. Lomakka, and S. Andersson. 1996. Harvest in spring improves yield and quality of reed canarygrass as a bioenergy crop. Biomass and Bioenergy 11:333-341.

Lemus, R.W. 2000. Effect of nitrogen on switchgrass yield and quality in southern Iowa. Unpubl. M.S. thesis. Iowa State University, Ames.

Lockridge, L.D. 1971. Soil Survey of Wayne County, Iowa. USDA-SCS, Washington, DC.

Lockridge, L.D. 1977. Soil Survey of Appanoose County, Iowa. USDA-SCS, Washington, DC.

Lynd, L.R., J.H. Cushman, R.J. Nichols, and C.E. Wyman. 1991. Fuel ethanol from cellulosic biomass. Science 251:1318-1323.

Marten, G.C., C.E. Clapp, W.E. Larson. 1980. Effects of municipal waste water effluent on performance and feed quality of maize vs. reed canarygrass. J. Environ. Quality 9:137-41.

McLaughlin, S.B. 1993. New switchgrass biofuels research program for the southeast. p. 111-115. In: Proc. 1992 Annual Automotive Technol. Dev. Contractor's Coordinating Meeting, 2-5 Nov. 1992, Dearborn, MI.

McLaughlin, S., J. Bouton, D. Bransby, R. Conger, W. Ocompaugh, D. Parrish, C. Talliaferro, K. Vogel, and S. Wullschleger. 1997. Evaluating and improving switchgrass as a bioenergy crop. p. 137-143. In: R.P. Overend and E. Chornet (eds.) Making a business from biomass. Vol. 1. Proc. 3rd Biomass Conf. of the Americas. Pergamon, Oxford, UK.

Miller, G.A. and T.E. Fenton. 1998. County weighted average corn suitability ratings. Agron. Dep., Iowa State University, Ames. http://extension.agron.iastate.edu/soils/ (reviewed August 02, 2001).

Molstad, N.E. 2000. Landscapes, soil morphology and switchgrass management and productivity in the Chariton River Valley, Iowa. Unpubl. M.S. thesis, Iowa State University, Ames

Oelmann, D.B. 1984. Soil Survey of Monroe County, Iowa. USDA-SCS, Washington, DC.

Oschwald, W.R., F.F. Riecken, R.I. Dideriksen, W.H. Scholtes, and F.W. Schaller. 1977. Principal Soils of Iowa. Iowa State University Cooperative Extension Service Special Report No. 42.

Patton, J.J. 1999. Soil morphology in Amish and conventional fields throughout the central United States. Unpubl. MS thesis, Iowa State University, Ames.

Prill, R.C. 1960. Soil Survey of Lucas County, IA. USDA-SCS, Washington, DC.

Prior, J.C. 1991. Landforms of Iowa. Bur Oak Press, Iowa City, IA.

Rathbun Land and Water Alliance. 2001. Rathbun Lake and Watershed. http://www.cvrcd.org/rathbun/rathbun_lake_and_water_shed.htm (reviewed July 23, 2001).

Ruhe, R.V. 1969. Quaternary landscapes in Iowa. Iowa State University Press, Ames.

Ruhe, R.V. and R.B. Daniels. 1965. Landscape erosion-geologic and historic. J. Soil Water Conserv. 20:52-57.

Ruhe, R.V., R.B. Daniels, and J.G. Cady. 1967. Landscape evolution and soil formation in southwestern Iowa. USDA-SCS Tech. Bull. 1349, Washington, DC.

Sanderson, M.A., R.L. Reed, S.B. McLaughlin, S.D. Wullschleger, B.V. Conger, D.J. Parrish, D.D. Wolf, C. Taliaferro, A.A. Hopkins, W.R. Ocumpaugh, M.A. Hussey, J.C. Read, and C.R. Tischler. 1996. Switchgrass as a sustainable bioenergy crop. Bioresource Tech. 56:83-93.

SAS Institute. 1994. The SAS system for Windows. Release 6.10. SAS Institute, Cary, NC.

Sellers, J. 1999. Written testimony to the Senate Committee on Agriculture, Nutrition, and Forestry regarding the Chariton Valley RC&D Project. http://www.senate.gov/~agriculture/Hearings/Hearings_1999/sel99527.htm (reviewed June 07, 2001).

Smith, S.J., I. Ridge, and R.M. Morris. 1985. The biomass potential of seasonally flooded wetlands. p. 190-195. In: H. Egnéus and A. Ellegård (eds.) Bioenergy 84, Vol. II, Biomass Resources. Elsevier, London.

Soil Survey Staff. 1993. Soil Survey Manuel. USDA Ag.Handbook 18. US Gov. Printing Office, Washington, DC.

Soil Survey Staff. 1996. Soil survey laboratory methods manual. Soil Survey Investigations Report No. 42. Version 3.0. USDA-NRCS National Soil Survey Center, Lincoln, NE.

Soil Survey Staff. 1999. Soil Taxonomy. (2nd ed) USDA Ag. Handbook 436. US Gov. Printing Office, Washington, DC.

Stevenson, F.J. and M.A. Cole. 1999. Cycles of soil (2nd ed). John Wiley & Sons, Inc. NY.

Thons, H. and S. Prufer. 1991. Indigenous grasses as renewable raw materials. Feldwirtshaft 32:168-71.

Tilman, D., D. Wedin, and J. Knops. 1996. Productivity and sustainability influenced by biodiversity in grassland ecosystems. Nature 379:718-720.

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

USDA. 1987. Basic Statistics 1982 National Resources Inventory. Soil Conservation Service, Iowa State University Statistical Laboratory, Statistical Bull. No. 756, Sept. 1987.

Vogel, K.P.I. 1996. Energy production from forages. J. Soil Water Conserv. 51:137-139.

Walker, P.H. and R.V. Ruhe. 1968. Hillslope models and soil formation, II. Closed systems. Ninth Intl. Cong. Soil Sci. Trans. 58:561-568.

Wander, M.M., M.G. Bidart, and S. Aref. 1998. Tillage impacts on depth distribution of total and particulate organic matter in three Illinois soils. Soil Sci. Soc. Am. J. 62:1704-1711.

Wright, N.A. 1988. Screening of herbaceous species for energy crops on wet soils in Ohio. p. 263-267. In: J. Janick and J.E. Simon (eds.) Advances in New Crops. Timber Press, Portland, OR.

Young, F.J. and R.D. Hammer. 2000. Soil-landform relationships on a loess-mantled upland landscape in Missouri. Soil Sci. Soc. Am. J. 64:1443-1454.

Young, F.J., R.D. Hammer, and D. Larsen. 1999. Frequency distributions of soil properties on a loess-mantled Missouri watershed. Soil Sci. Soc. Am. J. 63:178-185.

# APPENDICES

Costs of Producing Switchgrass for Biomass in Southern Iowa

Storage and Transportation Costs for Switchgrass

Farmer’s Motivations for Adopting Switchgrass

Preliminary Budgets for Switchgrass Establishment

# Costs of Producing Switchgrass for Biomass in Southern Iowa

Dr. Michael Duffy
Iowa State University, Department of Economics, 478 Heady Hall, Ames, IA 50011, USA
Tel: 515-294-6160. E-mail: mduffy@iastate.edu

Virginie Y. Nanhou
Iowa State University, Department of Economics, 478 Heady Hall, Ames, IA 50011, USA

November 2001

# Costs of Producing Switchgrass for Biomass in Southern Iowa[1]

Michael D. Duffy and Virginie Y. Nanhou

Switchgrass (*Panicum virgatum,* L., Poaceae) is a perennial warm-season grass native to Iowa, grown for decades on marginal lands not well suited for conventional row crops. It is now being recognized as a potential energy source and alternative cash crop for Iowans. The Chariton Valley Biomass Project is Iowa's first major switchgrass demonstration project, promoting switchgrass' potential for large-scale production. Iowa imports 98 percent of the fuels needed to generate energy in the state. Future success of a domestic energy industry in Iowa is dependent on the development of alternative energy sources, including biomass. The support and participation of biomass producers will be critical to this future.

Farmers' acceptance of switchgrass will be determined by its profitability relative to existing alternative land uses. Therefore costs of production are a major factor determining whether or not producers will grow switchgrass. Switchgrass has been planted by some farmers under the Conservation Reserve Program (CRP) but the management techniques were essentially minimal and thus different from the ones required to make it a viable activity for producers. Since switchgrass is a relatively new commercial crop little is known about the costs to produce the crop at a commercial level. Some researchers have estimated the costs of production using data from experimental plots. The problem with using experimental data is that they may be different from the situation on farmers' fields. This work estimates switchgrass production costs using producers' data as much as possible and incorporating their actual management techniques.

This paper provides information on the costs of producing switchgrass primarily for biomass in Southern Iowa. The details about switchgrass' production and cultural practices are not discussed here but can be found in other Iowa State University (ISU) extension publications (Teel et al. 1997; ISU 1998).

## WHAT IS SWITCHGRASS?

Switchgrass is a herbaceous biofuel crop adapted to Iowa environment. Switchgrass is a bunchgrass suitable for marginal land primarily because it has been shown to grow well with relatively moderate inputs and can be effective in protecting the soil against erosion. Switchgrass offers additional environmental benefits such as helping to improve water quality and wildlife habitat, helping to reduce carbon emissions through carbon sequestration in the soil, and serving as a replacement for fossil fuels in electricity generation. Switchgrass may be used as a pasture or hay crop. More recently it has been examined as a biomass crop to produce energy.

## DESCRIPTION OF SCENARIOS

Switchgrass cultural practices vary considerably among farmers in southern Iowa. This is due partially to farmer experimentation with alternative techniques and to the different soil types and existing practices. This variation results in a wide range of production costs. Overall the cultural practices in southern Iowa can be grouped into different scenarios based on the time

---

[1] Research sponsored by the Bioenergy Feedstock Development Program of the U.S. Department of energy under contract with the University of Tennesse-Battelle LLC. In cooperation with the Chariton Valley Resource Conservation District

of year for seeding, the type of seeding method and the land use. The time of year when switchgrass is planted affects the production costs through the amount of seed used, the success rate of the seeding, and the need to reseed. The existing land use before switchgrass is planted is crucial because it affects the land charge and thus the overall cost of producing switchgrass. Similarly, the type of machinery used for the seeding (airflow planter, drill, and no-till drill) influences the costs.

The costs of production were estimated for seven different scenarios and over four different yield levels; 3.36, 6.72, 8.96 and 13.44 Mg/ha (1.5, 3, 4 and 6 tons /acre). There are two different frost seeding scenarios and five spring seeding scenarios, all presented in Table 1. Cropland (Table 1) refers to land that was previously allocated to crop production while grassland indicates a pasture or land used for grass production before being used for switchgrass. This designation determines the land charge attributed to the scenario.

Table 1. Description of different scenarios

| Scenarios | Description of scenario |
|---|---|
| 1) Frost seeding on cropland with airflow planter | Use of disc and harrow for land preparation, airflow planter to seed (6 pounds of pure live seed) and spread fertilizers, frost seeding on land previously under crop production, use of atrazine and 2,4 D. |
| 2) Frost seeding on grassland with airflow planter | Mowing and use of Roundup™ for land preparation, airflow planter to seed (6 pounds of pure live seed) and spread fertilizers, frost seeding on land previously under grass production or pasture, use of atrazine and 2,4 D. |
| 3) Spring seeding on cropland with airflow planter | Use of disc, harrow, and roll for land preparation, airflow planter to seed (5 pounds of pure live seed) and spread fertilizers, spring seeding on land previously under crop production, use of atrazine and 2,4 D. |
| 4) Spring seeding on cropland with a drill | Use of disc and harrow for land preparation, drill seed (5 pounds of pure live seed), spread fertilizers, spring seeding on land previously under crop production, use of atrazine and 2,4 D. |
| 5) Spring seeding on cropland with a no-till drill | No-till drill seed (5 pounds of pure live seed), spread fertilizers, spring seeding on land previously under crop production, use of atrazine and 2,4 D. |
| 6) Spring seeding on grassland with a drill | Mowing and use of Roundup™ for land preparation, drill seed (5 pounds of pure live seed), spread fertilizers, spring seeding on land previously under grass production or pasture, use of atrazine and 2,4 D. |
| 7) Spring seeding on grassland with a no-till drill | Mowing and use of Roundup™ for land preparation, no-till drill seed (5 pounds of pure live seed), spread fertilizers, spring seeding on land previously under grass production or pasture, use of atrazine and 2,4 D. |

## METHODS USED FOR COST ESTIMATIONS

### Assumptions

In the literature, there is a wide range of switchgrass production costs estimates due to the variety of assumptions used. As much as possible, producers' data were used in the estimations presented in this paper, meaning that actual cultural and management practices were taken into consideration. However, some assumptions were also made. They are the following:

- A normal switchgrass stand has a life span of ten years.
- Harvest is done in large square bales with an average weight of 397 kg (875 pounds) per bale
- No harvest in the seeding (establishment) year. The harvest activities start in the second year of the stand life if there has not been any reseeding.
- Switchgrass is harvested during the fall period. This assumption has implications on the P and K removal rates; higher P and K removal rates are observed when harvest takes place in fall than spring.
- Probability of 25 percent reseeding for frost seeding and 50 percent for spring seeding.
- Machinery operations are done through custom hire. Machinery operations are charged at the prevailing custom rates for the area.
- Land charges: $185 per ha ($75 per acre) for cropland and $123 per ha ($50 per acre) for grassland
- Amortization of establishment costs and reseeding costs is at 8 percent on the ten years of the stand's life span.
- A 9 percent interest rate applied on operating expenses during each production year.
- Each scenario followed an appropriate weed management program. Herbicides were charged at average price per unit in the area.
- Estimated Costs are farm gate costs; they do not include transportation costs to the power plant nor storage costs.
- Switchgrass is a 10-year crop, therefore it is necessary to account for the lime needs. A lime charge is assessed during the establishment year and prorated over the life of the stand.
- A linear relationship between the rates of P and K removal rates and swithgrass yields during the production years is assumed.

### Input Costs Data

*Machinery.* Pre-harvest machinery operations vary by scenario. Some scenarios require more seed bed preparation while others rely more on chemicals. The cost for each machinery operation comes from Iowa State custom rate survey (Edwards et al. 2000). Staging and loading costs come from real harvest data collected by the Chariton Valley Biomass project.

*Seed.* Seed is assumed to cost $8.81 per kg ($4 per pound) of pure live seed (PLS). A variety commonly used in Southern Iowa is Cave-in-Rock. The seeding rate for frost seeding is a minimum of 6.72 kg/ha (six pounds per acre) of PLS whereas the spring-seeded scenarios use a minimum of 5.6 kg/ha (five pounds per acre) of PLS.

*Herbicides.* Each scenario is assumed to follow a standard herbicide treatment. Scenarios 1, 3, 4 and 5 use a combination of atrazine and 2,4 D for weed control, while scenarios 2, 6, and 7 use Roundup™ in addition to atrazine and 2,4 D. Roundup™ is used for land preparation in association with the mowing. The price per unit for herbicides reflects 2000 prices.

*Fertilizers and Lime.* During the establishment year, it is assumed that phosphorus and potassium are applied at the rate of 33.6 kg/ha (30lbs/acre) and 44.8 kg/ha (40lbs/acre), respectively. To avoid competition between the new switchgrass stand and weeds, no nitrogen is applied in the establishment year.

During production years, the phosphorus and potassium fertilization program varies by yield to compensate for the removal rate in potassium (K) and phosphorus (P). With each tonne (Mg) of switchgrass harvested, there are 0.97 kg of $P_2O_5$ and 11.41kg of $K_2O$ removed (1.94 pounds of $P_2O_5$ and 22.8 pounds of $K_2O$ per ton of switchgrass) (Radiotis et al. 1999; Lemus 2000). It is further assumed that the relationship between the rates of P and K removal and swithgrass yields is linear. Nitrogen fertilizer is applied at 112 kg/ha (100 pounds per acre). Prices for fertilizers used are reported in an Iowa State University extension publication (Duffy and Smith 2000).

Lime needs will vary by field. It was assumed, however, that at some time over the life of the switchgrass stand, lime would have to be applied. Therefore, a fixed charge per hectare is assessed for the establishment year that will be prorated over the stand life and included in the annual production costs.

*Harvesting Operations.* Harvesting activities involve mowing, raking, baling, staging, and loading. Depending on the equipment used, the estimates of time and cost of harvesting can vary considerably. Switchgrass harvesting differs from that of hay or alfalfa because of the difference in plant density (switchgrass is less dense than hay) and height (switchgrass is taller than hay). Some variations in the estimations can also occur due to the type of bale (large round bale or large square bale). These differences influence the harvesting time and thus the cost. It is assumed that harvesting costs are not linear; that is, as the yield increases the harvesting costs per hectare increase but the costs per tonne (Mg) decrease. For the budget estimations in this paper, it is assumed that harvest is done in large square bales[2] weighing 397 kg (875 pounds) each, which is the average weight observed for bales harvested in Southern Iowa. In addition, since the production costs are farm gate costs, this means that they don't include any costs associated with lengthy on-farm storage or transportation to final biomass facility. Estimates for transportation costs can be found in other studies **(**Walsh 1994; Walsh and Becker 1996; Park 1996).

The cost estimate for mowing and raking is on a per hectare basis, while cost estimates for baling and staging are on a per tonne (Mg) basis. Some of the harvest costs (mowing, raking and baling) come from Iowa State custom rate survey (Edwards et al. 2000). Staging and loading costs come from real harvest data collected by the Chariton Valley Biomass project.

## COST ESTIMATION PROCEDURES AND OUTCOMES

There are three main cost components to switchgrass production costs. There are the establishment costs, costs for reseeding and the production costs. Scenarios 1 and 2 are used for illustration.

*Establishment Costs.* The creation of the budget starts with estimating the establishment costs. The establishment costs were prorated over an 11-year period to obtain a yearly establishment cost. These costs consist of the standard components of seed, fertilizer, pesticides, and land preparation. Table 2 presents estimated establishment budgets for switchgrass under scenarios 1 and 2, frost seeding with an airflow planter on cropland and on grassland, respectively. Note the prorated establishment costs presented at the last line of Table 2. They

---

[2] Even though the bales are rectangular in shape, that is 0.9m high x 1.2m wide x 2.4m long (3 feet high x 4 feet wide x 8 feet long), the terminology "square bales" is common.

represent the yearly establishment cost that will be added to the annual production costs estimate. It assumed that there is no harvesting during the establishment year because the stand is not strong enough to justify harvesting.

Table 2. Estimated establishment budgets under frost seeding (scenario 1, switchgrass conversion from croplands, scenario 2, switchgrass conversion from grasslands)

| | | | | Scenario 1 | Scenario 2 |
|---|---|---|---|---|---|
| Pre-harvest Machinery Operations | | | | Cost per ha* ($/ha) | Cost per ha* ($/ha) |
| Disking | | | | 19.75 | - |
| Harrowing | | | | 9.51 | - |
| Mowing | | | | - | 16.79 |
| Airflow spreader (seed and fertilizers) | | | | 11.11 | 11.11 |
| Spraying Roundup ™ | | | | - | 10.62 |
| Spraying atrazine and 2,4 D | | | | 10.62 | 10.62 |
| Total Machinery Cost | | | | $50.99 | $49.14 |
| | | | | Scenario 1 | Scenario 2 |
| Operating Expenses | Unit | Price/Unit | Quantity | Cost per ha ($/ha) | Cost per ha ($/ha) |
| Seed (PLS) | kg | 8.81 | 6.72 | 59.21 | 59.21 |
| Fertilizer (P and K)** | kg | | | 33.83 | 33.83 |
| Lime (including its application | Mg | 13.23 | 6.72 | 88.91 | 88.91 |
| Herbicide | | | | | |
| Atrazine | L | 3.10 | 3.50 | 10.85 | 10.85 |
| 2,4 D | L | 3.45 | 1.75 | 6.04 | 6.04 |
| Roundup ™ | L | 9.92 | 4.67 | - | 46.35 |
| Total Operating Cost | $/ha | | | $198.83 | $245.18 |
| | | | | Scenario 1 | Scenario 2 |
| Land charge (cash rent equivalent) | $/ha | | | 185.19 | 123.46 |
| Total Establishment Costs | $/ha | | | 435.00 | 417.77 |
| Prorated Establishment Costs (11yrs.@ 8 percent) | $/ha | | | 60.94 | 58.52 |

*Source: Edwards et al. (2000)

** Phosphorus price = $0.59/kg; Potassium Price = $0.36/kg

*Reseeding Costs.* Switchgrass will not always establish in the first year. To account for the failure of seeding the first year, expected costs of reseeding were estimated and this constitutes the second step in the estimations. The reseeding costs contain seed, fertilizers and pesticides related costs, and a land charge (there is no land preparation cost included). Based on switchgrass producers' experience in southern Iowa, the expected probability of reseeding is set at 25 percent and 50 percent for frost seeding and spring seeding, respectively. The reseeding costs are multiplied by the expected probability of reseeding to produce the expected reseeding cost. This expected reseeding cost is prorated over 10 years to generate a yearly reseeding cost that is added to the annual production cost estimates. Table 3 shows estimated reseeding budgets for scenarios 1 and 2. Unlike the establishment budget, they do not include any land preparation costs (no disking and harrowing, no mowing and Roundup™ application). In addition, a reseeding rate of four pounds of pure live seed is recommended. The fertilization program applied during the establishment is followed here except there is no lime application. The herbicide program is similar to the one applied during the production year. A land charge is included in the cost. Note that the expected reseeding cost is equal to the total reseeding cost multiplied by the 25 percent probability of reseeding. Note also that the last line gives the prorated reseeding cost (over the 10 years of a stand's life) that will be added as a yearly reseeding cost to the prorated establishment cost and to the annual production cost. It is assumed that there is no harvest in the reseeding year.

*Annual Production Costs***.** The last step consist of estimating the annual production costs. These costs include the standard components for pesticides and fertilizers plus a yearly land charge. They also contain harvest costs, which will vary depending on the switchgrass yield. Table 4 presents estimated production year budgets for switchgrass under scenarios 1 and 2, frost seeding with an airflow planter on cropland and grassland respectively, assuming a 8.96 Mg/ha yield level (4 tons/acre). A variation in the yield level considered will result in a variation in costs. The fertilizer application rate varies by the yield to compensate for the removal rate of potassium (K) and phosphorus (P). The herbicide program is representative of practices followed by biomass producers in Southern Iowa. From harvest data gathered from the field, it appears that harvesting costs are not linear; that is as the yield increases, the harvesting costs per hectare increase but the costs per tonne (Mg) decrease. This observation is taken into consideration in harvest costs estimations. The cost estimate for mowing and raking is on a per hectare basis, while cost estimates for baling and staging are on a per tonne basis. The transportation cost to a biomass facility or the costs associated to lengthy on-farm storage are not included.

*Total Yearly Production Costs.* The overall estimated yearly costs of producing switchgrass are therefore equal to the prorated establishment costs plus the prorated expected reseeding costs plus the annual production costs. Note at the bottom of Table 5, the prorated establishment and reseeding costs are added to the annual production cost to produce the total estimated yearly production costs.

Table 3. Reseeding estimated costs under frost seeding, switchgrass conversion from cropland and switchgrass conversion from grassland (probability of reseeding, 25 percent)

| | | | | Scenario 1 and Scenario 2 | |
|---|---|---|---|---|---|
| Pre-harvest Machinery Operations | | | | Cost per ha ($/ha)* | |
| Airflow spreader (seed and fertilizers) | | | | | 11.11 |
| Spraying chemicals | | | | | 10.62 |
| Total Machinery Cost | | | | | $21.73 |
| | | | | Scenario 1 and Scenario 2 | |
| Operating Expenses | Unit | Price/Unit | Quantity | Cost per ha ($/ha) | |
| Seed (PLS) | kg | 8.81 | 4.48 | | 39.47 |
| Fertilizer (P and K)** | kg | | | | 33.83 |
| Herbicide | | | | | |
| Atrazine | L | 3.10 | 3.50 | | 10.85 |
| 2,4 D | L | 3.45 | 1.75 | | 6.04 |
| Total Operating Cost | $/ha | | | | $90.19 |
| | | | | Scenario 1 | Scenario 2 |
| Land charge (cash rent equivalent) | $/ha | | | 185.19 | 123.46 |
| Total Reseeding Cost | $/ha | | | 297.10 | 235.37 |
| Expected Reseeding Cost | $/ha | | | 74.28 | 58.84 |
| Prorated Reseeding Cost (10yrs.@ 8 percent) | $/ha | | | 11.07 | 8.77 |

*Source: Edwards et al. (2000)

** Phosphorus price = $0.59/kg; Potassium Price = $0.36/kg

Table 4. Estimated annual production costs for scenario 1; switchgrass conversion from cropland, scenario 2; switchgrass conversion from grasslands [expected yield: 8.96Mg / ha (4 tons/acre), approximately 23 large square bales: 397 kg (875 Pounds)/bale]

| | | | | Scenario 1 and Scenario 2 | |
|---|---|---|---|---|---|
| Pre-harvest Machinery Operations | | | | | Cost per ha* ($/ha) |
| Spreading liquid nitrogen | | | | | 10.74 |
| Applying P and K | | | | | 7.78 |
| Spraying chemicals | | | | | 10.62 |
| Total Machinery Cost | | | | | $29.14 |
| | | | | Scenario 1 and Scenario 2 | |
| Operating Expenses | Unit | Price/unit | Quantity | Cost per ha ($/ha) | Cost per ha ($/ha) |
| Nitrogen | kg | 0.46 | 112.00 | | 51.81 |
| P | kg | 0.59 | 8.69 | | 5.17 |
| K | kg | 0.31 | 102.14 | | 31.50 |
| Herbicide | | | | | |
| Atrazine | L | 3.10 | 3.50 | | 10.85 |
| 2,4 D | L | 3.45 | 1.75 | | 6.04 |
| Total Operating Cost | $/ha | | | | $ 105.36 |
| Interest on operating expenses (9 percent) | $/ha | | | | 4.74 |
| Harvesting Expenses | | | | Cost per Mg ($/ha) | Cost per ha ($/ha) |
| Mowing/conditioning | | | | 2.45 | 21.98 |
| Raking | | | | 1.07 | 9.63 |
| Baling (large square bales) | | | | 17.87 | 160.14 |
| Staging and loading | | | | 7.18 | 64.31 |
| Total Harvesting Cost per ha | $/ha | | | $28.58 | $256.06 |
| | | | | Scenario 1 | Scenario 2 |
| Land charge (cash rent equivalent) | $/ha | | | 185.19 | 123.46 |
| Annual Production Costs per ha | $/ha | | | 580.48 | 518.75 |

*Source: Edwards et al. (2000)

Table 5. Estimated total yearly production costs for scenario 1; frost seeding, switchgrass on cropland, scenario 2; frost seeding, switchgrass on grasslands [expected yield: 8.96Mg /ha (4 tons/acre)]

| | Unit | Scenario 1 | Scenario 2 |
|---|---|---|---|
| Prorated Establishment Costs (11yrs.@ 8 percent) | $/ha | 60.94 | 58.52 |
| Prorated Reseeding Costs (10yrs.@ 8 percent) | $/ha | 11.07 | 8.77 |
| Annual Production Costs per Hectare (ha) | $/ha | 580.48 | 518.75 |
| Total Yearly Production Costs per Hectare (ha) | $/ha | 652.49 | 586.04 |
| Total Costs per Bale | $/bale | 28.91 | 25.97 |
| Total Costs per Mg (tonne) | $/Mg | 72.82 | 65.41 |

**MAIN FINDINGS**

Frost seeding scenarios produced the lowest costs as shown in Figure 1. Table 6 summarizes the costs of producing switchgrass under each of the seven scenarios and for four different yield levels; 3.36, 6.72, 8.96 and 13.44 Mg/ha (1.5, 3, 4, and 6 tons/acre). Scenario 1, frost seeding on cropland with airflow planter, has the lowest cost of production among all the scenarios on cropland for either frost seeding or spring seeding. While scenario 2, frost seeding on grassland with airflow planter, has the lowest production cost among all the scenarios (Figure 1). As the yield increased from 3.36 to 13.44 Mg/ha (1.5 to 6 tons per acre), the costs under scenario 2 decrease by 57%, from $53.51 to $125.58 per Mg ($49 to $114 per ton) (Table 6). Overall, the cost of producing switchgrass is reduced by more than 50 percent when the yields go from 3.36 to 13.44 Mg/ha (1.5 to 6 tons per acre). The costs of production per tonne (Mg) decrease at a decreasing rate as yields increase. For example, with frost seeding on cropland costs decreased 40 percent when increasing yield from 3.36 to 6.72 Mg/ha (1.5 to 3 tons per acre). However, costs only decreased by 33 percent when going from 6.72 to 13.44 Mg/ha (3 to 6 tons per acre). This is similar to the frost seeding on grassland where the costs decreased by 38 percent going from 3.36 to 6.72 Mg/ha (1.5 to 3 tons per acre) and by 31 percent going from 6.72 to 13.44 Mg/ha (3 to 6 tons per acre).

These results demonstrate that yield is an important determinant of the level of costs. Switchgrasss yields observed in the field range from slightly less than one to over 9 Mg/ha (one to over four tons per acre) per year of biomass. It should be noted that, in most cases, biomass producers have not yet implemented all of the best management techniques that will likely improve yields. Consequently, the successful production of switchgrass for biomass depends on the use of practices that increase yields such as planting higher yielding varieties.

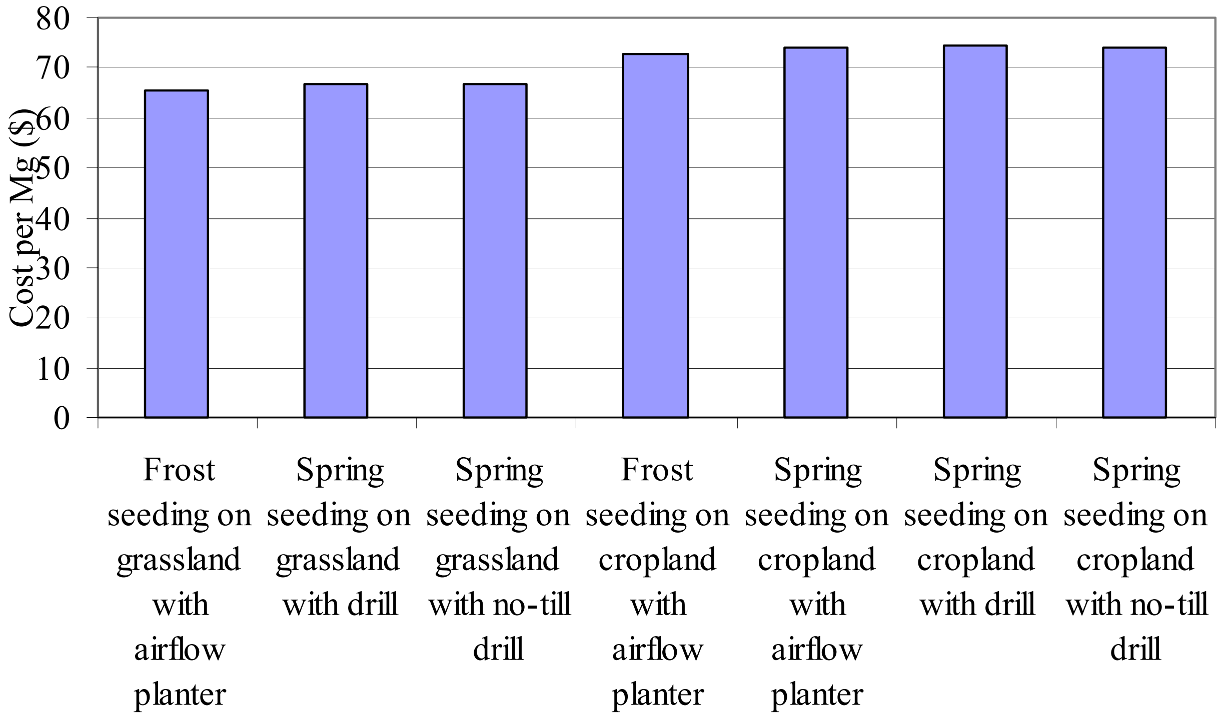


Figure 1. Costs comparison for seven scenarios at 8.96 Mg/ha (4tons/acre)

The costs were also estimated using different land charges (Table 7). A 33% increase in the land charge under scenario 1, from $185 to $247 per ha ($75 to $100 per acre), caused a 13, 11 and 8 percent increase in the cost per Mg for 3.36, 8.96 and 13.44 Mg/ha yields (1.5, 3, and 6 ton). Similarly, a 50% decrease in land charges under scenario 2, from $123 to $62 per ha ($50 to $25 per acre), decreased costs by 14, 12, and 8 percent for the 3.36, 8.96 and 13.44 Mg/ha yields (1.5, 3, and 6 ton yields). At $247/ha land charge, costs could be reduced by over 61% by tripling the yields from 3.36 to13.44 Mg/ha while at lower land charges such as $62/ha, approximately 58% costs reduction was observed. Regardless of the scenario, as the yield increases the effect on the costs from an increase in land charge lessens. Therefore, the cost for land has the second most significant influence on cost differences after the yields. This result is illustrated by Figure 2. The choice of the type of land for swithgrass production is important. Switchgrass production for biomass would be a viable activity primarily on marginal land using best management techniques.

Table 6. Cost summaries for the seven scenarios

| Scenario | Yield Mg/ha (Ton/acre) | Establish-ment costs (prorated) $/ha | Reseeding costs (prorated) $/ha | Yearly production costs, $/ha | Total cost per ha, $/ha | Total cost per Mg, $/Mg |
|---|---|---|---|---|---|---|
| 1 | 3.36 (1.5) | 60.94 | 11.07 | 417.82 | 488.27 | 145.36 |
| 1 | 6.72 (3.0) | 60.94 | 11.07 | 515.80 | 587.31 | 87.42 |
| 1 | 8.96 (4.0) | 60.94 | 11.07 | 580.48 | 652.49 | 72.82 |
| 1 | 13.44 (6.0) | 60.94 | 11.07 | 713.85 | 785.36 | 58.45 |
| 2 | 3.36 (1.5) | 58.52 | 8.77 | 143.80 | 421.85 | 125.58 |
| 2 | 6.72 (3.0) | 58.52 | 8.77 | 183.90 | 520.86 | 77.53 |
| 2 | 8.96 (4.0) | 58.52 | 8.77 | 210.64 | 586.86 | 65.41 |
| 2 | 13.44 (6.0) | 58.52 | 8.77 | 264.11 | 718.91 | 53.51 |
| 3 | 3.36 (1.5) | 60.42 | 22.15 | 168.80 | 499.36 | 148.65 |
| 3 | 6.72 (3.0) | 60.42 | 22.15 | 208.90 | 598.37 | 89.06 |
| 3 | 8.96 (4.0) | 60.42 | 22.15 | 235.64 | 664.40 | 74.17 |
| 3 | 13.44 (6.0) | 60.42 | 22.15 | 289.11 | 796.42 | 59.27 |
| 4 | 3.36 (1.5) | 61.60 | 22.15 | 168.80 | 500.52 | 149.00 |
| 4 | 6.72 (3.0) | 61.60 | 22.15 | 208.90 | 599.56 | 89.24 |
| 4 | 8.96 (4.0) | 61.60 | 22.15 | 235.64 | 665.56 | 74.30 |
| 4 | 13.44 (6.0) | 61.60 | 22.15 | 289.11 | 797.60 | 59.36 |
| 5 | 3.36 (1.5) | 58.02 | 22.15 | 168.80 | 496.96 | 147.94 |
| 5 | 6.72 (3.0) | 58.02 | 22.15 | 208.90 | 596.00 | 88.71 |
| 5 | 8.96 (4.0) | 58.02 | 22.15 | 235.64 | 662.00 | 73.90 |
| 5 | 13.44 (6.0) | 58.02 | 22.15 | 289.11 | 794.05 | 59.10 |
| 6 | 3.36 (1.5) | 59.19 | 17.53 | 143.80 | 431.78 | 128.53 |
| 6 | 6.72 (3.0) | 59.19 | 17.53 | 183.90 | 530.81 | 79.01 |
| 6 | 8.96 (4.0) | 59.19 | 17.53 | 210.64 | 596.81 | 66.63 |
| 6 | 13.44 (6.0) | 59.19 | 17.53 | 264.11 | 728.86 | 54.24 |
| 7 | 3.36 (1.5) | 59.73 | 17.53 | 143.80 | 432.32 | 128.70 |
| 7 | 6.72 (3.0) | 59.73 | 17.53 | 183.90 | 531.33 | 79.08 |
| 7 | 8.96 (4.0) | 59.73 | 17.53 | 210.64 | 597.36 | 66.68 |
| 7 | 13.44 (6.0) | 59.73 | 17.53 | 264.11 | 729.41 | 54.28 |

Table 7. Summary of switchgrass production costs per Mg with varying land charges

| Scenario | Yield Mg/ha (Ton/acre) | Land charge $61.73/ha ($25/acre) | $123.46/ha ($50/acre) | $185.19 ($75/acre) | $246.91 ($100/acre) |
|---|---|---|---|---|---|
| 1 | 3.36 (1.5) | * | 126.98 | 145.36 | 163.73 |
| 1 | 6.72 (3.0) | * | 78.22 | 87.42 | 96.60 |
| 1 | 8.96 (4.0) | * | 66.04 | 72.82 | 79.82 |
| 1 | 13.44 (6.0) | * | 53.85 | 58.45 | 63.04 |
| 2 | 3.36 (1.5) | 107.20 | 125.58 | * | * |
| 2 | 6.72 (3.0) | 68.34 | 77.53 | * | * |
| 2 | 8.96 (4.0) | 58.62 | 65.41 | * | * |
| 2 | 13.44 (6.0) | 48.91 | 53.51 | * | * |
| 3 | 3.36 (1.5) | * | 130.28 | 148.65 | 167.02 |
| 3 | 6.72 (3.0) | * | 79.88 | 89.06 | 98.25 |
| 3 | 8.96 (4.0) | * | 67.28 | 74.17 | 81.06 |
| 3 | 13.44 (6.0) | * | 54.67 | 59.27 | 63.87 |
| 4 | 3.36 (1.5) | * | 130.63 | 149.00 | 167.38 |
| 4 | 6.72 (3.0) | * | 80.06 | 89.24 | 98.42 |
| 4 | 8.96 (4.0) | * | 67.41 | 74.30 | 81.19 |
| 4 | 13.44 (6.0) | * | 54.76 | 59.36 | 63.95 |
| 5 | 3.36 (1.5) | * | 129.56 | 147.94 | 166.32 |
| 5 | 6.72 (3.0) | * | 79.53 | 88.71 | 97.89 |
| 5 | 8.96 (4.0) | * | 67.01 | 73.90 | 80.79 |
| 5 | 13.44 (6.0) | * | 54.50 | 59.10 | 63.68 |
| 6 | 3.36 (1.5) | 110.17 | 128.53 | * | * |
| 6 | 6.72 (3.0) | 69.82 | 79.01 | * | * |
| 6 | 8.96 (4.0) | 59.74 | 66.63 | * | * |
| 6 | 13.44 (6.0) | 49.65 | 54.24 | * | * |
| 7 | 3.36 (1.5) | 110.32 | 128.70 | * | * |
| 7 | 6.72 (3.0) | 69.90 | 79.08 | * | * |
| 7 | 8.96 (4.0) | 59.79 | 66.68 | * | * |
| 7 | 13.44 (6.0) | 49.69 | 54.28 | * | * |

* Amounts are out of range of possibilities

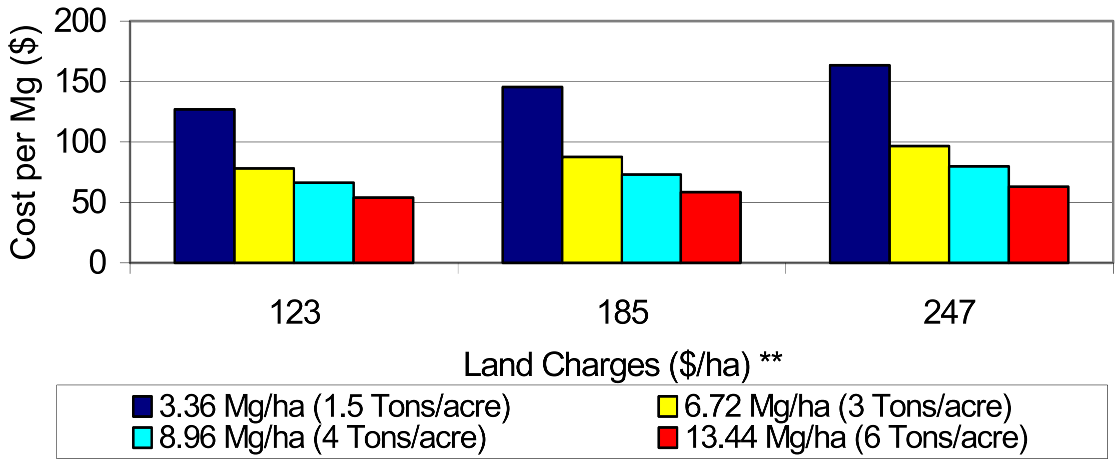


Figure 2. Cost per Mg with varying land charges and alternative yield levels, scenario1

**SUMMARY AND CONCLUSION**

The cost of producing switchgrass varies considerably. The biggest variation comes from alternative yield and land charge assumptions. The appropriate land charge depends on the alternative uses for the land, i.e. the quality of the land. If the land had been cropland then the opportunity costs will be higher, conversely if the land was grassland the costs will be lower. In the present study, converting land from pasture or hay ground produces the lowest costs of production. The scenario with the lowest cost is scenario 2; frost seeding on grassland with airflow planter.

The two major factors affecting switchgrass production cost are the expected yield and the land charge. Yields are the key factor in the cost of switchgrass production. Some producers using best management practices have reached yields of 8.96 Mg/ha (4 tons per acre). As improved management practices are applied and higher yielding varieties become available the cost of production will decrease.

Switchgrass is a new commercial crop in Iowa. Only recently has work begun to improve switchgrass yields. Emphasis should be put on research to improve yields.

Switchgrass has to be profitable to be adopted. One of the key components in profitability is knowing costs of production. Farmers must consider the costs and possible returns from switchgrass before planting. They must also consider the costs and returns of the alternatives when making a decision.

At this time, the expected price for switchgrass grown for biomass is uncertain. However, given the versatility and environmental benefits of switchgrass, it is anticipated that public subsidies and markets may develop to encourage its production. Farmers must consider all financial and environmental aspects of land use decisions before selecting the crop to plant and the land on which to plant it.

**REFERENCES**

Duffy, M.D. and D. Smith. 2000. Estimated costs of crop production in Iowa – 2001. Iowa State University Extension, Fm-1712. Revised in December 2000.

Edwards, W., D. Smith, B. Mc Lees, and J. Baitinger. 2000. 2000 Iowa farm custom rate survey. Iowa State University Extension, FM 1698. Revised March 2000.

Iowa State University (ISU) Extension. 1998. Switchgrass seeding recommendations for the production of biomass fuel in southern Iowa. Pm 1773.

Lemus, B.R.W. 2000. Cultivar and fertility effects on switchgrass biofuel production in southern Iowa. MS thesis. Iowa State University, Ames.

Park, Y.W. 1996. Economic feasibility of growing herbaceous biomass energy crops in Iowa. Ph. D. dissertation. Iowa State University, Ames.

Radiotis, T., J. Li , K. Goel, and R. Eisner. 1999. Fiber characteristics, pulpability, and bleachability of switchgrass. Tappi J. 82:100-105.

Teel, A., S. Barnhart, and G. Miller. 1997. Management guide for the production of switchgrass for biomass fuel in southern Iowa. Iowa State University Extension, Pm 1710.

Walsh, M.E. 1994. The cost of producing switchgrass as dedicated energy crop. Biologue, 4th Qtr: 35-36.

Walsh, M.E. and D. Becker. 1996. Biocost: A software program to estimate the cost of producing bioenergy crops. Proc. Bioenergy 96. Sept. 15-20, 1996, Nashville, Tennessee.

# STORAGE AND TRANSPORTATION COSTS FOR SWITCHGRASS

## Table of content

# STORAGE AND TRANSPORTATION COSTS FOR SWITCHGRASS

A series of assumptions have been made to assess the storage costs including costs associated to storage losses in dry matter (DM) as well as transportation costs to the power plant. The assumptions are based on the literature on hay and switchgrass storage, and hay transportation costs, and on personal communication. For the computations, it is assumed that the yield is 4tons/acre and that a bale weighs 950lbs. For a complete estimation of the costs of storage and transportation of switchgrass, three potential scenarios were considered.

Scenario 1: Switchgrass is hauled directly to the plant; that is, there is no storage on the farm but only staging at the farm gate.

Scenario 2: Switchgrass is harvested and stored on the farm and then transported to the plant.

Scenario 3: Switchgrass is harvested but stored at a collective storage facility and the transportation to the plant is from that intermediate storage place.

## I Switchgrass storage options and costs associated with each option

The choice of a storage option should be made based on the comparison of the cost associated with the option to the value of switchgrass being lost without the given storage option.

### I.1. Assumptions:

- Moisture content in hay when stored is below 15%
- Switchgrass is stored for a year
- Dry matter losses associated to each storage option are as listed in table 1.

Table 1: Storage systems and expected dry matter loss

| Storage system for square bales (950lb/bale) | Average DM loss (%)* |
|---|---|
| Pole frame structure-enclosed on crushed rock | 2** |
| Pole frame structure-open sides on crushed rock | 4 |
| Reusable tarp on crushed rock | 7 |
| Outside Unprotected on crushed rock | 15*** |
| Outside and Unprotected on ground | 25*** |

N.B.: * The selection of DM loss figures is from the literature and personal communications

** In Chariton Valley, a switchgrass storage facility- a totally enclosed structure with a limestone floor- has been built. It is used as a storage place by most switchgrass producers in the Chariton Valley Biomass project.

*** It is recommended to store switchgrass covered, at least under a tarp. According to Boylan et al (2001), the boiler efficiency with co-firing might be improved by reducing the losses due to moisture and thus by modifying how switchgrass is stored. Indoor storage is highly recommended

- Costs associated to each system (interest rate of 8%) are presented in table 2.

Table 2: Initial/construction costs of the selected storage systems (do not include storage losses)

| Storage system for square bales (950lb/bale) | Cost per $m^2$ ($) | Life years | Annual costs($/$m^2$) | Cost per bale ($) | | Cost per ton ($) | |
|---|---|---|---|---|---|---|---|
| | | | | 10 bales high | | 10 bales high | |
| Collective storage facility[1] | 107.64 | 15 | 12.58 | 3.77 | | 7.95 | |
| | | | | 5 bales high | 6 bales high | 5 bales high | 6 bales high |
| Pole frame structure-enclosed on crushed rock | 70.39-107.64 | 15 | 8.22-12.58 | 4.93 -7.55 | 4.11 - 6.29 | 10.39 -15.89 | 8.66 - 13.24 |
| Pole frame structure-open sides on crushed rock | 53.82 | 15 | 6.29 | 3.77 | 3.14 | 7.94 | 6.62 |
| | | | | 4 bales high | | 4 bales high | |
| Reusable tarp on crushed rock[2]* (19.8 sq. ft/bale i.e. 1.84 $m^2$ /bale) | 1.47 | 5 | 0.37 | 1.39 | | 2.92 | |
| Outside Unprotected on crushed rock * | 2.70 | 5 | 0.68 | 0.51 | | 1.07 | |
| Outside and Unprotected on ground* | 0.00 | - | 0.00 | 0.00 | | 0.00 | |

N.B.: * It is assumed that each stack is 4 bales high.

The data on construction cost or initial cost for material (crushed rock, tarp) and cost of equipment came from different sources: Chariton Valley Biomass Project, literature and personal communication.

For a collective storage facility, it is assumed that there should be a provision for:

- the equipment (i.e. telelift) appropriate for a 10 bales-high stack. It is assumed $1995/month rental costs for a telelift that is $23,940/year and
- at least a staff member to manage the facility; part time worker paid $12/hr that is $11,520/year.

The total cost for the equipment and labor used is $35,460 per year that is $8.86/ton for a storage capacity of 4000 tons (10 bales high). The storage costs including construction, equipment and labor cost but not including storage losses will be: $7.95/ton + $8.86/ton = $16.81/ton. These costs will likely decrease for a higher stack but there will be a need for special equipment to handle the bales. To this cost should be added later the costs for storage losses (2%). The computations of the annual cost, cost per bale and cost per ton for each of the storage systems are detailed in the appendix.

---

[1] The current storage facility used in Chariton Valley Biomass project represents an illustration of a potential collective storage facility.
[2] The cost per $m^2$ is only the cost for the tarp. The cost for blocks used to secure the tarp and for the crushed rock on the ground are included only in the cost per bale or per ton for simplicity.

Currently, producers in Chariton Valley pay $11/ton to the biomass project to store switchgrass bales.

### I.2. Storage costs estimates

- Total storage cost is the sum of storage system cost and cost of projected storage loss
- For the estimations, three levels of switchgrass price are considered: $40, $50 and $60 per ton

Table 3 shows switchgrass storage options and the costs associated with each of the options.

Table 3: Costs comparison of five switchgrass storage options (storage cost including losses in DM) with the storage of switchgrass bales outside unprotected on the ground

| Storage system for square bales (950lb/bale) | Avg DM loss (%) | **Cost w/o DM losses $/ton** | DM loss cost at $40/ton | **Cost incl. DM losses $/ton** | Cost Diff. w/ unprotected outside storage on ground at $40.00 | DM loss cost at $50/ton | **Cost incl. DM losses $/ton** | Cost Diff. w/ unprotected outside torage on ground at $50.00 | DM loss cost at $60/ton | **Cost incl. DM losses $/ton** | Cost Diff. w/ unprotected outside torage on ground at $60.00 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Collective storage facility (10 bales high)** | | | | | | | | | |
| Collective storage facility | 2 | 16.81 | 0.80 | **17.61** | 7.61 | 1.00 | **17.81** | 5.31 | 1.20 | **18.01** | 3.01 |
| | | **Costs of storage options with 6-bales high** | | | | | | | | | |
| Pole frame structure-enclosed on crushed rock | 2 | **8.66 to 13.24** | 0.80 | **9.46 - 14.04** | -0.54 - 4.04 | 1.00 | **9.66 - 14.24** | -2.84 - 1.74 | 1.20 | **9.86 - 14.44** | -5.15 to -0.56 |
| Pole frame structure-open sides on crushed rock | 4 | **6.62** | 1.60 | **8.22** | -1.78 | 2.00 | **8.62** | -3.88 | 2.40 | **9.02** | -5.98 |
| | | **Costs of storage options with 5-bales high** | | | | | | | | | |
| Pole frame structure-enclosed on crushed rock | 2 | **10.39 - 15.89** | 0.80 | **11.19 - 16.69** | 1.19 - 6.69 | 1.00 | **11.39-16.89** | -1.11 - 4.39 | 1.20 | **11.59-17.09** | -3.41 - 2.09 |
| Pole frame structure-open sides on crushed rock | 4 | **7.94** | 1.60 | **9.54** | -0.46 | 2.00 | **9.94** | -2.56 | 2.40 | **10.34** | -4.66 |
| | | **Costs of storage options with 4-bales high** | | | | | | | | | |
| **Reusable tarp on crushed rock** | **7** | **2.92** | **2.80** | **5.77** | **-4.23** | **3.50** | **6.42** | **-6.08** | **4.20** | **7.12** | **-7.88** |
| Outside Unprotected on crushed rock | 15 | **1.07** | 6.00 | **7.07** | -2.93 | 7.50 | **8.57** | -3.93 | 9.00 | **10.07** | -4.93 |
| Outside and Unprotected on ground | 25 | **0.00** | 10.00 | **10.00** | - | 12.50 | **12.50** | - | 15.00 | **15.00** | - |

Storing the bales outside unprotected is costly because of the high losses in dry matter and the deterioration of bales. The storage of bales under a tarp presents a cost advantage compared to storing bales unprotected and to storing bales in enclosed building. Nevertheless, it should be noted that the use of a tarp might not be the solution in some circumstances (i.e. in windy areas). Extra labor and cost might be needed to repair the tarp and to secure it. According to some researchers, there are potential risk of injury and other hazards when using tarps to cover stacks of bales.

A pole frame structure with open side(s) presents economic advantages compared to storing bales outside unprotected. The construction of an enclosed building on a farm solely for switchgrass storage purposes may not be justified economically if the price for switchgrass is low. As the price of switchgrass increases (and/or as the requirement for the quality of the bales becomes more rigorous), storing the bales indoors will become a more economically viable storage option.

## II. Post-harvest handling charges on the farm

### II.1. __Assumptions:__

- The bales are staged before being loaded on truck/semi trailers
- Loading and strapping down the bales on the semi-trailer take approximately 30-45mn
- Unloading and stacking the bales in the farm storage facility take approximately 45mn
- The unloading at the power plant is not the responsibility of the producer.
- Hauling distance from the field to the farm storage facility is ¾ miles on average (50% on bad roads (5 mph) and 50% on nicer road(15mph))
- Cost of moving the round bales by truck per mile of $1.80 (2002 ISU extension publication FM-1698). Average truckload is assumed to be 18 tons.
- Two persons at least are needed (loader/unloader and truck driver)

### II.2. __Handling cost for the three scenarios__

The bales have been staged and are ready to be loaded and hauled to the plant.

**__Scenario 1:__** No storage
Loading semi trailer (45 min =0.75hr): $28.38/hr[3] x 0.75 hr = $21.285 → $1.1825/ton
Total handling costs: $1.18/ton

[3] If rental cost for a tractor are estimated at $100/day (10hrs of use/day), adding labor cost (tractor operator is paid $12/hr) and fuel cost (100 * 0.044 * $1.45/gal = $6.38/hr ) will result in a cost/hr = $28.38/hr.

**Scenario 2:** Storage on the farm
Loading tractor (5 min = 0.08hr): $28.38/hr[1] x 0.08 hr = $2.27 → $1.19/ton
Hauling to the farm storage facility: 50% of ¾ miles at 5mph and 50% ¾ miles at 15mph that is 0.075 hr + 0.025hr = 0.1hr (6mn). Since the tractor should come back to the field, this time is doubled to 0.2hr. Thus hauling costs $28.38/hr x 0.2 hr = $5.676 → $2.987/ton ~$3.00/ton)
Generally, farmers will use a tractor to carry bales from the field to the on-farm storage facility. They can carry 4 bales at the same time or up to 8 bales if they have a hay rack (2-high, 8 bales in total)
Unloading tractor and stacking (5 min =0.08hr): $28.38/hr x 0.08 hr = $2.27 → $1.19/ton
Reloading semi-trailer for the final hauling to the power plant (45 min =0.75hr): $28.38/hr x 0.75 hr = $21.285 → $1.1825/ton
Total handling costs: $1.19/ton + $2.987/ton + $1.19/ton + $1.1825/ton = $6.5495/ton ~$6.55/ton

**Scenario 3:** Storage in a collective storage facility
Loading hay rack attached to a tractor (10 min =0.17hr): $28.38/hr[1] x 0.17 hr = $4.73 → $1.24/ton
Hauling to a collective storage facility (5 miles away from farm with a tractor to which a hay rack is attached[4]): $28.38/hr x 0.67 hr = $19.01 for 8 bales (3.8 tons) → $5.00/ton
Unloading and stacking (10 min =0.17hr): $28.38/hr x 0.17 hr = $4.73 → $1.24/ton
Reloading a semi-trailer for the hauling to the power plant (45 min =0.75hr): $28.38/hr x 0.75 hr = $21.285 → $1.1825/ton
Total handling costs: $1.24/ton + $5.00/ton + $1.24/ton + $1.1825/ton = $8.66/ton

## III Transportation costs

### III.1. Assumptions

It is assumed:
- Average distance from the farm to the plant is 40 miles. In the Chariton Valley, the minimum distance from the producers' farms to the power plant in Ottumwa is 26 miles and the maximum is 66 miles. Most farms are 35-40 miles from the power plant.
- A truck/semi-trailer load weighs on average 18 tons of switchgrass, or approximately 38 bales weighing on average 950 lbs.
- Cost of moving the round bales by truck per mile of $1.80 (2002 ISU extension publication FM-1698) is used in the estimations.
- A driver's waiting time cost (loading and unloading a truck of 18 tons) is included in the total transportation costs.

---

[4] It is assumed that the rental cost for the hay rack is not significant. Only the rental cost for the tractor, labor and fuel costs are considered here for simplicity.

### III.2. Transportation costs estimates

The cost of moving a ton of switchgrass per mile is; \$1.80/truck/mile (load of 18 tons) = \$0.0916/ton/mile, approximately \$0.09/ton/mile. The transportation cost for an average distance of 40 miles one way (80 miles round trip) is \$8 per ton (\$1.80/mile/truck load x 80 miles = \$144/truck load that corresponds to \$8/ton).
The driver's waiting time for loading and unloading a truck of 18 tons is 45mn x 2 = 90mn = 1.5hr. If the driver's labor is valued at \$12/hr, then the waiting time costs \$12/hr x 1.5hr = \$18/truck load that is \$1.00/ton. So total transportation costs per ton is: \$8.00/ton + \$1.00/ton = \$9.00/ton
The project coordinator reported (June 2002) that the cost per trip ranges from \$155 to \$200. That is \$8.61/ton to \$11.11/ton assuming a 18 ton truck load. The transportation cost used in the estimations is \$9/ton.

Using the formula of Bhat et al. (1992): TC (transportation costs) = 34.02 + 0.62 d where d is round trip distance in Km, we get the following cost:TC = 34.02 + 0.62* 80 *1.6 = \$113.38/truck load that is \$6.298/ton ~\$6.30/ton. Adding the waiting time cost of \$1.00/ton, Total transportation costs is \$7.2988/ton ~\$7.30/ton.

## IV Costs Summary

This section presents the delivered cost of switchgrass bales to the power plant. The delivered cost includes production, handling, storage and transportation costs. Productions costs are the costs incurred at a 4 ton yield levels.

**Scenario 1**: Switchgrass is hauled directly to the plant after it is harvested and staged.

Total handling and transportation costs: \$1.18/ton + \$9.00/ton = \$10.18/ton
The delivered costs per ton of switchgrass will be the sum of production costs, handling and transportation costs.

- Frost seeding on cropland: \$65.76 + \$10.18 = \$75.94/ton
- Frost seeding on grassland: \$59.05 + \$10.18 = \$69.23/ton

**Scenario 2:** Switchgrass is harvested and stored on the farm. Then it is transported to the plant.

Total handling and transportation costs: \$ 6.55/ton + \$9.00/ton = \$15.55/ton
The storage costs are those presented in table 3. Only the following options have been considered:

- Pole frame structure-enclosed on crushed rock
- Pole frame structure-open sides on crushed rock
- Reusable tarp on crushed rock
- Outside unprotected on crushed rock

Table 4 presents the details of all costs for this scenario.

Table 4: Delivered costs of switchgrass by storage system

| | | Pole frame structure-enclosed on crushed rock* | Pole frame structure-open sides on crushed rock * | Reusable tarp on crushed rock | Outside Unprotected on crushed rock |
|---|---|---|---|---|---|
| Storage cost including DM losses ($/ton) | Switchgrass price $40/ton | $11.19-16.69 | $9.54 | $5.77 | $7.07 |
| | Switchgrass price $50/ton | $11.39-16.89 | $9.94 | $6.42 | $8.57 |
| | Switchgrass price $60/ton | $11.59-17.09 | $10.34 | $7.12 | $10.07 |
| Handling costs | | $6.55 | $6.55 | $6.55 | $6.55 |
| Transportation costs (40 miles one way) | | $9.00 | $9.00 | $9.00 | $9.00 |
| Sub-total handling, storage and transportation costs ($/ton) | Switchgrass price $40/ton | $26.74-32.24 | $25.09 | $21.32 | $22.62 |
| | Switchgrass price $50/ton | $26.94-32.44 | $25.49 | $21.97 | $24.12 |
| | Switchgrass price $60/ton | $27.14-32.64 | $25.89 | $22.67 | $25.62 |
| Production costs (2002 figures) | Frost seeding on cropland | $65.76 | $65.76 | $65.76 | $65.76 |
| | Frost seeding on grassland | $59.05 | $59.05 | $59.05 | $59.05 |
| **Total delivered costs (cropland)** ($/ton) | | | | | |
| | Switchgrass price $40/ton | $92.50-98.00 | $90.85 | $87.08 | $88.38 |
| | Switchgrass price $50/ton | $92.70-98.20 | $91.25 | $87.73 | $89.88 |
| | Switchgrass price $60/ton | $92.90-98.40 | $91.65 | $88.43 | $91.38 |
| **Total delivered costs (grassland)** ($/ton) | | | | | |
| | Switchgrass price $40/ton | $85.79-91.29 | $81.14 | $80.37 | $81.67 |
| | Switchgrass price $50/ton | $85.99-91.49 | $84.54 | $81.02 | $83.17 |
| | Switchgrass price $60/ton | $86.19-91.69 | $84.94 | $81.72 | $84.67 |

* It is assumed that the stack of bales is 5-bales high

At the price level $50/ton and for switchgrass produced on grassland, the delivered costs range from $81.02/ton (bales stored under a tarp) to $91.49/ton (bales stored in a barn). While for switchgrass produced on cropland, the costs range from $87.73/ton (bales stored under a tarp) to $98.20/ton (bales stored in a barn).

**<u>Scenario 3</u>:** Switchgrass is harvested but stored at a collective storage facility

The estimated storage costs for a collective facility are $16.81/ton (10 bales-high, labor and equipment included). Including the storage losses, it becomes $17.61, $17.81 and $18.01 per ton for switchgrass prices of $40, $50, and $60 per ton, respectively. But
Total handling, storage and transportation costs:
At $40/ton, $8.66/ton + $17.61/ton + $9.00/ton = $35.27/ton
At $50/ton, $8.66/ton + $17.81/ton + $9.00/ton = $35.47/ton
At $60/ton, $8.66/ton + $18.01/ton + $9.00/ton = $35.67/ton

At the price level $50/ton, the delivered costs per ton of switchgrass (sum of production costs, storage, handling and transportation costs) are:
- Frost seeding on cropland: $65.76 + $35.47 = $101.23/ton
- Frost seeding on grassland: $59.05 + $35.47 = $94.52/ton

## V Findings and Discussion

The quality of the bales required by the power plant is an important factor affecting the choice of a storage system. High moisture content in bales creates handling problems, fuel degradation and increased boiler losses according to Bush, Bransby, Smith and Boylan (2001) who performed full scale co-firing tests for switchgrass and coal. One of their recommendations to improve boiler efficiency was to reduce the losses due to high moisture content through the modification of switchgrass storage system.

It is highly recommended to store square bales indoors because not only the quality of the bales is better preserved and there are relatively low levels of dry matter (DM) losses but also the moisture content is maintained at a recommended level (around 15%). The losses in quality and DM may be very high if the bales are stored unprotected outside. Therefore, storage of bales outside should be discouraged. The results indicate that storing bales under a tarp is cheaper than storing the bales indoors or even outside unprotected. Before recommending the best option, more research should be done on the losses in dry matter in storage under various storage options and particularly for switchgrass square bales.

Obviously, farmers lucky enough to deliver their switchgrass without undergoing the hassle of storage (scenario 1) will have low delivered costs. The issue of assuring a fair delivery schedule for producers at the power plant should be addressed.

## VI Comparisons of results with other costs found in the literature

### VI.1.Transportation costs

Transportation costs from field to processor found in other studies done in other states:

- Cundiff and Harris (1995) cited by Epplin (1996): 2 trips per day. 13 dry ton truck load, $126 total cost per load, $9.70/dry ton
- Jobes (1995) cited by Epplin (1996): 40 miles assumption, 17 dry ton load, $1.5 per truck per mile, $3.53/ton for the total hauling distance
- Bhat, English and Ojo (1992) cited by Epplin (1996): flatbed trailer truck carrying 17 dry tons (~ 40 bales of 1,000 lb. at 85% DM). Total cost per 17 ton load: $114 = $34 + $1.00*round trip in miles (80 miles). $114/truck (17 dry tons) for 80 miles round trip that is $6.71/dry ton
- Epplin (1996): $120 per load of 15 dry tons for an average hauling distance from the field to plant of 40 miles, $8.00/dry ton from field to plant
- Parks (1996): $4.15/ton for distance about 30 miles
- Walsh (1994): $0.10 /dry ton/mile for hauling distances of less than 50 miles
- Walsh and Becker and Graham (1996): $5-$10/dry ton for distances less than 75 miles

### VI.2. Delivered costs

Graham et al. (1995) found for the North Central region including Iowa an annualized farm costs of $47.60/ton (3.69 dry ton/acre yield) and an annualized delivered cost of $50.60/ton. They used the present value based on the dollar value in 1993 for cost calculations. They assumed $3.00/ton for transportation cost and they used an annual land rental rate from CRP data of $74/acre. There is no storage cost included.

Cundiff and Harris (1995), cited by Epplin (1996), estimated that switchgrass produced and delivered to a conversion facility in Virginia would cost from $46.00 to $54.00/dry ton. They assumed a land charge of $20.00/acre and a yield of 4 tons/acre.

Smith, Taylor and Bransby (2001) estimated a delivered cost for round baled switchgrass of $90/Mg, i.e. $81.67/ton. It did not include storage costs. The hauling distance considered was 80 km (49.68miles ~ 50 miles).

**References consulted**

Boylan D., Zemo B. and Eatis J., 2001: Switchgrass Co-firing at Alabama Power Company's Plant Gadsden. Final Report. Southern Company, PO Box2641, Birmingham, Al35291.

Boylan D., Bransby D. I., Bush P. V., Smith A. H. and Taylor R. C., 2001: Evaluation of Switchgrass as a co-firing fuel in the Southeast. Final technical report. 59 pages.

Buckmaster D. R., 1993: Round Hay Bales Storage, I-112, PSU. 4 Pages

Choiniere Y. and Munroe J., 1993: The Guidelines for Hay Storage in Ontario. Factsheet, Order # 93-005, Ministry of Agriculture, Food and Rural Affairs. 8 pages.

Collins M., Ditsch D., Henning J.C., Turner L.W., Isaacs S. and Lacefield G.D.: Round Bale Hay Storage in Kentuckey. AGR-171. Online publication. http://www.ca.uky.edu/agc/pubs/agr/agr171/agr171.htm

Cundiff J.S. and Marsh L.S., 1996: Harvest and Storage Costs for Bales of Switchgrass in the Southeastern United States. 1996 Elsevier Science Limited. pp.95-101.

Epplin F.M., 1996: Cost of producing and delivering switchgrass biomass to an ethanol conversion facility. Professional paper AEP-246 of Oklahoma Agricultural Experiment Station.

Graham R.L, Lichtenberg E., Roningen V.O., Shapouri H. and Walsh M.E., 1995: The Economics of Biomass Production in the United States. 10 pages. http://bioenergy.ornl.gov/papers/bioam95/graham3.html

Harrigan T.M., Rotz C.A. and Black J.R., 1994: A Comparison of Large Round Bale Storage and Feeding Systems on Dairy Farms. Applied Engineering in Agriculture, Vol.10(4):479-491. American Society of Agricultural Engineers.

Huhnke Raymond L.: Round Bale Hay Storage, Extension Publication F-1716, Oklahoma Cooperative Extension Service. 4 pages.

Huhnke Raymond L.: Hay Harvesting, Handling and Storage. Oklahoma Cooperative Extension Service E-826, Chapter 11. 9 pages

Iowa State University, 2001: Machinery Management: Estimating Field Capacity of Farm Machines. PM 696, Iowa State University.

Iowa State University, 2001: 2001 Iowa Farm Custom Rate Survey. FM 1698, Iowa State University.

Noon C.E, Daly M.J., Graham R.L. and Zahn F.B., 1996: Transportation and Site Location Analysis for Regional integrated Biomass Assessment (RIBA) in Proc., Bioenergy '96- The seven National Bioenergy Conference: Partnerships to Develop and Apply Biomass Technologies, Sept.15-20, 1996, Nashville, Tennessee. 7 pages. http://bioenergy.ornl.gov/papers/bioen96/noon1.html

Plue P.S., 1988: Big Bale hay Storage. Factsheet, Order # 88-052, Minsitry of Agriculture, Food and Rural Affairs. 7 pages.

Rotz C.A and Muck R.E.: Changes in forage quality during harvest and storage. Chapter 20.

Russel, J. Determining Forage Equipment Needs for Your Operation: A Beef Cow/Calf Nutritionist's Viewpoint

Sanderson M.A., Egg R.P. and Wiselogel A.E., 1997: Biomass losses during harvest and storage of switchgrass. Biomass and Bioenergy Vol. 12, No.2. pp107-114.

Smith J.A., Grisso R.D., Von Bargen K., and Anderson B.: Management Tips for Round bale Hay; Harvesting, Moving, and Storage, G88-874-A, University of Nebraska-Lincoln. 7 pages. http://www.ianr.unl.rdu/pubs/range/g874.htm

Smith H.A., TaylorC.R. and Bransby D.I., 2001: An interactive budget model for production, harvesting, handling and delivering switchgrass to an energy plant. Manuscript to be published in Biomass and Bioenergy.

**Appendix: Details of the computations of the annual cost, cost per bale and cost per ton for each of the storage systems**

**I. Bales stored unprotected outside on crushed rock (weight of bales = 950lbs)**

Cost for covering the floor with crushed rock = $2.70/m^2$
Area required for a bale: 4 ft * 8 ft = 32 sq ft = 2.9728 $m^2$ = $3m^2$
Height of stack = 4 bales high
Life span = 5 years
Interest rate: 8%
Amortization factor: 0.25046
Annual cost ($/m^2$): 0.25046 * $2.70/m^2$ = $0.68/m^2$
Cost per bale: ($0.68/m^2$ * $3m^2$) /4bales = $0.51/bale
Cost per ton: ($0.51/bale * 2000lbs/950lbs)=$1.07/ton

**II. Bales stored under a reusable tarp on crushed rock (weight of 0bales = 950lbs)**

Cost for covering the floor with crushed rock = $2.70/m^2$
Area required for a bale: 4 ft * 8 ft = 32 sq ft = 2.9728 $m^2$ = $3m^2$
Cost of the tarp[5] = $216.38 for a 33'x48' heavy duty tarp →$216.38 for 1584 sq.ft → 0.1366 /sq ft = $1.47/m^2$
Amount of tarp required per bale: 19.8 sq ft = 1.84 $m^2$
Cost of blocks: $2/block
Number of blocks needed: 32 blocks[6]
Height of stack = 4 bales high
Total number of bales in the stack: 80 bales
Weight of the stack = (80 *950)/2000 = 38 tons
Life span = 5 years
Interest rate: 8%
Amortization factor: 0.25046
Annual cost for crushed rock ($/m^2$): 0.25046 * 2.70 = $0.68/m^2$
Cost of crushed rock per bale: ($0.68/m^2$ * $3m^2$) /4bales = $0.51/bale
Cost of crushed rock per ton: ($0.51/bale * 2000lbs/950lbs)=$1.07/ton
Annual cost for whole tarp (1584 sq. ft): 0.25046 *216.38= $54.19
Annual cost for tarp ($/m^2$): (54.19/1584)/0.0929 = $0.37/m^2$
Cost of tarp per bale: $0.37/ $m^2$ * 1.84 $m^2$/bale = $0.68/bale

---

[5] Retail price October 2001 from Inland Plastics LTD: a heavy duty tarp 33'x48' cost $216.38.
[6] For 64 ft, 32 blocks are needed.

Cost of tarp per ton: $54.19/38tons = $1.43/ton
Annual cost for blocks: 0.25046 * 2*32 = $16.03
Cost of blocks per bale: $16.03 /80bales = $0.20/bale
Cost of blocks per ton: $16.03/38 tons=$0.42/ton
Total cost per bale: $0.51/ton + $0.68/ton + $0.20/ton = $1.39/bale
Total cost per ton: $1.43/ton + $0.42/ton + $1.07/ton = $2.92/ton

**III. Bales stored in a pole frame structure with open side (s) on crushed rock (weight of bales = 950lbs)**

Construction cost: $5/sq ft = $53.82/ $m^2$
Area required for a bale: 4 ft * 8 ft = 32 sq ft = 2.9728 $m^2$ = 3$m^2$
Height of stack = 5 to 6 bales high
Life span = 15 years
Interest rate: 8%
Amortization factor: 0.11683
Annual cost (\$/$m^2$): 0.11683 * $53.82/ $m^2$ = $6.29/$m^2$
Cost per bale: 5 bales high ($6.29/$m^2$ * 3$m^2$) /5 bales = $3.77/bale
6 bales high ($6.29/$m^2$ * 3$m^2$) /6 bales = $3.14/bale

Cost per ton: 5 bales high ($3.77/bale * 2000lbs/950lbs)=$7.94/ton
6 bales high ($3.14/bale * 2000lbs/950lbs)=$6.62/ton

**IV. Bales stored in a pole frame structure totally enclosed on crushed rock (weight of bales = 950lbs)**

Construction cost: $6.54 - $10/sq ft = $70.39 - 107.64/ $m^2$
Area required for a bale: 4 ft * 8 ft = 32 sq ft = 2.9728 $m^2$ = 3$m^2$
Height of stack = 5 to 6 bales high
Life span = 15 years
Interest rate: 8%
Amortization factor: 0.11683
Annual cost (\$/$m^2$): 0.11683 * $70.39 - 107.64/ $m^2$ = $8.22 - 12.58/$m^2$
Cost per bale: 5 bales high ($8.22 - 12.58/$m^2$ * 3$m^2$) /5 bales = $4.93 - 7.55/bale
6 bales high ($8.22 - 12.58/$m^2$ * 3$m^2$) /6 bales = $4.11 - 6.29/bale

Cost per ton: 5 bales high ($4.93 - 7.55/bale * 2000lbs/950lbs)=$10.39 - 15.89/ton
6 bales high ($4.11 - 6.29/bale * 2000lbs/950lbs)=$8.66 - 13.24/ton

**V. Bales stored in the Collective storage facility**

The collective storage facility is likely to be a totally enclosed facility with crushed lime rock for flooring
Height of stack could range from 9 to 14 bales high. Need of special equipment to lift the bales and of at least a part time staff for the monitoring of the operations and management of the storage facility. Farms located within 5 miles radius from the storage facility will likely be interested in storage because producers can use their tractors with or without a hay rack to move the bales (4 to 8 bales respectively) from the field to storage.

Total area of the building: 30,000 sq ft
Construction cost: $300,000 that is an estimated $10.00/sq ft that is $107.64/m$^2$
Area required for a bale: 4 ft * 8 ft = 32 sq ft = 2.9728 m$^2$ = 3m$^2$
Height of stack = 10 bales high
Capacity of storage: 4000 tons
Life span = 15 years
Interest rate: 8%
Amortization factor: 0.11683
Annualized construction cost ($/m$^2$): 0.11683 * $107.64/ m$^2$ = $12.58/m$^2$
Building cost per bale: (12.58/m$^2$ * 3m$^2$) /10 bales = $3.77/bale
Building cost per ton: ($3.77/bale * 2000lbs/950lbs)=$7.94/ton

Labor cost ($12/hr): 20hr/wk *4wks*12months*$12/hr = $11520 that is $2.88/ton
Equipment costs: Telelift (hi-lift) is needed to lift the bales. Cost for renting a telelift is $1,995 a month that is $23940 per year.
The cost per ton will be $5.985/ton.
Equipment and labor cost per ton: $5.99 + $2.88 =$8.865/ton
Total cost per ton: $7.945/ton + $8.865/ton =$16.81/ton on average.

As the storage capacity increases, this cost decreases.

# Biomass production in the Chariton Valley area of south central Iowa: Farmers' motivations for adoption of switchgrass

Patricia C. Hipple
1151 Bourland Avenue, Waterloo, Iowa 50702 USA

Dr Michael D. Duffy
Iowa State University, Department of Economics, 478 Heady Hall, Ames, IA  50011, USA.
Tel: 515-294-6160. E-mail: mduffy@iastate.edu

November 2001

# Biomass production in the Chariton Valley area of south central Iowa: Farmers' motivations for adoption of switchgrass

Patricia C. Hipple and Michael D. Duffy

Switchgrass (*Panicum virgatum,* L., Poaceae) is a perennial warm-season grass native to Iowa, grown for decades on marginal lands not well suited for conventional row crops. It is now being recognized as a potential energy source and alternative cash crop for Iowans. The Chariton Valley Resource Conservation and Development (RC&D) is coordinating Iowa's first major switchgrass demonstration project, promoting the crop's potential for large-scale production through its Chariton Valley Biomass Project. The project goal is to successfully use switchgrass as an energy source by co-firing it with coal at the Alliant Power generating station in Chillicothe, Iowa. If co-firing proves successful, project organizers estimate that 50,000 acres or 200,000 tons of switchgrass will be required to produce 35MW of electrical power at a 5 percent co-fire rate.

Prairie Lands Bio-Products, Inc. is a not-for-profit member organization affiliated with the Chariton Valley Biomass Project. In addition to producing switchgrass for biomass, Prairie Lands Bio-Products, Inc. is developing other markets for switchgrass, including forages, mulch for landscaping, fiberboard and paper, use as filler in plastic products, stove and fireplace pellets and logs for residential heating, and animal bedding. If these ventures also succeed, Chariton Valley promoters will be challenged to recruit as many as 500 switchgrass producers to meet demands.

Insights on current adoption of alternative crops, farming practices, and land use are needed to develop recruitment guidelines and strategies that will foster future switchgrass adoption and long-term commitment to production. Social research on the adoption process of switchgrass and other farming alternatives was designed to provide these insights.

Iowa imports 98 percent of the fuels needed to generate energy in the state. Future success of a domestic energy industry in Iowa is dependent on the development of alternative energy sources, including biomass. The support and participation of biomass producers will be critical to this future. Currently, more than 80 farmers in southern Iowa planted nearly 7,000 acres of land in switchgrass for the Chariton Valley Biomass Project. The majority of these producers have invested significant time and financial resources to assist with biomass project planning during the past three years despite the fact that no market currently exists for switchgrass as an energy crop.

Farmers must analyze financial and social costs and benefits of new crops, farming practices, and economic activities. Better understanding the factors southern Iowa farmers consider when evaluating alternative land uses, economic activities on the farm, and resource allocation will help the Chariton Valley Biomass Project develop and implement guidelines to recruit switchgrass growers and promote long-term producer participation.

Specifically, project members need to understand:

1. What motivates or discourages the adoption of energy crops, other alternative crops, new agricultural practices, and varied land uses?
2. What are the incentives and disincentives to adoption of alternative farming activities, including profit, risk, uncertainty, reputation, inputs and equipment availability, financial status, financial guarantees, program subsidies, support networks, learning curves, community attitudes, and family attitudes?

3. What crop and product attributes, infrastructure and markets, and financial and community support programs facilitate or impede adoption?

**COMPLEMENTARY RESEARCH**

Extensive economic and agronomic research is currently underway at Iowa State University to assess the viability of switchgrass as biomass. Research efforts focus on:

The economic potential of switchgrass as an agronomic crop for bioenergy

- Documenting on-farm costs and resource commitments for switchgrass production
- Assessing regional economic impacts of large-scale switchgrass production
- Quantification of energy consumption for switchgrass production.

Switchgrass production in relation to soil variability and environmental quality

- Identifying landscape and nitrogen effects on switchgrass production potential
- Quantification of soil properties and their relation to switchgrass yield and quality
- Assessing erosion potential in switchgrass fields.

Evaluation and development of switchgrass (and reed canarygrass) germplasm for bioenergy production and adaptation to Iowa

- Switchgrass cultivar evaluation for yield and biofuel quality (Brummer et al. 1998).

**RESEARCH METHODS**

To complement this agronomic and economic research on the viability of switchgrass production for biomass, we designed social research on the motivations behind, obstacles to, and consequences of adoption of alternative farming practices, especially switchgrass, in southern Iowa's Chariton Valley. Fifty-two members of the agricultural community in southern Iowa participated in extensive interviews. Among the participants were switchgrass producers; conventional farmers; GMO producers; organic farmers, livestock, small animal, and exotic species producers; individuals involved in agro-forestry and seed production; extension specialists; and agro-industry representatives. In addition to interviewing these individuals, we reviewed archival documents, took facility and farm tours, had casual conversations with other members of the rural community, and spent time in many fields, orchards, pastures, barns, and farm homes to better understand the context in which southern Iowa farmers make their decisions about adoption of alternative crops.

The Chariton Valley Biomass Project encompasses the four south central Iowa counties of Lucas, Wayne, Monroe, and Appanoose. Ethnographic fieldwork was conducted in these counties, as well as in contiguous Wapello and Davis counties. Several of the individuals interviewed, although they participate in alternative farming practices in the six identified counties, reside elsewhere, so Jefferson, Van Buren, and Mahaska counties, among others, are represented also.

Ethnographic fieldwork was conducted between March and August of 2000, with the majority of interviews conducted between mid-May to late July. Qualitative analysis began immediately and continued through the report writing phase, October through December of 2000.

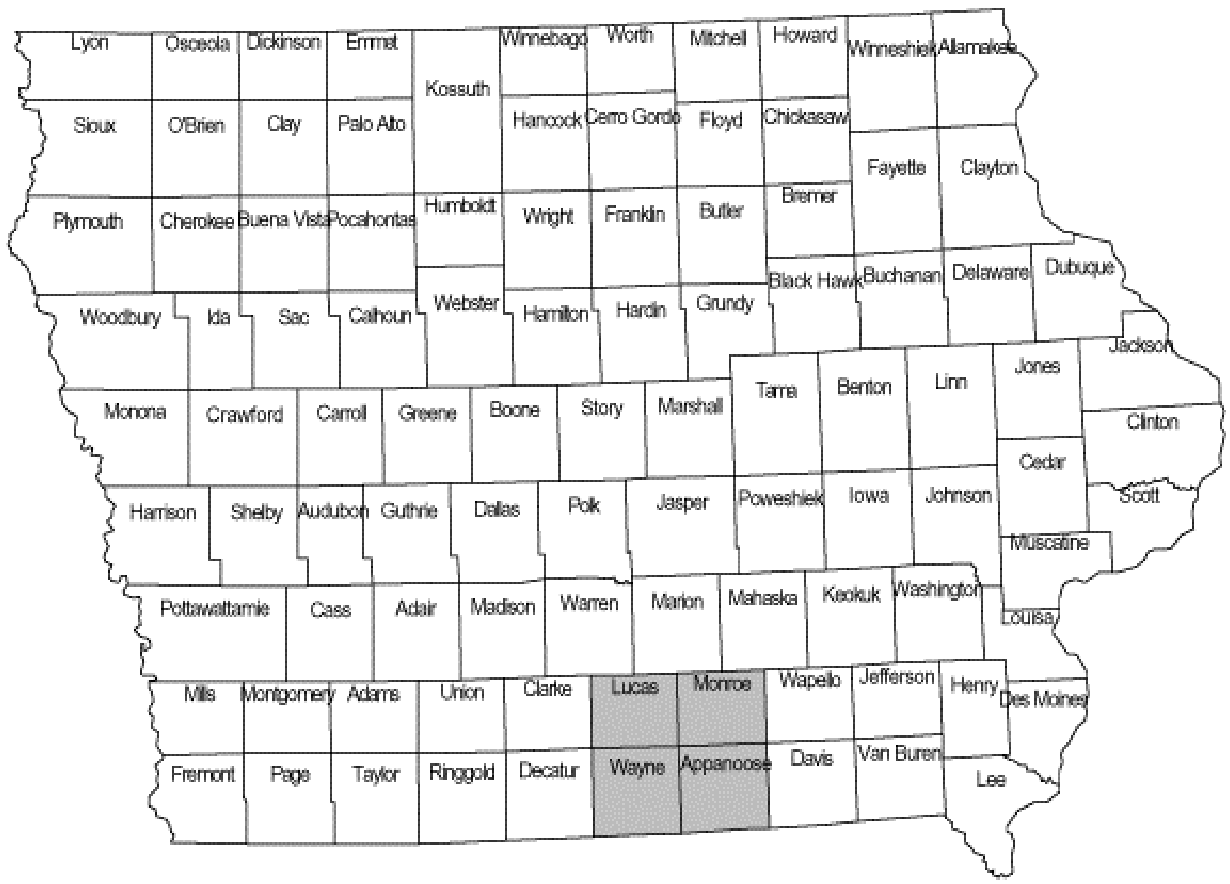


Figure 1. Map of Iowa Designating the Four Counties Served by the Chariton Valley Biomass Project

A convenience sample of 52 members of the agricultural community in the six counties targeted in this study was identified using a snowball sampling technique. Care was taken to gain broad representation of the farming community by sex, age, county of residence, and type of farming operation. During the fieldwork it became apparent that religion was a salient factor in adoption of alternatives. Researchers then sought participation from various faith groups in these six counties, including mainstream Protestant and Catholic denominations, as well as Amish, Mennonite, Apostolic Christians, and members of the Maharishi Vedic community. The sample included 47 men and 5 women. Although we did not ask the age of participants, we estimate they ranged in age from 35 to over 80, with the majority in their mid-40s to mid-50s. Although several of those interviewed have migrated to these counties within the past 10 years, most are native to their county, or have been in business in their county for more than 30 years.

Table 1 describes the sample. Nineteen of the farmers in the sample currently grow switchgrass and 15 of these participate in the biomass project. Five sample farmers have expressed interest in switchgrass production and attended informational meetings, but for a variety of reasons have chosen not to pursue switchgrass production at this time. Twelve of the sample might be characterized as conventional farmers, although switchgrass producers are likely to consider their operations "conventional" as well. (For our purposes, conventional refers to farmers who currently grow row crops using chemicals but do not produce switchgrass.) At least four participants plant genetically-modified organism (GMO) soybeans or corn, while four raise organic crops. At least 15 are livestock producers, and five raise small animals and/or exotic species. Seven of the sample are engaged in some aspect of agro-forestry (fruits or nuts or timber.) Nine of the sample hold volunteer or paid positions with the Extension Service, Farm Bureau, rural development agency, or agribusiness. Because a number of participants have dual or triple roles in the agricultural community, the total of these categories exceeds 52.

Table 1. Description of the Sample.

| | |
|---|---|
| Switchgrass producers | 19 |
| Switchgrass curious (not producers) | 5 |
| Conventional (row crops w/ chemicals) producers | 12 |
| GMO producers | 4 |
| Organics producers | 4 |
| Livestock producers | 15 |
| Small animals and exotics producers | 5 |
| Agro-forestry producers | 7 |
| Farm organization & industry representatives | 9 |

**THE GUIDING THEORY BEHIND SWITCHGRASS ADOPTION RESEARCH**

Adoption-diffusion theory, as elaborated by Rogers (1995), guides this research. Rogers explains diffusion as "the process by which (1) an innovation (2) is communicated through certain channels (3) over time (4) among members of a social system" (p. 10). An innovation, according to Rogers, is "an idea, practice, or object that is perceived as new by an individual or other unit of adoption" (p. 11). For the purpose of this research, alternative farming practices and land uses such as switchgrass production for biomass are innovations.

"Change agents" frequently encourage adoption of a new idea, practice, or object, communicating the value of innovations through interpersonal as well as mass media channels of either local or "cosmopolite" origin. Rogers identifies five distinct though overlapping stages in the innovation adoption process: (1) knowledge; (2) persuasion; (3) decision; (4) implementation; and (5) confirmation.

Classical adoption-diffusion theory has been criticized for pro-innovation bias, individual-blame bias, recall problems in diffusion research, and issues of equality. In the beginning, adoption-diffusion researchers identified characteristics of adopters, such as socio-economic status, personality, communication behavior, and risk tolerance (described as the innovativeness/needs paradox) that determine the likelihood of adoption. More recently, the focus of adoption-diffusion research has been on attributes of innovations and rates of adoption. Such attributes include relative advantage (economic factors, status aspects, effects of incentives); compatibility (with needs, values and beliefs, previously introduced ideas, and technology clusters); complexity; trialability; observability; diffusion affect; and, overadoption.

Rogers cautions that adoption-diffusion research must remain attuned to the desirable and undesirable, direct and indirect, anticipated and unanticipated consequences of innovations. Likewise, change agents of innovation, adoption and diffusion need to be aware of the "KAP gap," inconsistencies between knowledge, attitude, and practice, as well as issues of equality—

communication effects gaps, gap-widening consequences, and social structure inequities—to devise strategies for narrowing such gaps.

## SWITCHGRASS PROPONENTS AND ADOPTERS

### I - Prairie Lands Bio-Products, Inc.

Prairie Lands Bio-Products, Inc. (Prairie Lands) is a not-for-profit organization comprised of 60 switchgrass producers in southern Iowa. Their purpose, according to information available on their Internet Web site, is to "identify and develop switchgrass products and markets; produce switchgrass to satisfy demand for products; evaluate environmental benefits of producing and using switchgrass; and inform and educate the public about the potential of switchgrass." Their members receive "technical assistance with the establishment and management of switchgrass, current information on product development, opportunities to participate in new markets, regular updates on the biomass project, and opportunities to participate in demonstrations and research activities." They are, according to one of their members, "strange bedfellows" in that each member brings a unique set of motivations, needs, and desires to switchgrass production and Prairie Lands participation. Ten members oriented us to the culture of southern Iowa farming and shared their stories about switchgrass adoption.

One of the earliest adopters to reintroduce switchgrass in southern Iowa was cattle producer, Jay Merchant[1]. He has grown switchgrass intensively in Wayne County since 1980 as backup forage to feed cows during the hot summer months. Merchant also uses switchgrass as wildlife cover. The benefits of switchgrass as a feed source were immediately apparent to him, but regrettably, he explained, because palatability of switchgrass decreased at maturity, word spread that "cows won't eat it." This misinformation discouraged many cow/calf operators from following his lead. Undeterred, Merchant maintains 40 acres of switchgrass in the biomass project as well as mixed-grass stands for wildlife.

Kenneth Tides runs a cow/calf operation in Appanoose County and has been extremely successful using switchgrass as summer pasture and for bedding and calving in late winter and early spring. He too started growing switchgrass more than 20 years ago, but he noted that he had to seed four times before getting a respectable stand. He has 180 acres now. "It's as good a grass hay as you can get," he explained, citing protein content upwards of 12 percent. With stands 6-feet tall, Tides is able to calve cows in his switchgrass; he turns the herd loose allowing about 2 acres per cow.

To begin his original 7-acre stand, Harold Chambers got switchgrass seed from Pheasants Forever. Later he bought seed from Kenneth Tides for land he had bid into the Conservation Reserve Program (CRP). His main motivation beyond soil conservation through erosion control on marginal lands was the advantage switchgrass has for wildlife habitat. His stands were taken out of the CRP last year, but he bid the land back into the program this year. At the time of initial planting, only switchgrass was required in his CRP tract, but he explains that newer CRP requirements prohibit more than 15 percent switchgrass in a mix of other prairie grasses, legumes, and forbs. Unfortunately, switchgrass is so tenacious that it chokes out most other plants, and the cost of some seed mixes can exceed $250 an acre, making generous seeding prohibitively expensive. "One of the shortcomings of switchgrass," he cited is that unlike conventional row crops, "there is no loan deficiency payment (LDP) (or government price guarantee) for your switchgrass crop."

[1] All names are pseudonyms.

Casey Patterson joked that he "got talked into switchgrass" by some "silver-tongued" Prairie Lands member. He planted switchgrass two years ago in Mahaska County, but he didn't incur the exorbitant expense that Chambers had mentioned. Patterson reported that he was allowed to plant 100 percent switchgrass when he bid 15 acres in the CRP recently. But, he added, when the mistake was discovered, his land was reclassified as wildlife habitat "to keep everyone out of trouble."

Other producers influence adoption decisions of newer producers. Dennis Brader "blames" everything on Jay Merchant. As a result of his influence, Brader seeded 120 acres of switchgrass. He subsequently sold that farm and bought another, seeding the new farm with 45 acres of switchgrass. Brader's main motivation was wildlife habitat, although he admits that with his stands in the CRP "that's all we can use it for now." Brader has worked on several switchgrass harvest crews. He said switchgrass is obviously a great economic development opportunity for southern Iowa if the test burn works (referring to the planned co-firing of switchgrass with coal at the Alliant Power generating station), but it also has benefits to wildlife. Brader originally seeded Blackwell variety switchgrass, but has since shifted to seeding with Cave-in-rock, the current recommended variety.

Jerrold Messerli has been active in switchgrass harvesting because he owns the square baler that has been used on the switchgrass stands of many Prairie Lands members. Messerli baled switchgrass for Jay Merchant, but the crop was lost because the bales could not survive outdoor storage. In response, Prairie Lands invested in what is affectionately known as "the switchgrass palace," a large Morton-style building for indoor storage of switchgrass bales destined for the test burn at the Alliant Power generating station. Despite the availability of a secure storage facility, Messerli has not contributed his own yield. He reported that he has not been very successful in seeding his own 20-acre stands that are not in the CRP. "The spring was just too wet," he explained.

Wildlife habitat is a prime motivator for many switchgrass adopters. G. W. Benesch has 1,000 acres in the CRP, 300 of which are planted in switchgrass. Benesch loves to hunt and switchgrass habitat provides a great venue for fee-hunting. (He leases land to the Celebrity Corporation for the annual governor's hunt.) Benesch gives switchgrass high marks for its aesthetic value. He claims that more than sixty wild turkeys live in his switchgrass stands, providing lovely "music" with their frosty morning calls. In recent years, southern Iowa has been attracting hunters from great distances, and many area farmers have invested in fee-hunting retreats as a revenue source, as well as for their own recreation. "Poor hunting property is more lucrative than good farmland," according to Benesch.

Richard Hites was growing switchgrass for summer pasture when he heard about the biomass project. Encouraged by Kenneth Tides, a farmer Hites holds in high esteem, he decided to volunteer switchgrass acres for research and biomass harvest. Originally Hites had a cow/calf operation, but poor health forced him to give up the cattle and move more intensively into switchgrass. Hites has reseeded three times to improve his stand. He maintains it for attracting wildlife—deer, quail, and pheasants. Hites remarked that weeds are necessary as food for wildlife, but government regulations discourage weeds.

Jay Merchant explained that USDA rules also prohibit grazing or harvesting on CRP land, but thanks to a bill introduced by Senator Tom Harkin (Dem. IA), a temporary waiver has been granted for biomass research. As a result, switchgrass farmers with CRP contracts are permitted to volunteer their stands for research and limited harvest without a reduction in CRP receipts, provided they reap no financial gains from the switchgrass. If they are paid for their switchgrass, they will be required to repay the difference to the CRP.

CRP rules have changed several times, especially with regard to switchgrass management, according to William Sargent, another southern Iowa switchgrass producer. Initially, there were no restrictions, he reported. The goal was to merely get a switchgrass stand established. Later the expectation was for 80-90 percent of the CRP to be planted in switchgrass. Subsequent rulings have required varying levels of legumes, grasses, and forbs to be added to the seeding mix. Such federal rule changes, compounded by differing interpretations at the district administration level, threaten the viability of switchgrass production. With seed costs ranging from \$3/lb up to \$100/lb (some forbs list for more than \$25 an ounce), affordability and profitability become problematic. "No one likes the way the Conservation Reserve Program is managed," Sargent concluded.

Harold Chambers cited another example of government rules hostile to switchgrass production. "Research suggests harvesting switchgrass once every three to four years would benefit the stands," but rules prohibit the harvesting of grasses on CRP land. "These regulations will ruin the soil," G. W. Benesch added. Some members, bewildered with CRP proscriptions, ask "If the purpose of the CRP is to protect the soil from erosion and to conserve land for future generations, why would CRP regulations prohibit management practices that would improve soil quality? And why would CRP payments to farmers be in jeopardy for activities that assure land conservation?" (At the same time, they acknowledge that many of their farming peers view CRP payments as an unwarranted subsidy that unfairly rewards farmers who incur other benefits from land held in the CRP.) "The government is really working against us here," Harold Chambers protested. "Regulations get in the way. We are now required to enhance switchgrass stands with legumes, but we can't mow for cold-season grass, so grasses get choked out. If we could mow and manage one-third of the crop yearly, we could optimize the crop for wildlife management."

Also an advocate for wildlife, G. W. Benesch objects to U.S. Department of Agriculture and Department of Natural Resources rules that purport to protect wildlife while actually posing a greater threat to them. For example, he cites the prohibition against mowing during the nesting season, explaining that he watched a Cooper Red Hawk (a protected species) destroy other wildlife during harvest of row crops. "The hawk killed three pheasants and two rabbits within twenty minutes, but did not eat them. These were 'thrill kills'," Benesch explained. In the area of which he speaks, the quail are gone and the turkeys are in trouble, yet he is not allowed to kill or harass the hawks that are preying on other wildlife.

Economic and agronomic research at Iowa State University will be critical to switchgrass profitability. For example, Prairie Lands members noted that the 5 to 6 lbs. of pure live seed (PLS) once suggested for establishment of switchgrass are insufficient. The suggested amount is currently up to 10 lbs. PLS, and they predict it will eventually reach 15 lbs. PLS. (Research done in Kansas advises planting 25 lbs. PLS to establish optimal switchgrass stands.) Determining seeding rates and costs will be vital in determining profitability and viability of switchgrass as biomass. In addition to researching the economic potential of switchgrass as a biomass source, Iowa State University (ISU) scientists are studying management practices, transportation and storage, and erosion control, as well as the quality of switchgrass used as wildlife habitat and the effects of harvesting on wildlife populations.

Prairie Lands members are testing and demonstrating a variety of switchgrass management strategies. "Switchgrass can't tolerate depth," Kenneth Tides explained. "The best method for planting switchgrass is 'frosting' or 'frost-seeding'," that is, broadcasting the seed after the first freeze and rolling it to achieve a very shallow depth. Tides agreed that Prairie Lands has demonstrated the viability of switchgrass on CRP land, but he argues, "You can make switchgrass pay without CRP." He pastures cows on 75 acres until the end of May. He later sells the summer hay, reaping 120 tons from the 75 acres at $45 a ton.

Harold Chambers likewise has been able to realize a profit on switchgrass without CRP. He harvests the switchgrass for seed and sells the remaining straw to be used as mulch for highway construction. According to a Prairie Lands news release, Chambers harvested 150 to 200 pounds per acre of pure live seed that sold for $4 to $5 per pound. The straw residue was baled and sold to the Department of Transportation or local construction companies for $45 to $60 per ton. Chambers' harvest came from land that earlier had been in the CRP, otherwise he would have been prohibited from managing and harvesting and generating revenue from his CRP "crop."

The Prairie Lands discussion always seemed to return to concerns about CRP regulations. The CRP is an important source of income in southern Iowa. According to newspaper reports, the CRP enrolls nearly 140,000 acres of highly erosive land (HEL) in Wayne, Monroe, Lucas, and Appanoose counties, one-tenth of the 1.4 million acres in the four counties. At $65 to $80 per acre, CRP payments provide more than $10 million of revenue for southern Iowa. But the "aggravation factor" of CRP regulations discourages many potential producers from growing switchgrass. Prairie Lands members argue the need for legislation to allow management of CRP crops and foraging on CRP lands, claiming that alternative land uses could increase active use of the CRP without placing erosion control and soil conservation at risk. Indeed, proponents argue that prudent management could increase soil fertility. They disagree, however, on whether a payment reduction is warranted for such use. "Why reduce the CRP payment if there is no loss of CRP benefit?" some ask. Others recognize that non-CRP farmers are most critical of alternative uses of CRP and resent additional revenues being gleaned by CRP farmers who are already receiving a subsidy for the same land.

Like many of their contemporaries, these southern Iowa farmers remain skeptical of government programs aimed at reviving the farm economy. Most believe that government programs benefit large producers at the expense of the "little guy." Former Secretary of Agriculture Earl Butz's 1970s advocacy of farming "fence row to fence row" was disastrous for the marginal lands in southern Iowa. It aggravated erosion problems, further depleted soil nutrients, and reduced water quality as the result of chemical runoff and siltation, according to these farmers.

Decades earlier, the federal government introduced multi-flora rose to southern Iowa as a "living fence" that subsequently became a scourge to farmers; it has "fish-hook-like barbs" and is so thick you can't walk through it, and regrettably, it can't be killed. It proliferated throughout ditches and invaded farm fields and yards, causing injury and consternation to humans and animals in southern Iowa. (Thankfully, area farmers have reported a disease is now killing off much of the multi-flora rose.) Prairie Lands members, along with most southern Iowa farmers, will quickly name a dozen federal policies-gone-wrong. In contrast to their cynicism toward federal programs, many area farmers express greater comfort and trust in locally generated ideas and projects. Thus, the Chariton Valley Biomass Project and Prairie Lands Bio-Products, Inc. have an advantage.

Prairie Lands members warned that those least likely to adopt switchgrass, for biomass or any other purpose, are farmers currently growing 100 percent of their row crops on a rotational basis. "They're looking for profit, and although corn and beans are not profitable . . . at least they provide cash." According to G. W. Benesch, the wildlife benefits of switchgrass are unlikely to appeal to them. "Row crop folks don't appreciate wildlife; they begrudge even one-quarter of an acre for habitat and they don't want animals in their corn or beans." Prairie Lands members believe that many farmers can't or won't "think outside the box." Rather, they follow "tradition," preferring to farm "like their fathers and grandfathers." They argue that most farm transactions remain "off-the-cuff," what Prairie Lands members characterized as the "Whatareyapayin'today? syndrome," rather than taking the proactive position of "This is my crop and this is what I expect to be paid for it." But members also acknowledged that most farmers know little about switchgrass, and that's why the mission of Prairie Lands is so important. Admittedly, however, the biomass project has lost participation of "good members" due to its protracted start-up period. Cooperators already have committed three years and have yet to see profitable results.

While the profitability of switchgrass biomass remains uncertain, many switchgrass producers see the potential of carbon trading credits. Because switchgrass transfers its carbon to the soil and preliminary results suggest that little carbon is emitted into the air when switchgrass is burned, there is speculation that farmers will be able to earn revenue by trading credits they receive as the result of switchgrass carbon sequestration. Estimates range wildly, from $21 to $1500 (!) per acre. Prairie Lands members already report contacts from "carbon brokers" who are seeking to handle future carbon credit trading transactions. The reality of carbon credits seems plausible, but the future value is unclear.

**II - Harlan Payne**

Harlan Payne worked for the Agricultural Stabilization and Conservation Service (ASCS) office in Corydon when switchgrass was re-introduced in southern Iowa. "I'm the sort of guy who'll try anything new," explained Payne. Although an employee of ASCS and Natural Resource Conservation Service for more than twenty years, Payne was also active in farming and cattle production. Now retired, Payne still owns two farms; he rents pastureland to a neighbor for cattle grazing, maintains a food plot and pond for wildlife, and keeps the remainder of his land in the CRP. He has two stands of switchgrass committed to the biomass project, a 20-acre stand planted three years ago and 16 acres planted this year.

Payne planted his switchgrass for the CRP, learning about switchgrass management from magazines and newspaper articles. Although the first year yielded a poor stand, it got thicker each succeeding year with the addition of fertilizer, despite the fact that he never burned it or reseeded. For Payne, there was no investment in equipment. Initially, he hired a custom driller for planting. He inter-seeded, or "frost-seeded" his newest stand with the currently recommended variety, Cave-in-rock. He claims to have no weed problem and a "near-perfect" stand. Payne keeps a watchful eye on the switchgrass, out of curiosity mostly, as the Chariton Valley Biomass Project now manages his switchgrass. They check his stands, take soil samples, add fertilizer, study various management practices, mow, bale, and transport the biomass crop. Payne reported that his switchgrass was first harvested in February and again in October, explaining that the CRP prohibits harvesting the entire stand at once. Therefore, his stands are mowed in strips, alternating rows with each harvest. He gets annual updates on the progress of his stands and local biomass efforts from a biomass project folder.

Prior to retirement, Payne spent much of his career mapping ponds and terraces within the Chariton Valley drainage area. He has mobility problems today—weakening ligaments and muscles due to nerve damage he suspects is the result of custom spraying. Because of his concern about clean water, he has focused on wetland restoration, and his motivation for participating in the CRP was to eliminate chemical use that could harm the water in the South Chariton River and Lake Rathbun.

Payne also appreciates the wildlife benefits of switchgrass. He has three ponds on his land near which he grows two plots of food for wildlife, including 7 to 8 acres of corn and beans and milo (sorghum) for the birds. Even if the test-burn of switchgrass at the Alliant Power generating station fails, Payne will continue with switchgrass production for conservation, erosion control, and wildlife habitat. He has seen pheasant and quail populations increase as the result of switchgrass, and has seen a proliferation of songbirds, including finches, thrushes, bob-o-links, and red-winged blackbirds, as well as yard birds such as sparrows, bluebirds, jenny wrens, and hummingbirds. Payne noted that deer and turkey use his switchgrass for winter bedding.

Switchgrass has not been Payne's only experience with farming alternatives. He experimented with the trefoil legume as a non-chemical source of nitrogen for his pasture, and he has been planting trees as windbreaks and buffers. Payne has never grown organic or GMO crops because they were introduced after he retired from crop farming.

**III - Stephen and Julia Harms**

Stephen and Julia Harms contend that early adopters will be key to the diffusion of switchgrass for biomass among southern Iowa farmers. They believe the cutting edge of alternative practices will be an interesting marriage between conventional agriculture and niche or specialty farming. They expect that "modern-day hippies who are into alternative lifestyles" will be in the forefront. They don't consider Wayne County to be ripe with the innovative spirit required for the transformation. Instead they feel they are "out there by themselves" in their exploration of alternative agriculture, and are pleased to be involved with the biomass project. The Harms' also are members of Practical Farmers of Iowa, a group they say is leading the charge in community supported agriculture and other farming alternatives.

Like most Wayne County farmers, Stephen and Julia have jobs off the farm as well. He is a minister and she is a teacher, but they identify themselves as a farm family. Much of their land is in the CRP, and although they participate in the biomass project, Stephen and Julia still manage their own switchgrass, along with other prairie grass stands. They planted warm-season grasses on their CRP land, including switchgrass, 4 acres of Indian grass, and 1 acre of big bluestem that they seeded by hand. They also planted little bluestem and sideoats grama, but these failed because CRP regulations required a mix with switchgrass that choked out everything else. The Harms' also maintain stands of reed canarygrass and planted 10 acres of trees in a forest plot of hardwoods, red oaks, white oaks, walnuts, and food for wildlife.

A coincidence led to the Harms' participation in the biomass project. Stephen explained that they were interested in enrolling more land in the CRP at about the same time he began reading about biomass in the paper. A chance meeting with Jay Merchant outside the Soil Conservation Service (SCS) office resulted in their enlistment in switchgrass and biomass research.

Some of the Harms' switchgrass stands were more than 12-years-old and had never been harvested. "They were slow getting started," Stephen recalls, "due to weeds and problems with anthills. They required a lot of management." Huge anthills continue to hamper equipment use in the Harms' stands. "We need to disk in late spring to rid the stands of anthills," Stephen explained. The Harms' have had several intentional burns and one accidental burn in their switchgrass. Julia, who volunteers as a guide at a nearby prairie reserve, explained that switchgrass needs burns to flourish. “Prairie grasses need heat to germinate, but after a fire they rejuvenate immediately and they’re beautiful when they’re coming back,” she said.

Stephen and Julia have bid their poorest land patch-by-patch into the CRP. They explained that there were no strings attached 12 to 15 years ago. The goal was just to get a stand. Although it is a sod, switchgrass comes up in clumps and its main purpose in the CRP is to anchor the soil. But the CRP recently has required inclusion of legumes in switchgrass stands to add nutrients to the soil, although farmers argue that the requirement wastes money because most legumes are choked out by the switchgrass. Stephen notes that legumes are probably counterproductive for biomass production due to reduced switchgrass yields.

The Harms’ claim that the culture of southern Iowa is shaped, in large part, by the rugged individualism that characterized its early Scotch-Irish settlers. That’s why there are fewer cooperatives in southern Iowa then in central and northern Iowa, which was settled by other ethnic groups, according to Stephen. (Stephen believes that Amish entrepreneurs in southern Iowa are an anomaly in this regard.) Conventional farmers in southern Iowa are suspicious of alternatives, according to Stephen. “But conventional farmers have been sucked into something that’s crushing them,” he added, citing vertical integration of agriculture and Freedom to Farm as possible culprits. Although Wayne County was the first to fill its CRP quota, this was a very “rational” move on the part of area farmers, according to Stephen, not one based on a cooperative or communitarian ethic. He contends that convincing southern Iowa farmers to change will require a strategy attuned to rugged individualism. “These farmers are willing to change, but they change in ways different from other Iowa farmers,” Stephen concluded.

**IV - Tom Stoner**

Tom Stoner grows switchgrass, along with GMO beans and corn, on a farm close to the Missouri border in Wayne County. “Cropping is difficult in southern Iowa,” Stoner explained, admitting that he’s probably “farming land I shouldn’t be.” Stoner grows Bt corn because his land is vulnerable to corn borers, and he grows Roundup Ready® soybeans because they reduce worry and are more compatible with off-farm work. (In addition to farming, Stoner sells real estate.) Stoner raised hogs in confinement until the trend toward leaner hogs and declining hog prices convinced him it was time to get out. He added that he “should” be in cow/calf production, but it requires management and money to invest.

Stoner planted switchgrass 18 years ago in “set-aside” acres. (Set-aside acres were a feature of previous farm bills.) He learned about switchgrass through an alternative crop class offered by Iowa State University. He explained that the ground wasn’t very good for crops so he planted switchgrass mostly “to do something different.” His goal was seed production. Stoner converted his set-aside to CRP, but eventually pulled his switchgrass out of the CRP because payments were getting “chintzy”. “It wasn’t worth it,” Stoner explained. He harvested the seed but admits he wasn’t very efficient. Although the seed sold for $10 to $12 a pound then, all the profits evaporated when he had to repair the combine he had borrowed for the harvest. “But I had fun,” he chuckled. Seed production has been Stoner’s long-time dream, but he explained that his stands are not the variety recommended now. A Missouri seed man traded seed with him; he can’t add nitrogen to his variety.

Less of Stoner’s switchgrass is used for biomass research now that it is returned to the CRP, but ISU is conducting wildlife research there, enumerating pheasant populations per hectare with or without switchgrass cutting. The Biomass Project also manages some (but not the newest) of Stoner's stands. Current plans are to harvest half of his crop for biomass and allow wildlife research on the other half.

Stoner observed that most farmers in his area are taking a "wait-and-see" attitude toward switchgrass. In the beginning, most producers were growing switchgrass because it was eligible for the CRP. Potential new producers are waiting for an indication on price and profitability before making a decision. "Farmers change fast if there is an economic incentive," Stoner said. Personally, Stoner is eager for the day he can grow all switchgrass instead of row crops. He is concerned about erosive soils, admitting that soybeans are highly erosive, especially when it rains. But he is concerned that switchgrass currently is not profitable, even with its combined benefits as feedstock for cattle. And unlike row crops, there is no LDP on switchgrass, "but include carbon credits and it might become viable," Stoner adds. "We need alternatives to corn and soybeans," Stoner urged, "but how do we establish the markets? It'll take something like the switchgrass project; individual farmers can't do it alone."

**V - Daniel and Lori Irish**

The Daniel Irish family owns land in Appanoose County just north of the Chariton Valley RC&D office outside Centerville, Iowa. Employed off-farm, Irish has no intention of row-cropping on his land. "There's no need for me to add to the oversupply of corn and beans," he explained. Although Irish eventually plans to bid land into the CRP, he initially planted 4 acres of switchgrass to eliminate the need for weekly summer mowing.

Dan and his wife Lori find many things about switchgrass appealing. The primary attraction, after erosion control, is wildlife habitat. Irish planted corn in with the switchgrass to attract turkey, deer, quail, and pheasant. He is planning to add fruit trees, raspberries, blackberries, and wild plum as additional food sources. "I would like to see more reversion to prairie in southern Iowa, just for the pleasure it brings. Quality of life is the main attraction for me," Irish said. To enlist the support of others who treasure southern Iowa's wildlife, Irish noted that it will be important for biomass promoters to demonstrate that switchgrass harvests will not jeopardize habitat.

Lori is the daughter of Kenneth Tides, a prominent producer of switchgrass in southern Iowa and a pioneer cooperator in the Chariton Valley Biomass Project. Tides provides Dan and Lori with easy access to the latest information on switchgrass management, its promise as a biomass source, its other varied uses, and its economic viability. Curiously, Lori's brother, who farms land between the Tides' and the Irish's, grows no switchgrass. He has committed all his land to row crops and feeding cattle.

Irish explained that farmers need long-range security, CRP security, and acreage control in order to make a commitment to switchgrass. Several area farmers, he notes, have bid their whole farm into the CRP and then used their CRP payments to buy another farm on which they practice conventional agriculture, specifically chemical-dependent row crops. "You've got to be able to bear the risk involved in switchgrass production," Irish warned.

Irish is a strong proponent of alternative energy. He believes a number of potential switchgrass growers share his views. But, he says, using scare tactics such as the threat of global warming is unlikely to convince area farmers of the need for biomass as an alternative energy crop. More convincing, Irish believes, is to tout the potential of switchgrass to promote energy self-sufficiency in Iowa. "All our energy dollars leave the state, whether to Saudi Arabia, the Middle East, Wyoming, Colorado, Ohio, Pennsylvania, or West Virginia," he said. "Switchgrass promoters should report the amount of excise tax paid to Wyoming, for example. 'Is that why their taxes are so much lower than ours'?" Irish believes that touting switchgrass as an Iowa energy product, while demonstrating state savings in energy excise taxes, would be very convincing to potential biomass growers in southern Iowa.

And it is unlikely that other states would compete in the southern Iowa biomass market, Irish argues, because transportation costs from field to generating station would be prohibitive. But, he complains that, in this regard, farmers are their own worst enemies. "Rather than producing alternative crops or finding unique markets, they say 'Let's all do what the other guys are doing.' This leads to saturated markets and lower prices. Farmers undercut one another on price."

Conservation is a theme woven through much of Irish's discussion of switchgrass. A strong proponent of the CRP, for example, he sees it less as a farm subsidy program and more as a universal conservation program. "The CRP is the best government program, because it benefits all. It's an investment in our future. We all have a stake in soil conservation, reduced siltation in our waterways, reduced commodity market saturation." Similarly, Irish is impressed with the ability of switchgrass to sequester carbon in the soil and, as a result, is interested in the potential carbon credits that switchgrass production could generate. "I'm a greedy capitalist," he jokes, adding, "I'd also be interested in harvesting and selling switchgrass seed if it was worth it."

## SWITCHGRASS SKEPTICS AND DETRACTORS

### I - Wilson Spires

Wilson Spires has attended some of the informational meetings about switchgrass and researched its biomass potential in Farm Bureau and Farm Service Cooperative publications, but he decided not to participate. "It doesn't fit with my operation," he explained. His ground is "too good" to convert to switchgrass for the biomass project. He has the land in row crops and he needs the extra pasture for his cattle. Spires doesn't participate in the CRP either. He is opposed to the program, in part because too many "big people" are buying land and neglecting it. "They just want the government to pay for it," he said.

At 36, with children to support, Spires says he can't afford to take land out of production. He's reluctant even to put land in pasture. And he thinks other young farmers are unlikely to adopt switchgrass as a biomass crop for many of the same reasons. "Young farmers need revenue. They can't afford to be out for the two to three years it takes to establish a good stand of switchgrass," he said.

One of the big disincentives of switchgrass and other alternative crops, according to Spires, is that unlike corn and soybeans, you can't get crop insurance for them. "If you wait three years and still don't have a stand, you've lost income, interest, time, and expense, and you're still out. . . . I'm not afraid to try new things, to be a pioneer, but in my situation, I can't afford that risk—especially not on rented land." (He does grow food grade soybeans on 160 acres.) Despite his reluctance, Spires sees promise in biomass for southern Iowa. "With a change in circumstances, I could see making an investment in switchgrass," he said.

### II - Mark Steger

Mark Steger farms rented land in Wayne County. Last season he sold 6,000 units of soybeans and all but 50 were GMO varieties. Although they were introduced to the area as recently as 1996, GMO crops (Roundup Ready® soybeans and Bt corn) are not considered "alternative" crops in southern Iowa. Local extension agents estimated that adoption of genetically-modified soybeans has reached 80 percent in many southern Iowa counties, while Bt corn represented as much as 25 percent of the year 2000 corn crop.

Profits are usually touted as the main impetus for adoption of new crops or farming methods, but most farmers who switched to GMOs in southern Iowa admit they are not making more money. They believe that GMOs are more economical in other ways. Steger said he's not making more money with GMOs, but they are much less hassle. "They're easier. And there's no financial incentive to grow non-GMO in southern Iowa," Steger explained. "GMOs are not value-added, but rather production-oriented," he added. "They make chemical application easier, and because they require fewer passes through the field, they potentially reduce fuel costs." GMOs are particularly attractive to farmers whose off-farm jobs restrict the time available for crop management. Such farmers need the more flexible production schedule that Roundup Ready® beans allow, for example.

According to Steger, "Roundup Ready® beans make poor farmers into good farmers. Now weed control is a no-brainer. Previously, you had to identify each weed and its growth stage and determine the best chemical. If you missed the application window, it was a problem. . . . Roundup® provides a wider window of opportunity."

Steger also explains that the market for non-GMO beans, referred to as STS beans, is "in the wrong direction" for farmers in this area. In his county, markets are oriented toward the east. "Everything flows to the Mississippi. But STS goes west to Kansas City . . . that means increased transportation costs." In addition, producers of non-GMO crops are required to segregate their grains "with one-half to 1 percent bean tolerance, so one bean in 700 (sic) can disqualify you." In southern Iowa there has been little sign of the "GMO scare" experienced by Iowa farmers in the northwest, according to Steger. Elevators in southern Iowa continued to take GMO beans and corn without hesitation in 2000. In fact, growers of Bt corn received a premium for production in 1999. (Growers explained, however, that it will be "a wash" this year, because increased costs combined with reduced yields mean that even with a premium price, farmers won't net anything beyond their costs).

When contrasted with the increased ease of farming with GMOs, switchgrass produced as biomass introduces greater complexity, in Steger's opinion. He says that there are too many unknowns with switchgrass. "There's no historical record," he said, "so there's not enough guarantee of income. . . . We don't know what to expect for production or what they are going to pay. . . . Switchgrass may have many product options in the future, but you can't sell the program today because there's too much risk involved. Switchgrass is a long-term investment, so you must own land, lots of land; you can't be a tenant.

**III - Phillip Runyon**

Phillip Runyon is retired from farming, but his grandson raises cattle on land that Runyon once had in row crops. Several of Runyon's neighbors grow switchgrass and participate in the biomass project and he has attended a number of local informational meetings that promoted the crop. He also has read quite a bit about it in the local paper and said that word-of-mouth, especially testimonials from his neighbors, has been the most effective way to communicate the benefits of switchgrass. Still, Runyon wonders whether the project can be successful. "Where will they get enough?" he questions regarding Alliant Power's need for 200,000 tons of baled switchgrass to sustain a 5 percent coal substitution at the Alliant Power generating station. "And what with transportation costs and all, how will they ever be able to compete with Wyoming coal?"

Asked what might convince enough farmers to grow switchgrass as biomass, Runyon says it will require good information on how much profit farmers can expect, whether and how it will be economical to raise, and whether it can rival the admittedly low return of corn or beans. He also said that adding value by identifying other uses or by-products of switchgrass would help motivate farmers to produce switchgrass as a biomass crop.

**IV - Charles and Johanna Taylor**

Charles and Johanna Taylor are much more skeptical of switchgrass production for biomass, although they grow 40 acres of switchgrass in the CRP and cash rent an additional 5 acres of switchgrass to the biomass project for fertilizer testing. Their skepticism grows from past experience in "value-added" programs that never added any value to their operation. Among these programs were seed beans, seed oats, and high-oil corn that failed. Such ventures are personally stressful, especially when promised incentives evaporate by the second year, Taylor explained. "There are always too many hoops to jump through. You have to hit their windows, and if you don't there are penalties. Specialty crops typically offer price premiums, but with their lower yields, you rarely realize any real gains. And you have requirements such as changing crop rotations, crop segregation and grain isolation, and reduced capacity due to empty bins. . . . These kinds of requirements for alternative crops don't mesh well with corn and bean production. Management is possible, of course, but if the weather doesn't cooperate and you miss the production window, you lose the premium."

An additional frustration is what Taylor characterized as the arbitrary and capricious nature of program rules. "If you have what they want, then anything will pass. Otherwise they can reject you out-of-hand. We had grain they rejected due to 'bad germination,' but several months later (when production quotas weren't met), they called back and asked if we still had the grain. We got paid our premium, but it created 'bad faith,'" Taylor said. The Taylors feel that large-scale producers have a much easier time with special programs because they have greater leverage in the market.

Taylor readily admits his cynicism regarding biomass. "Switchgrass is a boondoggle. There is no way we can get as much energy off an acre of switchgrass as it is taking us to harvest it, store it, and deliver it to the generating plant. When they rented a storage shed for the switchgrass, it cost a full 50 percent of the producers' gross receipts. This entire program is artificially-supported. . . . The oil company PACs will thwart any cost differential geared toward alternatives." Taylor added, "The cost per ton must be $80—about 4 cents per pound. How different is that from coal? And how much more energy will that produce?" "Even with carbon credits, we're subsidizing something that's not economical," he concluded.

The Taylors don't expect relaxed CRP regulations to make switchgrass production easier; "with Freedom to Farm netting $40 and the CRP netting $60, the farm subsidy on regular land is getting closer to that for CRP." Government policies are not helping rural development, according to Taylor. "Cargill and ADM are getting rich on agriculture. 'Big Pork' gets a lot of support even though research has shown that small producers are more efficient. If a corporation goes into default, the debts are written off, the management stays, and the investors lose, but if small farmers default, they lose the farm. . . . Rather than allow a decent market price, the government initiates programs to 'prop things up'."

Like many of their counterparts, the Taylors are feeling the squeeze. Both Charles and Johanna work off-the-farm. "Wayne County has one-third the population today than were here in 1890," Taylor explained, "but the county has tripled the number of employees in recent years. Mandated programs that require increased property tax revenue to fund, even though the population is declining, increase the burden on farmers and landowners." "We're doing more and more," Taylor said of southern Iowa farm families.

## SUMMARY OF FINDINGS

- What motivates or discourages the adoption of energy crops, other alternative crops, new agricultural practices, and varied land uses?
- What are the incentives and disincentives to adoption of alternative farming activities, including profit, risk, uncertainty, reputation, inputs and equipment availability, financial status, financial guarantees, program subsidies, support networks, learning curves, community attitudes, and family attitudes?
- What crop and product attributes, infrastructure and markets, and financial and community support programs facilitate or impede adoption?

This research provided insights to all of these questions and identified factors favorable and unfavorable to adoption of switchgrass as an energy crop, as well as information farmers will continue to seek regarding the viability of biomass production.

### Favorable Factors

Profitability was usually the first identified as the motivation for adoption of any crop, farming practice, or alternative land use. However, it was apparent that intangibles not easily quantified or explained by economic theory are important determinants of adoption attitudes and behaviors as well. Participants in this study explained that they rarely were motivated by just one thing, but rather by a combination of factors. Most participants had difficulty identifying which motivations were primary, secondary, tertiary, and so forth. Instead they said a variety of considerations came into play at different times, and usually they weighed the relative advantages and disadvantages. During the adoption process, all adopters confronted a number of questions, either implicitly or explicitly. Affirmative answers to any of these questions reveal the kinds of considerations that motivated adoption of switchgrass or other alternative farming practices.

*Profitability/Return on Investment.* Can I make more with switchgrass than it costs me to produce it? Is it sustainable, that is, can I reasonably continue to support my family and myself on this, along with other economic activities?

*Other Economic Considerations.* Does switchgrass production fit with my current farming operation? Are management needs of switchgrass production compatible with other farming demands and/or my off-farm employment? Will it be easier or harder to farm? If it is harder to farm, are the rewards commensurate? What additional capital outlay is required for switchgrass production? Is switchgrass production compatible with my land tenure and acreage control? Can I tolerate the risk inherent in switchgrass production?

*Compatibility with Values and Beliefs.* Is this the right thing to do socially, ethically, or morally? Will this activity benefit my family and community? Does this fit with the lifestyle my family and I value? Is this activity or practice consistent with my mission in life? Is switchgrass production compatible with my concerns about health, safety, conservation, and/or the environment? Is switchgrass production good for the soil? The water? The air? Animal health? Human health? Is this activity sustainable?

*Aesthetic Considerations.* Will switchgrass production provide me with an interesting and rewarding challenge? Will it improve the quality of life for me and my family? Will it improve the quality of life for the larger community? Will I gain greater pleasure as a result? Will I be better-educated, more excited, or intellectually stimulated by this activity or practice?

*Success.* Can I achieve my goals with switchgrass production? Will there be visible proof of economic gain? Increased yield? Better erosion control? Habitat diversity? Increased wildlife? Improved health for me and my family? Improved health for my livestock? Improved soil, air, and/or water quality? Is this activity sustainable?

*Extended Benefits*. Is there a need for what I produce through this activity or practice? For me and my family? For the community? Is switchgrass production good for the family farm? Is it good for the rural economy? Will switchgrass production induce greater energy self-sufficiency for my community and/or state?

While negative responses to any of these questions could discourage adoption of switchgrass, a few negatives introduced the kind of challenge that actually served to motivate the adoption of switchgrass, other biomass crops, and other alternative farming activities and practices. Such negatives became obstacles to overcome, adversities to manage, challenges to face. But very tangible benefits motivate farmers in southern Iowa to adopt switchgrass, including:

- Need for summer forage
- Need for spring calving milieu
- Recommended grass for CRP land
- Erosion control on marginal land
- Soil conservation
- Improved water quality through reduced use of chemicals
- Wildlife habitat to increase populations of deer, turkey, pheasants, quail, and songbirds, among others
- Appreciation of native forbs and grasses, along with prairie restoration
- Eliminated need for extensive lawn mowing
- Aesthetic qualities, beauty, and quality of rural life
- Management requirements compatible with off-farm employment
- Best fit with capitalization and land tenure situation
- Environmental concerns, especially reduced dependence on pesticides and improved soil quality
- Farm safety, especially concerns about handling chemicals
- Income to supplement other economic activities
- Compatibility with land use priorities
- Desire to supply a demand
- Supplement income from off-farm employment
- Potential benefit to community by reducing dependency on out-of-state energy sources.

Research participants identified other factors favorable to the adoption of alternatives such as switchgrass, although many of these considerations fit within the broader questions and categories discussed earlier. Few of these individual factors can make or break an adoption decision, but they are important considerations for farmers. They include:

- Tax incentives—for value-added products or renewable fuels, for example
- Expanded use of CRP lands to support production—with or without payment deductions
- Ease of application—for programs or practices
- Reduced expenditures—cost savings can be as important as increased revenues
- Cash receipts—promised future income is sometimes less important that cash-in-hand today
- Secure incentives—no evaporation in subsequent years

**Unfavorable Factors**

While either contentment or inertia could explain why farmers in southern Iowa would not readily adopt farming activities and practices better suited to area soil conditions and resources, there are many things that discourage them or thwart their attempts. Most farmers confront the same sorts of questions listed previously with regard to profitability and other economic considerations, compatibility with values and beliefs, aesthetic considerations, success, and so forth. Negative responses to any of these questions could discourage farmers from making changes in their farming operations. Listed below are a number of factors that discourage adoption of switchgrass and/or other alternative farming activities and practices:

- Southern Iowa farmers expressed a general and pervasive skepticism and/or distrust of government programs, policies, rules, and regulations they say discourage or thwart adoption of farming alternatives. Among these, paradoxically, is reduced federal support of agriculture. CRP restrictions against land management, grazing, or harvesting, whether beneficial or benign to marginal soils, were often cited, as were financial penalties (withholding of CRP payments or repayment requirements) for breach of CRP rules, when such breach did not reduce the conservation benefits of the program. More recent requirements to mix expensive (indeed, cost- prohibitive) forbs and legumes with switchgrass, despite evidence that they are eventually choked out, were an example of policies hostile to biomass production.
- Small farm operators, in particular, reported that universally applied government rules and regulations penalize smaller producers because their costs of compliance are disproportionately higher. Small producers feel they are placed at a disadvantage by prevailing farm policies geared to big producers. The "aggravation factor" of federal, state, and local bureaucracy discourages adoption.
- Many farmers prefer to "test the waters" before making a larger commitment ("commit no more than 10 percent and go slowly," several advised). Alternative activities, practices, or land uses that cannot be implemented gradually or incrementally were less likely to be adopted. (This is referred to as "trialability" in diffusion literature.)
- A large number of southern Iowa farmers have jobs off-the-farm as well. Farming activities and practices that create scheduling conflicts between on-farm management and off-farm employment discourage adoption of alternatives. (This aspect of "compatibility" is discussed in diffusion literature.)
- Increased complexity of alternative farming, coupled with the lack of adequate information, guidance, role models, and/or training, discourages adoption, as does the distance southern Iowa farmers must travel to access services such as Internet marketing and web page design.

- Additional capital outlay, particularly the need for specialized equipment, crop isolation, grain segregation, increased storage capacity, and transportation costs, discourages adoption of alternatives.
- Lack of secure land tenure and/or acreage control discourages adoption, especially of a commodity with a lengthy establishment period such as switchgrass for biomass.
- The lack of secure, reliable, alternative markets, whether distant or local, foreign or domestic, discourages adoption of new and/or untried crops.
- The inability to obtain crop insurance or receive LDP on alternative crops discourages adoption, especially by risk-averse farmers, many of whom are younger or newer to farming.
- General uncertainty about the viability and profitability of alternative farming activities, practices, and land uses discourages adoption.
- Concern about the sustainability of alternative farming in terms of economics, farming "fads," soil quality, water quality, and so forth discourages adoption.
- A general "lack of fit" between current and contemplated farm operations discourages adoption. (This is another aspect of compatibility discussed in the diffusion literature.)

**Needs to Know**

Many southern Iowa farmers are taking a "wait-and-see" attitude toward switchgrass as an energy crop. They are eager for encouraging results of the economic and agronomic research of Iowa State University, Chariton Valley RC&D, Prairie Lands Bio-Products, Inc., and Alliant Power. Here are some things research participants, especially reluctant adopters, said they need to know before making decisions about switchgrass or other farming alternatives. (This "wait-and-see" attitude is indicative of the "observability" requirements of innovations discussed in diffusion literature.)

Potential adopters need to know actual or anticipated:

- Costs per acre
- Labor involved
- Equipment requirements
- Other capital requirements
- Fertilizer needs
- Land best suited for production
- Expected return on investment
- Market identification and stability
- Cost-benefit comparison between switchgrass, conventional row crops, and other alternatives.

Southern Iowa farmers indicated a need for particular services to support their farm operations and facilitate adoption of alternatives such as switchgrass as biomass. These included: market development, marketing assistance, bookkeeping training and assistance, computer and Internet training (web page development and management), and strategies for adapting to rapid change within the rural/agricultural economy.

## REFERENCES CONSULTED

Barnhart, S.K. and R. Dayton. 1986. Seeding and planting specifications for the Conservation Reserve Program in Iowa-Grassland Practices. Iowa State University Cooperative Extension Service, AG-113.

Bransby, D.I. 1999. The Value of survey information on the potential to grow switchgrass for energy in Alabama. In Biomass: A Growth Opportunity in Green Energy and Value-Added Products, Proceedings of the 4th Biomass Conference of the Americas, Oakland, California, August 29-September 2. 1747-51.

Brummer, E.C., C.L. Burras, M.D. Duffy, K.J. Moore, R. Lemus, N. Molstad, V. Nanhou, and V. Weaver. 1998. Switchgrass production in Iowa: Economic analysis, soil suitability, and varietal performance. 1998 Annual Report. Iowa State University, Ames, IA.

Cooper, J.T. Policy considerations for biomass commercialization and its impact on the Chariton Valley Biomass Project. Unpublished paper.

Cooper, J.T. and M.L. Braster. Switchgrass for energy in southern Iowa: Developing and maintaining producer involvement. Unpublished paper.

Duffy, M. and D. Smith. 2000. Estimated costs of crop production in Iowa – 2000. Iowa State University Extension publication, Fm-1712. Revised January 2000.

Erb, G. 2000. Lacking electricity, Amish still powerful. Des Moines Sunday Register. May 28, 2000. p. 10A.

Erb, G. 2000. Saving rural Iowa: Amish-owned businesses thrive. Des Moines Sunday Register. May 28, 2000. p. 1A.

Fitzgerald, A. 2000. 'New ag' takes root in Iowa: Fresh ways tried to grow and sell food. Des Moines Sunday Register, July 9, 2000. 1A, 6A, 7A.

Fitzgerald, A. 2000. Iowa farm family chooses eggs over bacon. Des Moines Sunday Register, July 9, 2000. p. 6A.

http://www.biomass.org

http://www.cvrcd.org/biomass.htm

http://www.ott.doe.gov/rbep/

http://www.repp.org

http://www.state.is.us/dnr/energy/programs/ren/switchgrass.htm

Johnson, D. Farm Bureau works with producers in using switchgrass as an alternative energy source. Iowa Farm Bureau Spokesman; Iowa Farm Bureau Federation, Des Moines, IA. Date and page numbers unknown.

Natural Resources Conservation Service. 1998. Native Prairies: Establishment and management of native prairie. Iowa Job Sheet. Des Moines, Iowa, March 1998.

Perkins, J. 2000. Power plant to test grass as energy source. Des Moines Sunday Register, February 13, 2000. p. J-2J.

Rogers, E.M. 1995. Diffusion of innovations. Fourth Edition, New York: The Free Press.

Iowa State University Extension. 1998. Switchgrass seeding recommendations for the production of biomass fuel in southern Iowa. PM 1773.

Soybean Digest. 2000. Cash for carbon: A group of Iowa no-tillers could soon earn carbon credits. Find out how this environmentally friendly deal might work. Mid-February, 2000. p. 32.

Teel, A., S. Barnhart, and G. Miller. 1997. Management guide for the production of switchgrass for biomass fuel in southern Iowa. Iowa State University Extension, Pm 1710.

Van, L.J. 2000. Southern Iowa has much to offer. Editorial, Des Moines Sunday Register, December 3, 2000. p. 15A.

Waterloo-Cedar Falls Courier. 2001. Iowa power plant burns switchgrass for energy. Monday, January 8, 2001. p. 6A.

**PRELIMINARY BUDGETS FOR SWITCHGRASS ESTABLISHMENT**
**PART A: ESTABLISHMENT ON CROPLAND**

**Table 1:** Estimated budgets for switchgrass established with corn on cropland previously under corn production (frost seeding, $75/acre land charge)

| **Preharvest Machinery Operations (Switchgrass)** | | | | **Cost Per Acre*** |
|---|---|---|---|---|
| Tandem Disc (x 2) | | | | $15.80 |
| Harrow | | | | 4.50 |
| Broadcast seed | | | | 5.90 |
| Spreading fertilizers | | | | 3.10 |
| Spraying herbicide | | | | 4.70 |
| **Total machinery cost** | | | | **$34.00** |
| **Operating Expenses** | **Unit** | **Price/Unit** | **Quantity** | **Cost Per Acre** |
| Seed (Cave-in-Rock) | lb of PLS | $3.50 | 6.00 | $21.00 |
| Fertilizer (0-30-40)** | (0-30-40)** | | | 12.70 |
| Lime (including its application) | ton | 12.00 | 3.00 | 36.00 |
| Herbicide | | | | |
| - atrazine 90 DF | lb | 2.50 | 2.78 | 6.94 |
| **Total operating cost** | **$/acre** | | | **$76.64** |
| **Land Charge** (cash rent equivalent) | $/acre | | | $75.00 |
| **Total Switchgrass Establishment Costs** | | | | $185.64 |
| **Prorated Establishment Costs** (11 yrs. @ 8 percent) | | | | $26.01 |

| **Preharvest Machinery Operations (Corn)** | | | | **Cost Per Acre*** |
|---|---|---|---|---|
| No till Planter | | | | $12.00 |
| Spraying insecticide | | | | 5.30 |
| **Total machinery cost (Corn)** | | | | **$17.30** |
| **Operating Expenses** | **Unit** | **Price/Unit** | **Quantity** | **Cost Per Acre** |
| Seed (Corn) | 1000 k | $1.00 | 30.00 | $30.00 |
| Fertilizer (Nitrogen) | lb of N | 0.21 | 100.00 | 21.00 |
| Insecticide | | | | |
| - Lorsban 15G | lb | 2.50 | 9.00 | 22.50 |
| **Total operating cost** | **$/acre** | | | **$73.50** |
| **Interest on operating expenses** (9 percent) | **$/acre** | | | **$3.31** |

| Harvesting and Storing Expenses (Corn) | Cost/bushel | Cost Per Acre |
|---|---|---|
| Corn combining | $0.267 | $23.85 |
| Drying (continuous flow dryer) | 0.081 | 7.24 |
| Handling grain | 0.044 | 3.93 |
| Hauling grain, on-farm, wagon per bu | 0.052 | 4.65 |
| **Total harvesting cost** | **$0.44** | **$39.67** |
| **Total Corn Production Costs Per Acre** | | **$133.78** |
| **Cost per bushel** | | **$1.50** |

| Corn Revenue | Unit | Price/Unit | Quantity | Value Per Acre |
|---|---|---|---|---|
| Value of corn ($/bu) | bu | 1.85 | 95.00*** | 175.75 |
| **Net corn revenue ($/acre)** | | | | **$41.97** |

*** Source: 2002 Iowa Farm Custom Rate Survey, FM-1698, March 2002**
**** Phosphate Price = $.25/lb; Potash Price = $.13/lb**
***** Source: Hintz R.L., Harmoney K. R., Moore K.J., George J.R. and Brummer E.C., 1998: Establishment of Switchgrass and Big bluestem in Corn with Atrazine in Agronomy journal, Vol.90, No.5: 591-596.**

**Table 2:** Estimated budgets for switchgrass established with corn on cropland previously under soybean production (frost seeding, $75/acre land charge)

| **Preharvest Machinery Operations (Switchgrass)** | | | | **Cost Per Acre*** |
|---|---|---|---|---|
| Tandem Disc (x 2) | | | | $15.80 |
| Harrow | | | | 4.50 |
| Broadcast seed | | | | 5.90 |
| Spreading fertilizers | | | | 3.10 |
| Spraying herbicide | | | | 4.70 |
| **Total machinery cost** | | | | **$34.00** |
| **Operating Expenses** | **Unit** | **Price/Unit** | **Quantity** | **Cost Per Acre** |
| Seed (Cave-in-Rock) | lb of PLS | $3.50 | 6.00 | $21.00 |
| Fertilizer (0-30-40)** | (0-30-40)** | | | 12.70 |
| Lime (including its application) | ton | 12.00 | 3.00 | 36.00 |
| Herbicide | | | | |
| - atrazine 90 DF | lb | 2.50 | 2.78 | 6.94 |
| **Total operating cost** | **$/acre** | | | **$76.64** |
| **Land Charge** (cash rent equivalent) | $/acre | | | $75.00 |
| **Total Switchgrass Establishment Costs** | | | | $185.64 |
| **Prorated Establishment Costs** (11 yrs. @ 8 percent) | | | | $26.01 |

| **Preharvest Machinery Operations (Corn)** | | | | **Cost Per Acre*** |
|---|---|---|---|---|
| No till Planter | | | | $12.00 |
| **Total machinery cost (Corn)** | | | | **$12.00** |
| **Operating Expenses** | **Unit** | **Price/Unit** | **Quantity** | **Cost Per Acre** |
| Seed (Corn) | 1000 k | $1.00 | 30.00 | $30.00 |
| Fertilizer (Nitrogen) | lb of N | 0.21 | 60.00 | 12.60 |
| **Total operating cost** | **$/acre** | | | **$42.60** |
| **Interest on operating expenses** (9 percent) | **$/acre** | | | **$1.92** |
| **Harvesting and Storing Expenses** | | **Cost/bushel** | | **Cost Per Acre** |
| Corn combining | | $0.267 | | $23.85 |
| Drying (continuous flow dryer) | | 0.081 | | 7.24 |
| Handling grain | | 0.044 | | 3.93 |
| Hauling grain, on-farm, wagon per bu | | 0.052 | | 4.65 |
| **Total harvesting cost** | | **$0.44** | | **$39.67** |

| | | | | |
|---|---|---|---|---|
| **Total Corn Production Costs Per Acre** | | | | **$96.19** |
| **Cost per bushel** | | | | **$1.08** |
| **Corn Revenue** | **Unit** | **Price/Unit** | **Quantity** | **Value Per Acre** |
| Value of corn ($/bu) | bu | 1.85 | 95.00*** | 175.75 |
| **Net corn revenue ($/acre)** | | | | **$79.56** |

*** Source: 2002 Iowa Farm Custom Rate Survey, FM-1698, March 2002**
**** Phosphate Price = $.25/lb; Potash Price = $.13/lb**
***** Source: Hintz R.L., Harmoney K. R., Moore K.J., George J.R. and Brummer E.C., 1998: Establishment of Switchgrass and Big bluestem in Corn with Atrazine in Agronomy journal, Vol.90, No.5: 591-596.**

**Table 3:** Estimated budgets for switchgrass established with corn on grassland (frost seeding, $50/acre land charge)

| **Preharvest Machinery Operations (Switchgrass)** | | | | **Cost Per Acre*** |
|---|---|---|---|---|
| Mow | | | | $7.35 |
| Broadcast seed | | | | 5.90 |
| Spreading fertilizers | | | | 3.10 |
| Spraying herbicide | | | | 4.70 |
| Spraying roundup | | | | 4.70 |
| **Total machinery cost** | | | | **$25.75** |
| **Operating Expenses** | **Unit** | **Price/Unit** | **Quantity** | **Cost Per Acre** |
| Seed (Cave-in-Rock) | lb of PLS | $3.50 | 6.00 | $21.00 |
| Fertilizer (0-30-40)** | (0-30-40)** | | | 12.70 |
| Lime (including its application) | ton | 12.00 | 3.00 | 36.00 |
| Herbicide | | | | |
| - atrazine 90 DF | lb | 2.50 | 2.78 | 6.94 |
| - roundup | qt. | 9.77 | 2.00 | 19.55 |
| **Total operating cost** | **$/acre** | | | **$96.19** |
| **Land Charge** (cash rent equivalent) | $/acre | | | $50.00 |
| **Total Switchgrass Establishment Costs** | | | | $171.94 |
| **Prorated Establishment Costs** (11 yrs. @ 8 percent) | | | | $24.09 |

| **Preharvest Machinery Operations (Corn)** | | | | **Cost Per Acre*** |
|---|---|---|---|---|
| No till Planter | | | | $12.00 |
| **Total machinery cost (Corn)** | | | | **$12.00** |
| **Operating Expenses** | **Unit** | **Price/Unit** | **Quantity** | **Cost Per Acre** |
| Seed (Corn) | 1000 k | $1.00 | 30.00 | $30.00 |
| Fertilizer (Nitrogen) | lb of N | 0.21 | 100.00 | 21.00 |
| **Total operating cost** | **$/acre** | | | **$51.00** |
| **Interest on operating expenses** (9 percent) | **$/acre** | | | **$2.30** |
| **Harvesting and Storing Expenses** | | **Cost/bushel** | | **Cost Per Acre** |
| Corn combining | | $0.267 | | $23.85 |
| Drying (continuous flow dryer) | | 0.081 | | 7.24 |
| Handling grain | | 0.044 | | 3.93 |
| Hauling grain, on-farm, wagon per bu | | 0.052 | | 4.65 |
| **Total harvesting cost** | | **$0.44** | | **$39.67** |

| | | | | |
|---|---|---|---|---|
| **Total Corn Production Costs Per Acre** | | | | **$104.97** |
| **Cost per bushel** | | | | **$1.17** |
| **Corn Revenue** | **Unit** | **Price/Unit** | **Quantity** | **Value Per Acre** |
| Value of corn ($/bu) | bu | 1.85 | 95.00*** | 175.75 |
| **Net corn revenue ($/acre)** | | | | **$70.78** |

*** Source: 2002 Iowa Farm Custom Rate Survey, FM-1698, March 2002**
**** Phosphate Price = $.25/lb; Potash Price = $.13/lb**
***** Source: Hintz R.L., Harmoney K. R., Moore K.J., George J.R. and Brummer E.C., 1998: Establishment of Switchgrass and Big bluestem in Corn with Atrazine in Agronomy journal, Vol.90, No.5: 591-596.**

**PRELIMINARY BUDGETS FOR SWITCHGRASS ESTABLISHMENT**
**PART A: ESTABLISHMENT WITH PERENNIAL LEGUMES (ALFALFA, BIRDSFOOT TREFOIL, AND RED CLOVER)**

**Table 1:** Estimated production budgets for switchgrass (years 1 to 5, switchgrass conversion from croplands or grasslands)

**Cropland and Grassland**

| **Preharvest Machinery Operations** | **Cost Per Acre*** |
|---|---|
| Spreading liquid nitrogen | $4.60 |
| Applying P&K | 3.10 |
| Spraying chemicals | 4.70 |
| **Total machinery cost** | **$12.40** |

**Cropland and Grassland** (~ 4tons/acre, i.e. 8 bales/acre, each bale weighing 950lb)

| **Operating Expenses** | **Unit** | **Price/Unit** | **Quantity** | **Cost Per Acre** |
|---|---|---|---|---|
| Nitrogen | lb. | $0.21 | 100.00 | $21.00 |
| P | lb. | 0.25 | 7.76 | 1.94 |
| K | lb. | 0.13 | 91.20 | 11.86 |
| Herbicide | | | | |
| - atrazine | qt. | 2.85 | 1.50 | 4.28 |
| - 2,4 D | pt. | 1.60 | 1.50 | 2.40 |
| **Total operating cost** | **$/acre** | | | **$41.47** |
| **Interest on operating expenses** (9 percent) | **$/acre** | | | **$1.87** |

| **Harvesting and Storing Expenses** | **Cost/Ton** | **Cost Per Acre** |
|---|---|---|
| Mowing/conditioning | $2.20 | $8.80 |
| Raking | 1.06 | 4.25 |
| Baling (large square bales) | 15.47 | 61.89 |
| Staging and loading | 6.51 | 26.04 |
| **Total harvesting cost** | **$25.25** | **$100.98** |

| | Cropland | Grassland |
|---|---|---|
| **Land Charge** (cash rent equivalent) | $75.00 | $50.00 |
| **Prorated Establishment Costs** (10 yrs. @ 8 percent) | $28.20 | $27.21 |
| **Total Production Costs Per Acre** | $259.93 | $233.93 |
| **Total Costs Per Ton** | $64.98 | $58.48 |

*** Source: 2002 Iowa Farm Custom Rate Survey, FM-1698, March 2002**

**Table 2.a:** Estimated biomass production budgets for the sixth year with alfalfa establishment (croplands or grasslands)

**Cropland and Grassland**

| **Preharvest Machinery Operations (Alfalfa)** | **Cost Per Acre*** |
|---|---|
| No till drill | $11.65 |
| **Total machinery cost** | **$11.65** |

| **Operating Expenses (Alfalfa)** | **Unit** | **Price/Unit** | **Quantity** | **Cost Per Acre** |
|---|---|---|---|---|
| Seed (alfalfa) | lb of PLS | $2.40 | 12.00 | $30.00 |
| **Total operating cost** | **$/acre** | | | **$30.00** |
| **Interest on operating expenses** (9 percent)**$/acre** | | | | **$1.35** |
| **Total alfalfa Establishment Costs $/acre** | | | | **$43.00** |
| **Prorated alfalfa Establishment Costs $/acre** | | | | **$10.77** |

**Cropland and Grassland** (~ 4tons/acre, i.e. 8 bales/acre, each bale weighing 950lb)

| **Preharvest Machinery Operations** | **Cost Per Acre*** |
|---|---|
| Applying P&K | $3.10 |
| **Total machinery cost** | **$3.10** |

| **Operating Expenses** | **Unit** | **Price/Unit** | **Quantity** | **Cost Per Acre** |
|---|---|---|---|---|
| P | lb. | 0.25 | 27.88 | $6.97 |
| K | lb. | 0.13 | 125.60 | 11.33 |
| **Total operating cost** | **$/acre** | | | **$23.30** |
| **Interest on operating expenses** (9 percent)**$/acre** | | | | **$1.05** |

| **Harvesting and Storing Expenses** | **Cost/Ton** | **Cost Per Acre** |
|---|---|---|
| Mowing/conditioning | $2.20 | $8.80 |
| Raking | 1.06 | 4.25 |
| Baling (large square bales) | 15.47 | 61.89 |
| Staging and loading | 6.51 | 26.04 |
| **Total harvesting cost** | **$25.25** | **$100.98** |

| | Cropland | Grassland |
|---|---|---|
| **Land Charge** (cash rent equivalent) | $75.00 | $50.00 |
| **Prorated Switchgrass Establishment Costs** | $28.20 | $27.21 |
| **Prorated Alfalfa Establishment Costs** | $10.77 | $10.77 |
| **Total Production Costs Per Acre** | $242.41 | $216.41 |
| **Total Costs Per Ton** | $60.60 | $54.10 |

______________

*** Source: 2002 Iowa Farm Custom Rate Survey, FM-1698, March 2002**

**Table 2.b:** Estimated biomass production budgets for the sixth year with birdsfoot trefoil establishment (on croplands or grasslands)

**Cropland and Grassland**

| **Preharvest Machinery Operations (Birdsfoot Trefoil)** | **Cost Per Acre*** |
|---|---|
| No till drill | $11.65 |
| **Total machinery cost** | **$11.65** |

| **Operating Expenses (Birdsfoot Trefoil)** | **Unit** | **Price/Unit** | **Quantity** | **Cost Per Acre** |
|---|---|---|---|---|
| Seed (Birdsfoot Trefoil) | lb of PLS | $1.50 | 5.00 | $7.50 |
| **Total operating cost** | **$/acre** | | | **$7.50** |
| **Interest on operating expenses** (9 percent) | **$/acre** | | | **$0.34** |
| **Total Birdsfoot Trefoil Establishment Costs** | **$/acre** | | | **$19.49** |
| **Prorated Birdsfoot Trefoil Establishment Costs** | **$/acre** | | | **$4.88** |

**Cropland and Grassland** (~ 4tons/acre, i.e. 8 bales/acre, each bale weighing 950lb)

| **Preharvest Machinery Operations** | **Cost Per Acre*** |
|---|---|
| Applying P&K | $3.10 |
| **Total machinery cost** | **$3.10** |

| **Operating Expenses** | **Unit** | **Price/Unit** | **Quantity** | **Cost Per Acre** |
|---|---|---|---|---|
| P | lb. | 0.25 | 18.88 | $4.72 |
| K | lb. | 0.13 | 85.60 | 11.13 |
| **Total operating cost** | **$/acre** | | | **$15.85** |
| **Interest on operating expenses** (9 percent) | **$/acre** | | | **$0.71** |

| **Harvesting and Storing Expenses** | **Cost/Ton** | **Cost Per Acre** |
|---|---|---|
| Mowing/conditioning | $2.20 | $8.80 |
| Raking | 1.06 | 4.25 |
| Baling (large square bales) | 15.47 | 61.89 |
| Staging and loading | 6.51 | 26.04 |
| **Total harvesting cost** | **$25.25** | **$100.98** |

| | Cropland | Grassland |
|---|---|---|
| **Land Charge** (cash rent equivalent) | $75.00 | $50.00 |
| **Prorated Switchgrass Establishment Costs** | $28.20 | $27.21 |
| **Prorated Birdsfoot trefoil Establishment Costs** | $4.88 | $4.88 |
| **Total Production Costs Per Acre** | $228.73 | $202.73 |
| **Total Costs Per Ton** | $57.18 | $50.68 |

*** Source: 2002 Iowa Farm Custom Rate Survey, FM-1698, March 2002**

**Table 2.c:** Estimated production budgets for the sixth year with red clover (on croplands or grasslands)

**Cropland and Grassland**

| **Preharvest Machinery Operations (Red Clover)** | **Cost Per Acre*** |
|---|---|
| No till drill | $11.65 |
| **Total machinery cost** | **$11.65** |

| **Operating Expenses (Red Clover)** | **Unit** | **Price/Unit** | **Quantity** | **Cost Per Acre** |
|---|---|---|---|---|
| Seed (Red Clover) | lb of PLS | $1.00 | 8.00 | $8.00 |
| **Total operating cost** | **$/acre** | | | **$8.00** |
| **Interest on operating expenses** (9 percent) | **$/acre** | | | **$0.36** |
| **Total Red Clover Establishment Costs** | **$/acre** | | | **$20.01** |
| **Prorated Red Clover Establishment Costs** | **$/acre** | | | **$6.04** |

**Cropland and Grassland** (~ 4tons/acre, i.e. 8 bales/acre, each bale weighing 950lb)

| **Preharvest Machinery Operations** | **Cost Per Acre*** |
|---|---|
| Applying P&K | $3.10 |
| **Total machinery cost** | **$3.10** |

| **Operating Expenses** | **Unit** | **Price/Unit** | **Quantity** | **Cost Per Acre** |
|---|---|---|---|---|
| P | lb. | 0.25 | 23.88 | $5.97 |
| K | lb. | 0.13 | 111.60 | 14.51 |
| **Total operating cost** | **$/acre** | | | **$20.48** |
| **Interest on operating expenses** (9 percent) | **$/acre** | | | **$0.92** |

| **Harvesting and Storing Expenses** | **Cost/Ton** | **Cost Per Acre** |
|---|---|---|
| Mowing/conditioning | $2.20 | $8.80 |
| Raking | 1.06 | 4.25 |
| Baling (large square bales) | 15.47 | 61.89 |
| Staging and loading | 6.51 | 26.04 |
| **Total harvesting cost** | **$25.25** | **$100.98** |

| | Cropland | Grassland |
|---|---|---|
| **Land Charge** (cash rent equivalent) | $75.00 | $50.00 |
| **Prorated Switchgrass Establishment Costs** | $28.20 | $27.21 |
| **Prorated Red Clover Establishment Costs** | $6.04 | $6.04 |
| **Total Production Costs Per Acre** | $234.73 | $208.73 |
| **Total Costs Per Ton** | $58.68 | $52.18 |

______________

*** Source: 2002 Iowa Farm Custom Rate Survey, FM-1698, March 2002**

**Table 3.a:** Estimated production budgets for the mix of switchgrass and alfalfa (years 7 to10, on croplands or grasslands)

**Cropland and Grassland** (~ 4tons/acre, i.e. 8 bales/acre, each bale weighing 950lb)

| **Preharvest Machinery Operations** | **Cost Per Acre*** |
|---|---|
| Applying P&K | $3.10 |
| **Total machinery cost** | **$3.10** |

| **Operating Expenses** | **Unit** | **Price/Unit** | **Quantity** | **Cost Per Acre** |
|---|---|---|---|---|
| P | lb. | 0.25 | 27.88 | $6.97 |
| K | lb. | 0.13 | 125.60 | 11.33 |
| **Total operating cost** | **$/acre** | | | **$23.30** |
| **Interest on operating expenses** (9 percent) | **$/acre** | | | **$1.05** |

| **Harvesting and Storing Expenses** | **Cost/Ton** | **Cost Per Acre** |
|---|---|---|
| **First cut (50%)** | | |
| Mowing/conditioning | $4.40 | $8.80 |
| Raking | 2.13 | 4.25 |
| Baling (large square bales) | 15.47 | 30.95 |
| Staging and loading | 6.51 | 13.02 |
| **Total first harvesting cost** | **$28.51** | **$57.02** |
| **Second cut (50%)** | | |
| Mowing/conditioning | $4.40 | $8.80 |
| Raking | 2.13 | 4.25 |
| Baling (large square bales) | 15.47 | 30.95 |
| Staging and loading | 6.51 | 13.02 |
| **Total second harvesting cost** | **$28.51** | **$57.02** |

| | Cropland | Grassland |
|---|---|---|
| **Land Charge** (cash rent equivalent) | $75.00 | $50.00 |
| **Prorated Switchgrass Establishment Costs** | $28.20 | $27.21 |
| **Prorated Alfalfa Establishment Costs** | $10.77 | $10.77 |
| **Total Production Costs Per Acre** | **$255.45** | **$229.46** |
| **Total Costs Per Ton** | **$63.86** | **$57.37** |
| **For forage price of $58/ton, price per ton of biomass required to breakeven** | **$69.73** | **$56.73** |
| **For forage price of $75/ton, price per ton of biomass required to breakeven** | **$52.73** | **$39.73** |
| **For forage price of $85/ton, price per ton of biomass required to breakeven** | **$42.73** | **$29.73** |

*** Source: 2002 Iowa Farm Custom Rate Survey, FM-1698, March 2002**

**Table 3.b:** Estimated production budgets for the mix of switchgrass and birdsfoot trefoil (years 7 to 10, on Croplands or Grasslands)

**Cropland and Grassland** (~ 4tons/acre, i.e. 8 bales/acre, each bale weighing 950lb)

| Preharvest Machinery Operations | Cost Per Acre* |
|---|---|
| Applying P&K | $3.10 |
| **Total machinery cost** | **$3.10** |

| Operating Expenses | Unit | Price/Unit | Quantity | Cost Per Acre |
|---|---|---|---|---|
| P | lb. | 0.25 | 18.88 | $4.72 |
| K | lb. | 0.13 | 85.60 | 11.13 |
| **Total operating cost** | **$/acre** | | | **$15.85** |
| **Interest on operating expenses** (9 percent) | **$/acre** | | | **$0.71** |

| Harvesting and Storing Expenses | Cost/Ton | Cost Per Acre |
|---|---|---|
| **First cut (50%)** | | |
| Mowing/conditioning | $4.40 | $8.80 |
| Raking | 2.13 | 4.25 |
| Baling (large square bales) | 15.47 | 30.95 |
| Staging and loading | 6.51 | 13.02 |
| **Total first harvesting cost** | **$28.51** | **$57.02** |
| **Second cut (50%)** | | |
| Mowing/conditioning | $4.40 | $8.80 |
| Raking | 2.13 | 4.25 |
| Baling (large square bales) | 15.47 | 30.95 |
| Staging and loading | 6.51 | 13.02 |
| **Total second harvesting cost** | **$28.51** | **$57.02** |

| | Cropland | Grassland |
|---|---|---|
| **Land Charge** (cash rent equivalent) | $75.00 | $50.00 |
| **Prorated Switchgrass Establishment Costs** | $28.20 | $27.21 |
| **Prorated Birdsfoot trefoil Establishment Costs** | $4.88 | $4.88 |
| **Total Production Costs Per Acre** | **$241.78** | **$215.79** |
| **Total Costs Per Ton** | **$60.44** | **$53.95** |
| **For forage price of $58/ton, price per ton of biomass required to breakeven** | **$62.89** | **$49.89** |
| **For forage price of $75/ton, price per ton of biomass required to breakeven** | **$45.89** | **$32.89** |
| **For forage price of $85/ton, price per ton of biomass required to breakeven** | **$35.89** | **$22.89** |

*** Source: 2002 Iowa Farm Custom Rate Survey, FM-1698, March 2002**

**Table 3.c:** Estimated production budgets for the mix of switchgrass and red clover (years 7 to 10, on Croplands or Grasslands)

**Cropland and Grassland** (~ 4tons/acre, i.e. 8 bales/acre, each bale weighing 950lb)

| **Preharvest Machinery Operations** | **Cost Per Acre*** |
|---|---|
| Applying P&K | $3.10 |
| **Total machinery cost** | **$3.10** |

| **Operating Expenses** | **Unit** | **Price/Unit** | **Quantity** | **Cost Per Acre** |
|---|---|---|---|---|
| P | lb. | 0.25 | 23.88 | $5.97 |
| K | lb. | 0.13 | 111.60 | 14.51 |
| **Total operating cost** | **$/acre** | | | **$20.48** |
| **Interest on operating expenses** (9 percent) | **$/acre** | | | **$0.92** |

| **Harvesting and Storing Expenses** | **Cost/Ton** | **Cost Per Acre** |
|---|---|---|
| **First cut (50%)** | | |
| Mowing/conditioning | $4.40 | $8.80 |
| Raking | 2.13 | 4.25 |
| Baling (large square bales) | 15.47 | 30.95 |
| Staging and loading | 6.51 | 13.02 |
| **Total first harvesting cost** | **$28.51** | **$57.02** |
| **Second cut (50%)** | | |
| Mowing/conditioning | $4.40 | $8.80 |
| Raking | 2.13 | 4.25 |
| Baling (large square bales) | 15.47 | 30.95 |
| Staging and loading | 6.51 | 13.02 |
| **Total second harvesting cost** | **$28.51** | **$57.02** |

| | Cropland | Grassland |
|---|---|---|
| **Land Charge** (cash rent equivalent) | $75.00 | $50.00 |
| **Prorated Switchgrass Establishment Costs** | $28.20 | $27.21 |
| **Prorated Red Clover Establishment Costs** | $6.04 | $6.04 |
| **Total Production Costs Per Acre** | $247.77 | $221.78 |
| **Total Costs Per Ton** | $61.94 | $55.45 |
| **For forage price of $58/ton, price per ton of biomass required to breakeven** | **$61.94** | **$52.89** |
| **For forage price of $75/ton, price per ton of biomass required to breakeven** | **$48.89** | **$35.89** |
| **For forage price of $85/ton, price per ton of biomass required to breakeven** | **$38.89** | **$25.89** |

*** Source:  2002 Iowa Farm Custom Rate Survey, FM-1698, March 2002**