Switchgrass Production in Iowa: Economic Analysis, Soil Suitability, and Varietal Performance

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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)

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.

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. Further analysis of quality is needed, especially because all data evaluated to date have been collected in central Iowa on soils quite different from those in southern Iowa.

All the field experiments discussed are continuing for at least another year. 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.

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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 for each section follow immediately after the text for that section. Figures are attached at the end of the document, after the appendices.

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

I. ECONOMICS OF SWITCHGRASS PRODUCTION

The preparation of budgets for the costs of producing switchgrass has been completed. This work has been prepared as an Iowa State University Extension Publication. The publication is at the printers.

The publication has the following outline:

What is switchgrass?
Description of the scenarios
General assumptions
- Assumptions on input costs
  - Mchinery
  - Seed
  - Herbicides
  - Fertilizers and lime
- Harvesting data

Summary of costs
Summary

The publication is entitled; Costs of Producing Switchgrass for Biomass in Southern Iowa, Iowa State University Extension Publication PM 1866. There were 500 hard copies of the publication order. In addition, the publication will be available electronically on the extension home page.

In addition to the extension publication, this work will be presented at the Fifth Annual Biomass Conference of the Americas.

Since the completion of the budgets reported in the extension publication we have learned more about the production of switchgrass. To continue our work with switchgrass production costs we incorporated some of the changes into new budget estimations. The primary changes that we examined were the impacts of increasing the seeding rates and changing the probability of needing to reseed.

The extension budget estimations were based on using 6 pounds of pure live seed for the seeding rate. In this new series of estimations we increased the seeding rate to 10 pounds pure live seed per acre. The heavier seeding rate was more reflective of current production practices and it is consistent with what has been learned in the field.

The extension budget also assumed a 50% reseeding rate for spring seeded switchgrass and a 25% reseeding rate under a frost seeding system. The heavier seeding rates and experience have shown the probability of reseeding varies. Therefore, we also re-estimated the budgets using a 25, 15, 10 and 0% probability of reseeding.

The new estimations were only for a frost-seeding regime. The previous work showed that in all cases the frost seeding costs of production were lower than the spring seeding. In addition, frost seeding regime was also selected because it has become the establishment technique of choice by producers in southern Iowa. Therefore, we chose to concentrate further analysis on only the frost-seeding system.

Changing the seeding rate from 6 to 10 pounds made very little difference in the final costs per ton. The estimated costs increased by 1% or less, depending on the yield. Summary Tables 1 and 2 show the costs per ton for frost-seeding at 10 pounds per acre with alternative yield levels, alternative probabilities for reseeding, and alternative land charges. Table 1 costs at $75 per acre and a 25% reseeding probability can be compared to Appendix 3 in the extension publication to obtain a comparison of the cost differences for 6 and 10 pound seeding rates.

Summary Table 1 shows that changing the probability of having to reseed causes little change in the costs of production. At the lowest yield, 1.5 tons per acre on cropland, the cost per ton drops from $133.63 with a 25% probability of reseeding, to $130.34 per ton with no reseeding. This is a change of only 2%. The impact lessens the higher the yield.

Appendix I contains all the tables used to create Summary Tables 1and 2. The appendix tables are for the establishment costs, the reseeding costs, and the various yield and reseeding probability scenarios.

The analysis based on heavier seeding rates and alternative assumptions regarding the probability of reseeding do not change the basic conclusions from the initial work. Yield per acre has the greatest impact on the costs per ton. The second greatest impact is attributed to the land charge per acre. With the highest yield, 6 tons per acre, the costs per ton vary from the low $50 range with a $75 per acre land charge to less than $45 per ton with a $25 per acre land charge.

Examining alternative production techniques, reseeding rates, and other production aspects will not appreciably impact switchgrass costs of production. The most important research must be on ways to increase yields. This work has shown that the switchgrass at a 6 ton yield level can be cost competitive for biomass production.

We have completed work on estimating the costs of production for reed canarygrass. These initial budgets will change as we learn more about production techniques and how to manage reed canarygrass.

The most significant reed canary production practices are the following:

- Land preparation is usually done through no till drill following crops and killed sod.
- The seed variety commonly used is Palaton, and seeding rate is 10 to 12 pounds pure live seed per acre.
- Spring or late summer seeding, but late summer (August) seeding preferred.
- No nitrogen application in the establishment year and two nitrogen applications during production years.
- Two harvests per year, in large bales, weighing 1,100 pounds on average.

Summary Table 3 presents the estimated costs for establishing reed canarygrass following cropland and grassland. We assumed a $50 per acre charge for grassland and a $75 per acre land charge for cropland. We assumed that the stand would last for 11 years. Further, we assumed there is no reseeding necessary. Notice that there is no appreciable difference in the establishment cost estimates. This is due to the assumptions used, especially regarding the herbicide choices. These costs would change depending upon the production system chosen by the producer. The costs per ton range from a high of $79.62 per ton for the 3 ton yield on cropland ($75 per acre land charge) to a low of $45.17 per ton for the 6 ton yield on grassland ($50 per acre land charge).

Appendix II contains the tables used to create Summary Table 3. The appendix tables are for the establishment costs and the estimated production costs for 3, 4, and 6 ton yield assumptions.

The costs of producing reed canarygrass follow a similar pattern to switchgrass in that yield is the most important variable in determining the costs per ton. Land charges are the second most important variable. However, as yield increases the effect of the land charge decreases.

Summary Table 1. Summary of frost seeding on cropland, four levels of reseeding probability and two levels of land charge (seeding rate 10lbs/acre).

Scenario	Type of costs	Yield (ton/acre)	25% reseeding probability		15% reseeding probability		10% reseeding probability		0% reseeding probability	
			$25	$50	$25	$50	$25	$50	$25	$50
Frost seeding on cropland	Yearly production cost	1.5	143.80	168.80	143.80	168.80	143.80	168.80	143.80	168.80
		3.0	183.90	208.90	183.90	208.90	183.90	208.90	183.90	208.90
		4.0	210.64	235.64	210.64	235.64	210.64	235.64	210.64	235.64
		6.0	264.11	289.11	264.11	289.11	264.11	289.11	264.11	289.11
	Total cost per acre	1.5	171.01	200.44	169.41	198.47	168.61	197.48	167.01	195.51
		3.0	211.11	240.55	209.51	238.57	208.71	237.59	207.11	235.62
		4.0	237.85	267.28	236.25	265.31	235.45	264.32	233.85	262.35
		6.0	291.32	320.76	289.72	318.78	288.92	317.80	287.32	315.83
	Total cost per ton	1.5	114.01	133.63	112.94	132.31	112.41	131.66	111.34	130.34
		3.0	70.37	80.18	69.84	79.52	69.57	79.20	69.04	78.54
		4.0	59.46	66.82	59.06	66.33	58.86	66.08	58.46	65.59
		6.0	48.55	53.46	48.29	53.13	48.15	52.97	47.89	52.64

Summary Table 2. Summary of frost seeding on grassland, four levels of reseeding probability and two levels of land charg (seeding rate 10lbs/acre).

Scenario	Type of costs	Yield (ton/acre)	25% reseeding probability		15% reseeding probability		10% reseeding probability		0% reseedin probability	
			$25	$50	$25	$50	$25	$50	$25	$50
Frost seeding on grassland	Yearly production cost	1.5	118.80	143.80	118.80	143.80	118.80	143.80	118.80	143.8
		3.0	158.90	183.90	158.90	183.90	158.90	183.90	158.90	183.9
		4.0	185.64	210.64	185.64	210.64	185.64	210.64	185.64	210.6
		6.0	239.11	264.11	239.11	264.11	239.11	264.11	239.11	264.1
	Total cost per acre	1.5	144.10	173.53	142.87	171.93	142.26	171.13	141.03	169.5
		3.0	184.20	213.63	182.98	212.04	182.36	211.24	181.14	209.6
		4.0	210.94	240.37	209.71	238.77	209.10	237.97	207.87	236.3
		6.0	264.41	293.85	263.19	292.25	262.57	291.45	261.35	289.8
	Total cost per ton	1.5	96.07	115.69	95.25	114.62	94.84	114.09	94.02	113.0
		3.0	61.40	71.21	60.99	70.68	60.79	70.41	60.38	69.8
		4.0	52.73	60.09	52.43	59.69	52.27	59.49	51.97	59.0
		6.0	44.07	48.97	43.86	48.71	43.76	48.57	43.56	48.3

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

Scenarios	Yield (ton /acre)	Prorated establishment cost ($)	Production cost per acre ($)	Production cost per ton ($)
Seeding on cropland	3.0	26.43	238.86	79.62
	4.0	26.43	258.28	64.57
	6.0	26.43	297.12	49.52
Seeding on grassland (1)(Burn down of grass and No till grass seed drill)	3.0	26.20	213.63	71.21
	4.0	26.20	233.05	58.26
	6.0	26.20	271.89	45.31
Seeding on grassland (2)(Plow and disk and grass seed drill)	3.0	25.33	212.76	70.92
	4.0	25.33	232.18	58.04
	6.0	25.33	271.02	45.17

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

Introduction

The Chariton Valley in southern Iowa is well suited for agronomic crop production in many respects. The average frost-free season and precipitation are nearly 170 days and 80 cm inches, respectively. A well-developed farm culture is in place. It consists of about 2500 farms, numerous agribusinesses and knowledgeable support organizations. However, production is limited in parts of the region by soils that restrict the types of crops that can be profitably grown. This limitation arises from the prevalence of soil consociations throughout the central Southern Iowa Drift Plain (Figures 1 and 2; see separate document "ISU 2000 Final Report Figures") that are highly erosive, shallow to root restrictive zones and/or excessively wet. Furthermore, dramatic differences among soils are common within a given field. Consequently, development of a sustainable, profitable agronomic production scheme has been very difficult, especially over the last 40 years as the farmers have expanded machinery and field size.

The introduction of switchgrass (Panicum virgatum, L.) in CRP and as a biofuel has been widely supported because it was thought to thrive in an environmentally benign way across the soil-landscapes of the Chariton Valley while at the same time not competing with traditional farm crops. The goal of this study was to document the reality of current switchgrass production practices vis-à-vis switchgrass yields and environmental benefits (or costs). The specific objectives follow.

The areas within the Chariton Valley chosen for intensive plant and soil sampling are shown in Figures 3-5. The predominant soil series within these fields is described in Table II.1.

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, and 2000, 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. To an extent, the deep roots of switchgrass probably allowed the plants to avoid serious moisture stress, but a more consistent rainfall pattern during the growing season may have improved nitrogen use and growth. 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 (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. We will continue to monitor yield in these plots in 2001.

Nitrogen fertilization increased biomass both when averaged across the three years (Table II.2). In 2000, the most striking response came with the addition of 56 kg ha^{-1}, with no difference between 56 and 112 kg ha^{-1}, or between 112 and 224 kg ha^{-1}. The 224 kg ha^{-1} level was higher than 56, however. Across the three years, improvements in yield were realized by sequential increases of N from 0 to 56 kg ha^{-1} and from 56 to 112 kg ha^{-1}. Increasing nitrogen application above 112 kg ha^{-1} did not result in further yield increases averaged across the three years or in 2000. 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).

Plant height appears to be related to yield from 1998 to 2000 (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 data were collected at harvest time. Heights did not differ in a meaningful manner between locations or among nitrogen treatments in 2000 (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 the other years. This may be related to the yield improvement seen in 2000. 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, both averaged across years (Table II.2) and in 2000 (Table AII.1). 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. 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).

		Field number* and estimated MU area (%)			
Map unit	Series and great group classification	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, and 2000 in two southern Iowa locations and at four nitrogen fertilization rates.

	Yield	Height	NDF	ADF	ADL	Hemicellulose	Cellulose	N	Ash
	Mg/ha	cm	----------	----------	----------	g/kg ------	----------	----------	----------
Year									
1998	2.88	118	776.0	454.9	75.9	321.1	379.0	3.47	43.4
1999	3.90	145	710.7	414.1	70.7	296.6	343.4	5.48	56.1
2000	6.04	190	778.2	458.5	63.0	319.6	395.5	5.86	49.8
LSD (5%)	0.28	3	9.3	11.7	3.6	8.9	8.7	0.38	2.8
Location									

Lucas	4.43	151	745.5	432.1	66.5	313.4	365.7	4.57	51.6
Wayne	4.12	151	764.4	452.9	73.3	311.5	379.6	5.30	47.9
LSD (5%)	0.23	ns	ns	9.5	2.9	ns	7.1	0.31	2.3
N Level									
0	3.62	145	751.4	432.1	66.6	319.3	365.5	5.01	52.9
50	4.15	149	757.9	444.0	69.3	313.9	374.7	4.59	48.8
100	4.60	155	749.1	434.7	69.1	314.4	365.6	4.90	50.1
200	4.73	155	761.5	459.3	74.5	302.2	384.8	5.24	47.2
LSD (5%)	0.32	4	10.8	13.5	4.1	10.2	10.1	0.44	3.2
Grand mean	4.27	150.98	754.98	442.52	69.89	312.46	372.63	4.93	49.75

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

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 mean
Element	Unit	1999	2000	LSD	Lucas	Wayne	LSD	0	112	224	LSD	
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

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 mean
Element	Unit	1999	2000	LSD	Lucas	Wayne	LSD	0	112	224	LSD	
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†	%	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
												continued
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
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. HILLSLOPE PEDOLOGY AND ITS IMPLICATIONS TO SWITCHGRASS PRODUCTION IN THE LAKE RATHBUN WATERSHED, IOWA

Demand for biofuel-grade switchgrass (Panicum virgatum, L.) in the Lake Rathbun Watershed (Figure II.1) has created a need for improved understanding of switchgrass growth, yield and quality. And while that understanding must largely come from traditional agronomic research, ongoing crop production studies indicate a need for improved knowledge of hillslope pedology. Hillslopes were identified as the landscape feature most needing study because much of the switchgrass in the watershed is grown on them. This is not to suggest that switchgrass is agronomically better adapted to hillslopes relative to other parts of the landscape, rather its reflects the historical tie between switchgrass plantings and soil conservation programs designed for highly erosive and/or marginal lands (Vogel, 1996; Sanderson et al., 1996; Sellers, 1999).

The Lake Rathbun watershed is a 140,000 ha rural region in south central Iowa noted for its rolling landscapes, mixed grain and livestock farming, and generally erosive soils (Rathbun Land and Water Alliance, 2001; EPA, 2001; Prior, 1991; Boeckman, 1999; Oschwald et al., 1977).

Countywide corn suitability ratings (CSR), which are indices of the inherent agronomic productivity of soils, are among the lowest in Iowa (Miller and Fenton, 1998). Over 60% of the farms in the watershed are limited resource farms (Rathbun Land and Water Alliance, 2001). Over one-half of the watershed consists of highly erodible land (Sellers, 1999). These soil and landscape limitations served as an incentive for farmers to put their marginal fields into switchgrass when the USDA's conservation reserve program (CRP) began in 1985 (Sellers, 1999; Molstad, 2000). It is currently estimated switchgrass is grown on about 15% or 50,000 hectares of the watershed (Sellers, 1999).

A complex Quaternary history created the landscape and soils of the Lake Rathbun Watershed. Numerous Pre-Illinoinan glacial advances deposited thick strata of Alburnett and Wolf Creek drift between 1.7 and 0.5 million years before present (BP) (Prior, 1991). This was followed by the Yarmouth-Sangamon interglacial stage, which lasted nearly 500,000 years. The Yarmouth-Sangamon is recognized as a period of extensive landscape development and drainage network incision as well as paleosol formation (Prior, 1991; Ruhe, 1969). Yarmouth-Sangamon paleosols are especially extensive, deep, and agronomically problematic in south-central Iowa, which includes all of the Lake Rathbun Watershed (Oschwald et al, 1977). Yarmouth-Sangamon weathering ended with the deposition of a two to three meter thick strata of Peorian loess, which mantled the entire landscape of the Lake Rathbun Watershed during Late Wisconsinan time (31,000 to 12,500 years BP) (Ruhe, 1969). Ruhe (1969) documents the Missouri River valley as the primary source of this loess and that the loess of the Lake Rathbun Watershed is typically about 40% clay. The thin clayey character of the Peorian loess that mantles the even more clayey Yarmouth-Sangamon paleosols of the Lake Rathbun Watershed creates many serious agronomic management problems. The Holocene (12,500 to 150 years BP) resulted in continued landscape evolution with one important feature being the partial to complete erosion of Peorian loess off of hillslopes (Ruhe, 1969; Prior, 1991). This natural erosion resulted in many footslopes aggrading with the addition of loess-derived hillslope sediment as well as exhumation of Yarmouth-Sangamon paleosols and/or Pre-Illinoisan till.

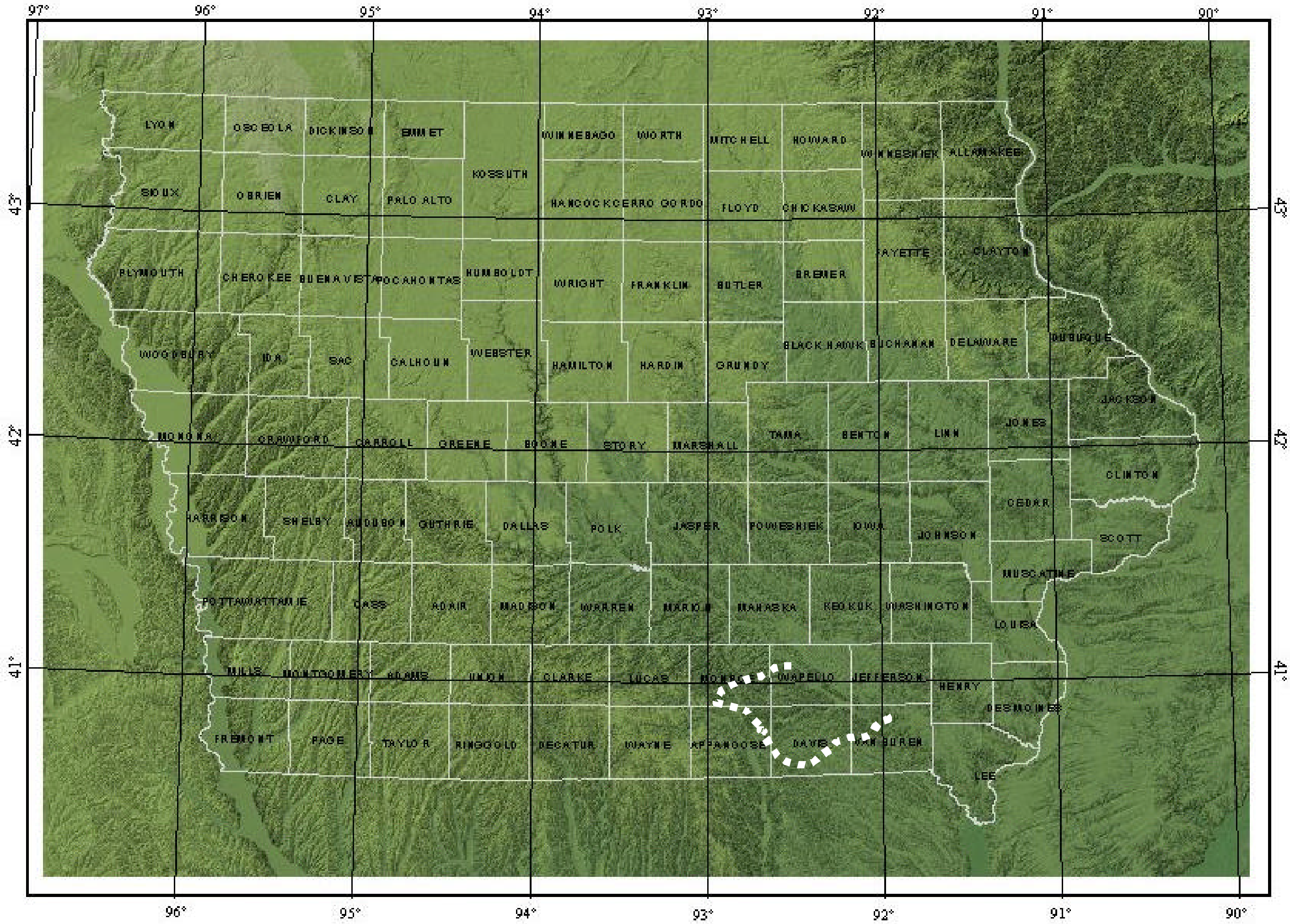


Figure II.1. Relief map of Iowa showing location of the Lake Rathbun Watershed (encircled with dashed line).

Agriculture during the past 150 years is the most recent widespread modifier of the region's soils and landscapes. In a study on nearly identical soils and landscapes to the area of interest about 100 km west of the Lake Rathbun Watershed, Daniel and Ruhe (1965) reported average rates of historical erosion between 1840 and 1965 as 0.2 cm yr^{-1}, which equals 20 m tons ha^{-1} yr^{-1}. In a related study, Ruhe et al. (1967) documented sedimentation rates between about 1850 and 1970 on footslopes and toeslopes to be up to 0.5 cm yr^{-1}, which equals about 65 mtons ha^{-1} yr^{-1}. For unknown reasons, geologic erosion and sedimentation appear to have been especially pronounced in south central Iowa, which includes the Lake Rathbun Watershed. Prior (1991) notes the Lake Rathbun Watershed as one that is more dissected, has more deeply incised streams, and much smaller upland plains (summits) than much of the rest of the Southern Iowa Drift Plain.

Objectives

The goal of this project is to better document and explain soils across hillslopes in the Lake Rathbun Watershed with the final context being switchgrass production potential. The underlying hypothesis is that soil spatiality (and ultimately switchgrass productivity) is a function of landscape position and that the stratigraphic-based model given in Oschwald et al (1977) and the modern soil surveys of the counties will explain soil distribution (see Lockridge, 1977; Prill, 1960; Oelmann, 1984; Lockridge, 1971; Boeckman, 1999). These models are based upon Ruhe (1969), Ruhe and Walker (1968) and Ruhe et al. (1967), and Daniels and Hammer (1992). A secondary hypothesis is that epipedon properties will exhibit morphological evidence of the impact of the past century's farming.

The objectives of this project are to:

1. Quantify selected pedon properties associated with shoulders, backslopes, and footslopes of 10-year old switchgrass fields from typical hillslope reaches in the Lake Rathbun Watershed,

2. Compare soils found on summits in switchgrass fields with ones in row crop fields in order to compare pedon properties found under these two cropping schemes, and,

3. Examine preliminary statistical relationships between switchgrass yields and soils in order to provide a basis for further yield-soil-landscape research.

Materials and Methods

This manuscript is based upon two sets of data. The first set is based upon detailed fieldwork from four small switchgrass fields and two adjoining row crop fields. It is referred to as the "intensive project." The second or "extensive project" is based upon yields collected along 45 about 1 ha strips as well as yields collected from eight entire fields. In both cases, yields were collected from georeferenced sites, for which soil survey soils' data was examined. Both data sets are necessary in order to adequately investigate all objectives.

Intensive Project

Field selection and sampling. Criteria examined when choosing fields for study were date of switchgrass establishment, a good quality switchgrass stand present, variation in soil types between the fields, and the presence of most if not all of the upland landscape positions described by Ruhe (1969). All of the fields selected contained flat or slightly convex summit/shoulders, linear backslopes, and less sloping lower backslope and footslope areas. The presence of this landscape continuum in all of the fields was critical. Additionally, all of the fields had been in continuous switchgrass production since 1986. This criterion was included to limit another potential source of error caused by comparing soils under stands of differing ages.

Four fields were used in this study, with each field consisting of two to four plots (Table II.5). Table II.5 lists the latitude and longitude, topographic relief and soil series for each plot.

Field sampling and pedon descriptions. Field sampling entailed collecting pedons from hillslope transects. Most transects begin on the summit and extend across the shoulder and backslope and ending on the toeslope. In addition six pedons were collected from summits in row crop fields. Pedon sampling was completed using a hydraulic probe to a depth of 1.2 m. Each pedon consisted of two soil cores, which were collected 0.5 meters apart.

A total of 47 pedons were collected; 41 were taken from the four study fields while six were taken from crop fields adjacent to the study fields. These pedons from crop fields crop field were sampled in two transects. One crop field core transect was sampled in a field to the south of Field 1 and the other crop field core transect was sampled in a field to the east of Field 3.

Pedons were described using the procedures and nomenclature established by the Soil Survey Staff (1993). A sample from each horizon described within each core was removed from the core, dried, ground, sieved, and stored in the same manner as the surface and hand core samples.

Laboratory analysis. Soil samples from horizons of a subset of the pedons were sent to the Iowa State University Soil Testing Laboratory for chemical analysis. Analyses included pH, plant available phosphorus, plant available potassium, plant available zinc, percent organic matter, and total nitrate-nitrogen. Additionally, the total carbon and nitrogen contents of pedon samples were determined by dry combustion using a LECO CHN-600 analyzer.

Bulk density, stable aggregate content, and particle size distribution were determined for selected soil samples using standard methods described in Soil Survey Staff (1996).

Yield. The four study fields were harvested to determine total switchgrass yield in fall 1998, 1999, 2000 and 2001 although only the 1998 data is used herein. Readers interested in greater year-by-year analysis of switchgrass yields are directed to Lemus (2000). Harvesting methods were consistent with standard farm practices of the Lake Rathbun Watershed.

Statistical analysis. Data were analyzed using the Statistical Analysis System (SAS) and the Microsoft Excel statistics package. More sophisticated analyses were completed using SAS, more routine analyses using Excel.

Table 11.5. General characteristics of the four switchgrass fields studied in the Lake Rathbun Watershed. Each field was subdivided into two to four plots, with each plot having one pedon sampling transect extending from its shoulder to its footslope.

Field	Plot number	Area	Maximum elevation	Minimum elevation	Relief	Map unit number, series name, and area[2]
		ha	m	m	m	
Field 1—NE ¼, sec. 21, T71N, R22W, Lucas County, IA						
	1	0.60	326.4	323.1	3.3	364B Grundy (0.20 ha), 23C2 Arispe (0.28 ha), 222C2 Clarinda (0.12 ha)
	2	0.65	326.4	324.3	2.1	364B Grundy (0.13 ha), 23C2 Arispe (0.30 ha), 222C2 Clarinda (0.22 ha)
Field 2—SW ¼, sec. 22, T71N, R22W, Lucas County, IA						
	1	0.31	324.6	320.0	4.6	23C2 Arispe (0.23 ha), 222C2 Clarinda (0.08 ha)
	2	0.44	324.6	318.5	6.1	23C2 Arispe (0.20 ha), 222C2 Clarinda (0.24 ha)
	3	0.38	326.1	322.4	3.7	23C2 Arispe (0.13 ha), 222C2 Clarinda (0.25 ha)
	4	0.31	326.4	320.0	6.4	364B Grundy (0.05 ha), 23C2 Arispe (0.26 ha)
Field 3—SE ¼, sec. 27, T70N, R21W, Wayne County, IA						
	1	0.18	318.5	307.8	10.7	SfC2 Seymour (0.03 ha), CmC3 Clarinda (0.10 ha), ShD2 Shelby (0.05)
	2	0.18	317.0	307.8	9.2	SfC2 Seymour (0.02 ha), CmC3 Clarinda (0.11 ha), ShD2 Shelby (0.05)
	3	0.18	315.5	307.8	7.7	SfC2 Seymour (0.03 ha), CmC3 Clarinda (0.12 ha), ShD2 Shelby (0.03)
Field 4—NE ¼, sec. 27, T70N, R21W, Wayne County, IA						
	1	0.23	318.5	313.9	4.6	SfC2 Seymour (0.12 ha), CmC3 Clarinda (0.10 ha), LaD2 Lamoni (0.01)
	2	0.23	315.5	309.4	6.1	SeB Seymour (0.05 ha), SfC2 Seymour (0.15 ha), CmC3 Clarinda (0.03 ha)

[1]All elevation information from current USGS topographic maps (1:24,000 scale).
[2]All map unit information from USDA-NRCS soil surveys (1:15:840 scale).

Extensive Project

Switchgrass yield was measured along 45 strips and 12 additional fields from throughout the Lake Rathbun Watershed following the 1999 growing season. Strips were each about 1 ha in area and located in a larger field. The eight fields ranged from about 5 to 25 ha in area, which is typical for the Lake Rathbun Watershed. Each strip and field was managed identically. This included applying 160 kg ha^{-1} N fertilizer prior to the growing season and use of recommended rates of atrazine and 2,4-D for weed control.

Average yields for the strips and 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 and selected attributes of each map unit. Switchgrass yields-soil properties relationships were then examined using regression and stepwise analysis of variance.

Results and Discussion

Intensive Project

Objective A. Quantify selected pedon properties associated with shoulders, backslopes, and footslopes of 10-year old switchgrass fields from typical hillslope reaches in the Lake Rathbun Watershed.

The properties of pedons collected from summits, backslopes, and footslopes in fields of long-term switchgrass are surprisingly alike (Table II.6). Few pedologically significantly differences are apparent although several statistically significant ones exist (Table II.7). Summit pedons tend to be somewhat poorly drained while backslopes and footslope pedons are generally more poorly drained (Tables II.6 and II.7). Epipedons and A-horizons average about 25 to 35 cm thick with the summit epipedons generally being the thickest. The organic carbon content at each landscape position is around 2% with the footslope pedons having less carbon content than those on backslopes and summits. The average common rooting depth is 50 to 70 cm with deeper rooting being more common in summit pedons. Granular structure extends to the greatest depth (45 cm) in summit pedons. Coarse fragment content becomes 3% on average at 73 cm in footslope pedons, which is more shallow by 20 cm than in backslope and summit pedons. Mean stable aggregate content of the surface horizon ranges from 55 to 67%, with the lower mean being found in pedons from summits. Pedons from all three landscape positions are consistently silty clay loam, silty clay, or clay textured throughout their sola (data not presented, see Molstad, 2000). Clay content of the surface horizon and the B-horizon are around 27 to 29 and 44 to 46%, respectively. The surface horizon C:N ratio is 10. Solum pH ranges from around 5 to between 6.5 and 7.0 (Table II.6).

Table II.6. Selected pedon properties from summits, backslopes, and footslopes under long-term switchgrass in four fields in the Lake Rathbun Watershed. All data except for pH range reported as means ±standard deviations, number of pedons having data.

Pedon property⇓	Summit	Backslope	Footslope
Slope (%)	3.0±1.2, 11	5.6±1.6, 18	3.8±1.3, 12
Drainage class[1]	3.0±0.5, 11	3.5±0.5, 18	3.3±0.9, 12
A-horizon thickness (cm)	33.0±6.1, 11	23.2±10.1, 18	27.2±14.5, 12
Epipedon thickness (cm)	33.0±13.6, 11	24.9±13.5, 18	29.9±21.5, 12
Org. carbon surface horizon (%)	2.4±0.2, 6	2.3±0.4, 9	1.9±0.5, 7

Depth to 0.6% org. carbon (cm)	46.0±11.2, 6	38.4±21.0, 9	45.1±25.4, 7
Maximum depth of common roots (cm)	70.0±26.4, 11	52.3±16.2, 18	57.7±24.3, 12
Thickness of granular structure (cm)	44.6±7.6, 11	25.2±20.4, 18	29.5±25.3, 12
Depth to common concretions (cm)	56.3±23.1, 11	43.1±27.3, 18	65.2±37.9, 12
Depth to ≥3% coarse fragments (cm)	95.5±25.2, 11	91.0±25.5, 18	72.5±46.4, 12
Clay content of surface horizon (%)	26.8±2.4, 6	28.6±3.6, 9	29.4±4.3, 7
Maximum clay content of B horizon (%)	45.4±3.8, 6	44.7±5.0, 9	43.9±7.4, 7
Stable aggregate content of surface horizon (%)	54.5±16.5, 5	66.1±17.0, 8	67.1±16.2, 7
C:N of surface horizon	10.5±1.4, 2	11.4±0.8, 3	9.0±2.7, 3
pH range of solum	5.3-7.0	5.2-6.8	5.3-7.1

[1]Drainage class is treated as a continuous variable where 1 indicates well drained and 4 indicates poorly drained.

Table II.7. Probability of pedon properties being different across landscape positions in switchgrass fields as well as across summits in switchgrass fields versus row cropped fields. Probability determined using a two-tailed t-test assuming unequal variance. All values reported are as P(T≥≤t).

Populations compared ⇒	Summit-backslope	Summit-footslope	Backslope-footslope	Summit-Summit
Pedon property ⇓	-------Within switchgrass field comparisons -----			Switchgrass—row crop comparison
Slope (%)	<0.001	0.16	0.002	0.02
Drainage class[1]	<0.001	0.12	0.36	<0.001
A-horizon thickness	<0.001	0.08	0.25	0.23
Epipedon thickness	0.03	0.56	0.32	0.21
Org. carbon surface horizon	0.82	0.01	0.01	0.47
Depth to 0.6% org. carbon	0.22	0.90	0.43	0.01
Maximum depth of common roots	0.01	0.11	0.35	<0.001
Thickness of granular structure	<0.001	0.01	0.49	<0.001
Depth to common concretions	0.06	0.34	0.02	0.56
Depth to ≥3% coarse fragments	0.51	0.04	0.09	0.11
Clay content of surface horizon	0.12	0.08	0.63	0.01
Maximum clay content of B horizon	0.67	0.52	0.74	0.08
Stable aggregate content of surface horizon	0.10	0.09	0.88	0.01
C:N of surface horizon	0.41	0.33	0.11	0.88

[1]Drainage class is treated as a continuous variable where 1 indicates well drained and 4 indicates poorly drained.

The pedologically similar character of pedons in all three landscape positions was not expected. The NRCS soil maps for these fields were viewed to indicate there should be more difference than was found from one landscape position to the next although it was recognized significant overlap in the acceptable range in properties for the mapped series is possible. Another reason it was expected that a more clear difference would emerge in properties from the three landscape positions is the soil-landscape models of Ruhe (1969) and Ruhe and Walker (1968) indicate there should be a systematic distribution of a fairly wide range of properties across these hillslopes.

The lack of distinct pedological properties associated with the three landscape position are similar to the findings of Young and Hammer (2000)), except they found greater differences between the pedons on summits and backslopes than this study did. Young and Hammer (2000) studied a single 40 ha loess-mantled upland landscape in Missouri that is 200 km south of this site project. They analyzed 257 pedons, with about 100 being from summits and 100 being from backslopes

(Young et al., 1999). The remainder was from shoulders, which were included in the summit grouping in this study. Within their backslope pedons, they further considered upper, mid, and lower positions. It is thought the greater difference Young and Hammer (2000) found between summit and backslope pedons is the product of three differences between their study and this one. First, their larger sampling size resulted in more precise comparisons. Second, they completed a more intense statistical analysis (see Young et al., 1999), which was well beyond the goal and scope of this work. Third, they worked with a single field whereas this study used four fields. Their study appears to have included only one soil consociation having one inclusion whereas this one included six consociations, most of which have inclusions. Consequently, it is to be expected that more variability within pedons from a given landscape position would be found in this study relative to Young and Hammer (2000).

Young and Hammer (2000) suggest the differences between summit-shoulder pedons and backslope pedons is due to differences in pedogenesis related to landscape dependent differences in hydrology, intensity of leaching and parent material stratigraphy as well as perhaps differences in vegetation histories. It is certain these pedogenic processes have also been important in forming the soil-landscapes studied herein although it is speculated that hillslope sedimentation is a major process in the Lake Rathbun Watershed. Hillslope sediments are thin deposits quasi-colluvial deposits on valley slopes that important in explaining soil variability (Daniels and Hammer, 1992). Evidence for hillslope sediments in this study included buried A horizons in some toeslope pedons as well as the 90 cm depth to coarse fragments on backslopes (Table II.6).

Natural local variability of soils and their parent materials as well as non-normal distribution of soil properties within a landscape position is a second and related explanation for the lack of systematic variability across these landscape positions. Conclusively demonstrating this phenomenon is well beyond the intent and scope of this work although the data permit three comparisons to be made that illustrate this. First, calculating coefficients of variability (CV) from the 39 means and standard deviations in Table 2 results in the average CV equaling 34%. Obviously, this indicates there was a wide range in measured values for some of these properties, even within a single landscape position. For example, epipedon thickness for pedons from backslopes in the switchgrass fields ranged from12 to 69 cm, with the mean being 25 cm. A second and better means of illustrating local variability—as well as explaining the cause of the high CV within this data—is the comparison of data from the two 1.2 m deep soil cores collected per pedon (i.e., these two cores were collected approximately 50 cm from one another). These comparisons show within pedon variability is often as large as the mean difference between landscape positions (Table II.8, Figure II.2). This within pedon variability has important implications for future soil sampling strategies aimed at assessing changes in properties like soil carbon content, soil quality, etc.

A third illustration of soil variability across these landscapes comes from examination of pedon classification, which is means to integrate soil properties into one coherent descriptor (Table II.9). Five of the 11 summit pedons are Aquertic Argiudolls, which is the subgroup classification of the Seymour, Grundy, and Arispe series. These three series are the ones identified by the NRCS soil survey maps as being present on the summits. Four pedons are Vertic Argiaquolls, which is a common inclusion in Grundy map units (Boeckman, 1999). Thus, nine out of 11 pedons studied are what was expected for the summit position. The other two pedons are classified as

Vertic Hapludalfs (Table II.9). This classification is likely to a result of historical soil erosion having thinned the original mollic epipedon into an ochric epipedon.

A striking feature of the 30 backslope and footslope pedons is their variability even at the order level (Table II.9). Twenty-five of the 59 core descriptions are Mollisols while the remaining 31 are Alfisols (26) and Inceptisols (5). The presence of all three soil orders was expected because of the prominence of eroded Mollisol map units on the NRCS soil maps for these sites [Table II.5, also see Boeckman (1999) and Lockridge (1971)]. That is, erosion of Mollisols commonly results in Alfisols or Inceptisols. The presence of both udic- and aquic-suborder classification groups was expected in pedons from backslopes and footslopes based upon the soil series identified on the NRCS soil maps.

What was not expected at any of these landscape positions was the magnitude of within taxonomic variability found within pedons (Table II.9). Yet comparison of Core A with Core B on a pedon-by-pedon basis shows noteworthy variability. This variability was least for the summit, where 7 of 11 pedons had identical classification for the A and B cores (Table II.9). The backslope pedons only had 12 of 17 pedons having identical classification for A and B cores. Footslope pedons had 6 of 12 pedons having identical classification. Thus, over 60% of all pedons exhibit morphological difference of enough magnitude to result in subgroup classification differences. In most cases where A and B cores did not have identical classification the morphological differences are the result of accelerated soil erosion and sedimentation. It is clear from the NRCS soil survey soil maps that much of this erosion occurred prior to the establishment of the switchgrass currently being grown in these fields. However, the commonality of active gullying in switchgrass fields throughout the Lake Rathbun Watershed indicates erosion remains an active process (Molstad, 2000).

Objective B. Compare soils found on summits in switchgrass fields with ones in row crop fields in order to assess the impact of different farming practices on pedon properties.

Summit pedons from switchgrass fields and ones from row cropped fields exhibit a number of similarities and dissimilarities (Tables II.6, II.7, and II.10). Pedons in row cropped fields were statistically significantly more poorly drained than in switchgrass fields although the pedological significance of this is minimal. Five of the six pedons from row cropped fields were poorly drained while one was somewhat poorly drained. This compares with nine out of 11 summit pedons in switchgrass fields being poorly or somewhat poorly drained (data not reported). In other words, summit pedons in switchgrass fields are better drained than in row cropped fields albeit this difference is slight. Most farmers or engineers who were to use these soils for crop production and/or construction would not detect this difference. Clearly, the more poorly drained nature of summits in fields is not preventing row crop production.

Table II.8. Comparison of morphological properties along 11 paired hillslope transects in switchgrass fields and two transects from within row crop fields, C R Watershed, Iowa. All values reported as means ±standard deviations n= number of profiles used.

Transect number ⇓	Thickness of "mollic" (≤3/3) colors (cm)		Drainage class (1 = wd, 4 = pd)		Maximum depth granular structure (cm)		Minimum depth common concretions (cm)		Maximum depth common roots (cm)	
Transect letter⇒	A	B	A	B	A	B	A	B	A	B
1 (n = 5)	38.8±23.5	48.0±36.7	3.8±0.4	4.0	18.4±25.3	18.6±25.6	54.0±33.1	54.8±28.9	41.6±17.4	53.4±16.3
2 (n = 5)	22.8±8.0	23.6±7.5	3.6±0.5	3.8±0.4	23.2±22.3	30.4±9.0	44.8±41.3	47.6±38.7	56.0±18.7	52.2±27.7
3 (n*)	39.0±12.5	34.8±9.8	3.3±0.6	3.3±0.5	48.7±2.9	54.6±16.2	82.7±29.1	80.0±23.0	66.7±17.9	83.8±29.6
4 (n = 4)	29.5±6.5	31.0±7.2	3.3±0.5	3.5±0.6	39.0±12.9	41.0±13.9	54.5±29.0	60.0±32.1	57.3±22.7	57.3±23.4
5 (n = 4)	19.8±16.9	36.5±19.8	3.5±0.6	3.8±0.5	10.5±21.0	18.0±25.9	71.5±52.8	52.5±51.3	47.8±15.9	55.8±8.6
6 (n = 4)	36.3±18.9	29.5±17.2	3.3±0.5	3.0	39.5±16.8	44.5±17.1	50.3±23.4	60.8±31.0	54.3±10.6	65.3±12.6
7 (n = 3)	17.3±3.0	21.0±11.4	3.7±0.6	3.3±0.6	20.7±8.0	19.3±16.8	28.3±34.7	41.3±12.6	41.7±7.8	36.3±12.4
8 (n = 3)	20.7±7.3	21.7±11.9	2.3±1.5	2.7±0.6	26.0±25.5	25.3±24.1	60.7±39.4	44.0±17.7	64.0±9.2	55.0±7.6
9 (n = 3)	21.0±7.8	25.7±11.4	3.3±0.6	2.7±0.6	27.3±24.4	35.0±8.0	50.3±9.3	35.3±12.4	46.7±6.5	59.7±8.4
10 (n= 3)	22.7±19.7	26.7±4.2	3.0	2.7±0.6	45.3±7.1	40.0±7.2	45.3±7.1	42±18.3	56.0±25.2	62.3±7.5
11 (n= 3)	21.3±7.6	22.7±9.3	3.0±1.0	3.0±1.0	42.0±40.1	47.3±12.9	51.7±48.3	46.7±30.9	60.0±17.8	52.0±25.5
12 crop (n = 3)	42.3±22.3	44.0±18.3	4.0	4.0	12.0±20.8	7.3±12.7	41.3±16.3	47.3±12.0	5.7±9.8	15.3±13.8
13 crop (n = 3)	39.3±18.2	34.7±15.1	3.7±0.6	3.7±0.6	33.0±13.1	33.7±11.3	59.7±14.5	61.7±12.7	28.7±15.9	28.7±15.5

*Transect 3—A transect only had three profiles described; B transect had four profiles.

Table II.9. Classification of A and B cores which collectively comprise a single pedon, Lake Rathbun Watershed, IA.

Summit position—Switchgrass fields		Summit positions—Crop fields	
A core	B core	A core	B core
Vertic Argiaquoll	Vertic Argiaquoll	Vertic Argiaquoll	Vertic Argiaquoll
Aquertic Argiudoll	Vertic Endoaqualf	Vertic Endoaquept	Vertic Endoaquept
Aquertic Argiudoll	Aquertic Argiudoll	Vertic Argiaquoll	Vertic Argiaquoll
Aquertic Argiudoll	Vertic Argiaquoll	Vertic Endoaqualf	Vertic Endoaquept
Vertic Argiaquoll	Vertic Argiaquoll	Vertic Argiaquoll	Vertic Argiaquoll
Vertic Argiaquoll	Vertic Argiaquoll	Aquertic Argiudoll	Aquertic Argiudoll
Vertic Hapludalf	Aquertic Argiudoll		
Aquertic Argiduoll	Aquertic Argiudoll		
Aquertic Hapludoll	Aquertic Hapludoll		
Vertic Argiaquoll	Vertic Argiaquoll		
Vertic Hapludalf	Vertic Hapludalf		

Backslope position—Switchgrass fields		Footlslope position—Switchgrass fields	
A core	B core	A core	B core
Vertic Argiaquoll	Vertic Argiaquoll	Vertic Endoaqualf	Vertic Endoaquept
Vertic Argiaquoll	Vertic Endoaquoll	Vertic Argiaquoll	Vertic Argiaquoll
Vertic Endoaqualf	Vertic Endoaqualf	Vertic Endoaqualf	Vertic Argiaquoll
Vertic Endoaqualf	Vertic Endoaqualf	Vertic Argiaquoll	Aquertic Argiudoll
Chromic Vertic Endoaqualf	Chromic Vertic Endoaqualf	Aquertic Hapludalf	Vertic Endaquept
--not described--	Aquertic Argiudoll	Vertic Argiaquoll	Vertic Argiaquoll
Aquertic Argiudoll	Vertic Argiaquoll	Vertic Endoaquoll	Vertic Endoaquoll
Aquertic Argiudoll	Vertic Endaquept	Vertic Endoaquept	Vertic Hapludalf
Vertic Argiaquoll	Vertic Argiaquoll	Vertic Eutrudept	Vertic Eutrudept
Vertic Hapludalf	Aquertic Argiudoll	Vertic Endoaqualf	Vertic Hapludalf
Vertic Endaquept	Vertic Endoaqualf	Vertic Endoaqualf	Vertic Eutrudept
Vertic Endoaqualf	Vertic Endoaqualf	Aquertic Hapludoll	Aquertic Hapludoll

Vertic Endoaqualf	Vertic Endoaqualf
Chromic Vertic Endoaqualf	Chromic Vertic Endoaqualf
Vertic Endoaqualf	Vertic Endoaqualf
Vertic Hapludalf	Aquertic Hapludoll
Vertic Argiaquoll	Vertic Argiaquoll
Vertic Endoaqualf	Vertic Endoaqualf

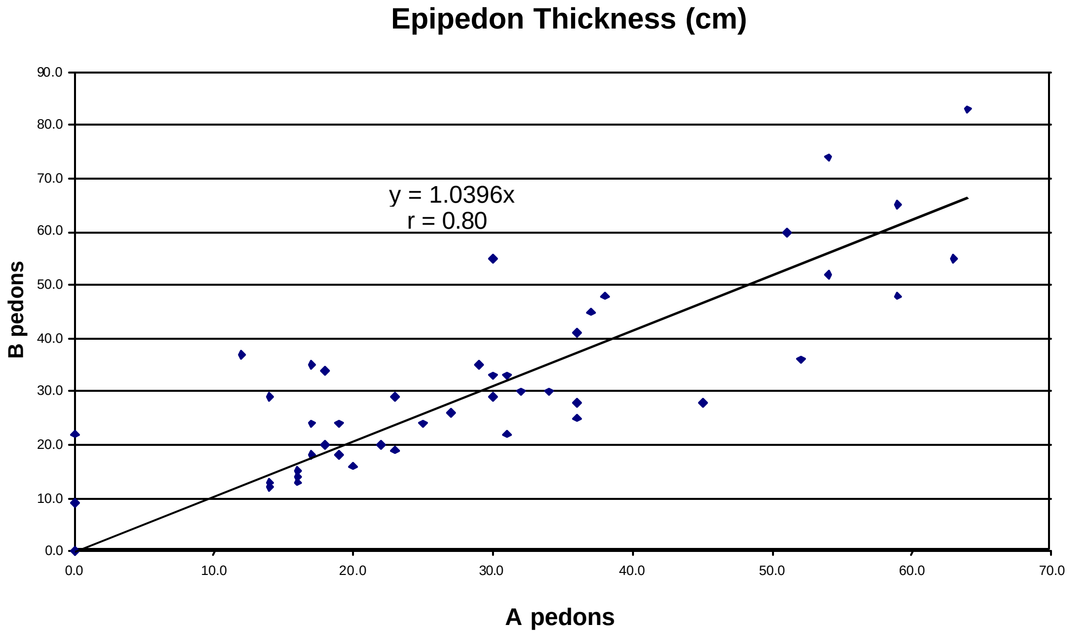
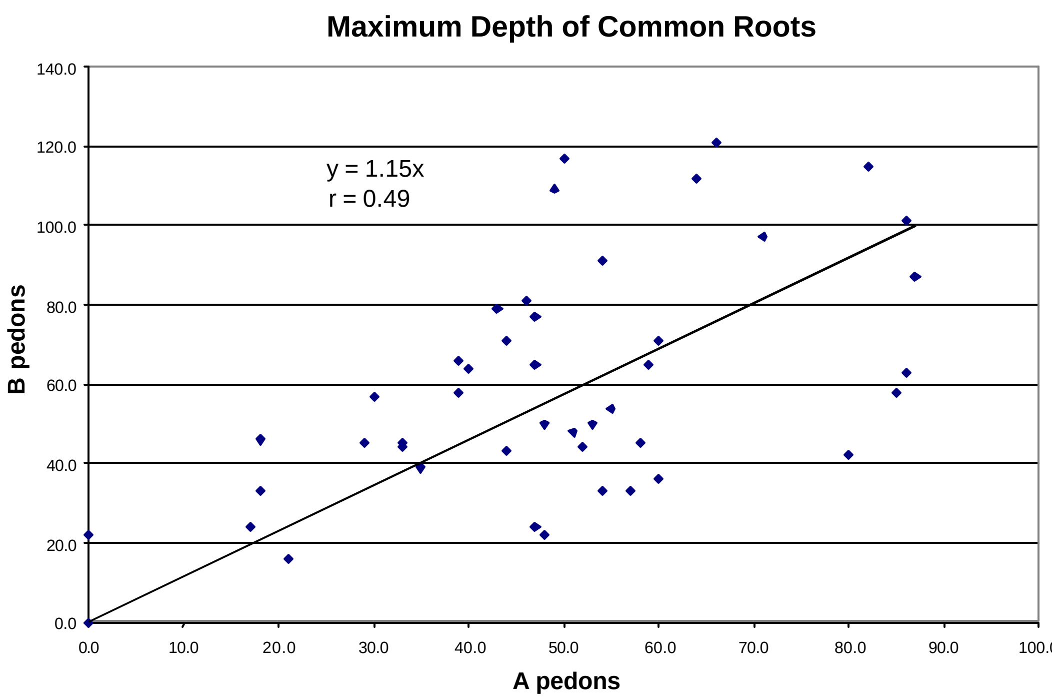


Figure II.2. Within pedon soil variability as illustrated by plotting data from soil cores collected 50 cm apart, Lake Rathbun Watershed, Iowa. “A pedons” were always collected 50 cm to the right of “B pedons.”



Depth to 0.6% organic carbon and maximum depth of common roots are generally viewed as being pedologically related since root dynamics largely control organic carbon content deep in soil profiles. Depths to 0.6% organic carbon are 46 cm and 60 cm in switchgrass and row cropped fields, respectively. Maximum depth of common roots are 70 and 20 cm for switchgrass and cropped fields, respectively. Both sets of pedons average 2.3 to 2.4% organic carbon content in their surface horizons. This indicates that 15 years of switchgrass production (following row crop production) has not significantly changed gravimetric organic carbon content between cropped fields and switchgrass fields although switchgrass is resulting in more deep roots. Yet even with the deeper common root volumes in switchgrass fields, 0.6% organic carbon content is present deeper into row cropped pedons.

It is unclear what mechanism could result in these differences. It may be the result of switchgrass fields having been preferentially sited on severly eroded fields. Evidence for erosion includes the significantly lower clay contents of the surface horizon of row cropped pedons (Table II.7). Alternatively or in addition it may be the result of organic carbon lessivage being promoted by row cropping although this does not seem likely a difference of 14 cm would develop in a few years (see Wander et al., 1998). Or it may indicate that switchgrass roots are not resulting in increased soil organic carbon contents. This is possible if microbial decomposition of the switchgrass roots is limited by lack of nitrogen. However, all C:N ratios measured for B horizons in this study found C:N ratios of 12 or less, which suggests that microbial decomposition would promote soil organic carbon accumulation (Killham, 1994; Stevenson and Cole, 1999).

The 20% greater stable aggregate content in the surface horizons of switchgrass pedons is the most obvious difference between summit pedons under switchgrass and row crops (Tables II.6 and II.9). It is an important difference given that aggregate stability is a measure of the degree to which soils are vulnerable to externally imposed destructive forces (Hillel, 1982). The presence of aggregates in soils is due to a number of interacting chemical, physical, and biological processes that involve texture, organic matter, pH, types and numbers of micro- and macro fauna, wetting and drying, etc. (Amezketa, 1999; Jenny, 1941; Jenny, 1980). In general, best aggregate stability occurs on soils that are well vegetated and have high clay and organic matter content (Jordahl and Karlen, 1993). Soil erodibility and runoff increases as aggregate stability decreases (Kemper and Rosenau, 1986).

Extensive Project

Objective C. Examine preliminary statistical relationships between switchgrass yields and soils in order to provide a basis for further yield-soil-landscape research.

Switchgrass harvested in 1999 from 45 1-ha strips located across eight fields had yields ranging from three to 16 Mg ha^{-1}, with the average being 6.47 Mg ha^{-1} (Table II.11). These strips consist of 45 soil map units representing 25 different soil series. However, only 15 series were common. Thus, in order to make manageable soil interpretations, all soils information was combined into these 15 series. This was completed by first combining all map units belonging to a single series. Second, each series having minor distribution in these strips was combined with the most similar series having major distribution. This means that some of the series listed in Table II.II consists of that series (inclusive of all its slope and erosion classes) as well as some minor inclusions of other series. It is recognized that this approach appears to be questionable; however, it is a standard soil survey practice because it is impossible to include in any table or map all of the soil variability that exists (Soil Survey Staff, 1993).

Figure II.3 shows the relationship between switchgrass yields and four soil series from 15 strips where a single series comprised at least 75% of a given strip. Figure II.3 suggests that strips or fields wherein Pershing is the predominant soil series have the highest yields while strips that are predominantly Lamoni will have very low yields. Qualitatively, mean CSR values for the four series shown seem to be more-or-less proportional to the actual yields (Figure II.3).

Table II.10. Selected pedon properties from summits in row cropped fields adjacent to switchgrass fields in the Lake Rathbun Watershed. All data except for pH range reported as means±standard deviations, number of pedons having data.

Pedon property ⇓	Summit
Slope (%)	2.0 ± 0.0, 6
Drainage class[1]	3.8 ± 0.4, 6
A-horizon thickness (cm)	29.7 ± 8.0, 6
Epipedon thickness (cm)	40.1 ± 16.3, 6
Org. carbon surface horizon (%)	2.3 ± 0.4, 6
Depth to 0.6% org. carbon (cm)	60.4 ± 13.2, 6
Maximum depth of common roots (cm)	19.6 ± 15.6, 6
Thickness of granular structure (cm)	21.5 ± 17.8, 6
Depth to common concretions (cm)	52.5 ± 15.0, 6
Depth to ≥3% coarse fragments (cm)	106.2 ± 12.3, 6
Clay content of surface horizon (%)	24.0 ± 2.8, 6
Maximum clay content of B horizon (%)	50.1 ± 4.1, 6
Stable aggregate content of surface horizon (%)	34.0 ± 15.8, 6
C:N of surface horizon	10.7 ± 1.0, 5
pH range of solum	5.1 - 7.2

[1]Drainage class is treated as a continuous variable where 1 indicates well drained and 4 indicates poorly drained.

A more specific comparison of CSR and yields is shown in Figure II.4. Regression results indicate that mean CSR values predict 22% of the actual yield or normalized yield (Figure II.4). A better fit was not found in part because of the combining of map units described above, especially the combining of eroded and uneroded phases and different slope classes of the same series. Thus, this relationship merits additional testing using map unit specific CSR values, which are available from the cooperative soil survey program on a county-by-county basis. It is expected doing so will result in CSR successfully predicting 50% or so of the yields.

Regression analysis of yield-soil series relationships was completed using normalized yields. Normalized yields were used in order to minimize location effect such as differences in local weather that occurred during the growing season across the Lake Rathbun Watershed. The equation used was $NormYield = (StripYield - MeanYield)/(\sqrt{variance/n})$. Regression results indicate that knowledge of soil series areas (without weighting for CSR's) explain about 75% of the yield for 1999 in these 45 strips (Table II.12). The regression coefficients suggest the presence of Haig, Kniffen, and Pershing soils in strips had very positive impacts on yields in the strips. The presence of Shelby, Weller, and Seymour had slightly positive impacts on yields. The presence of Bucknell, alluvial, Clarinda, Grundy, Lamoni and Armstrong soils had negative impacts on switchgrass yields (Table 8).

Application of the regression equation generated from the 45 strips to the yields and soils of the 12 fields wherein switchgrass was harvest was a failure (Figure II). In the case of the 45 strips, the yields predicted by the regression equation were high for low yielding strips and low for high yielding strips. In the case of the 12 fields, the yields predicted by the regression equation generated from the 45 strips exhibited no pattern of relationship with the actual field yields (Figure II). A more sophisticated analysis of the data using more years of yield is needed before a clear quantitative relationship between soil series and switchgrass yields is available. One component thought to hold great promise is direct use of county-by-county map unit CSR (as opposed to the watershed-wide soil series CSR's used herein).

Table II.11. Area, switchgrass yield, stand age, and soil series found in the 45 yield strips from 1999, Lake Rathbun Watershed, IA.

	Area	Average yield	Normal yield	Age	Proportion of area per series (given in decreasing order)					
	ha	Mg/ha								
Field w/ strips 1										
1	0.30	11.55	11.55	8	1.00 Weller					
2	0.17	7.52	2.39	8	1.00 Weller					
3	0.22	7.88	3.21	8	0.87 Weller	0.13 Armstrong				
4	0.21	8.28	4.12	8	0.83 Weller	0.17 Armstrong				
5	0.15	11.23	10.83	8	0.84 Weller	0.16 Armstrong				
6	0.22	7.84	3.11	8	0.95 Weller	0.05 Armstrong				
7	0.71	6.80	0.74	8	0.50 Pershing	0.48 Weller	0.02 Armstrong			
8	0.32	16.20	22.14	8	1.00 Pershing					
Field w/ strips 2										
9	0.57	1.93	-10.33	12	0.46 Shelby	0.34 Clarinda	0.2 Lamoni			
10	0.73	1.48	-11.34	12	0.48 Clarinda	0.42 Shelby	0.07 Alluvial	0.03 Seymour		
11	0.76	3.58	-6.56	12	0.37 Seymour	0.30 Clarinda	0.21 Lamoni	0.07 Shelby	0.05 Alluvial	
12	0.83	3.59	-6.54	12	0.53 Seymour	0.30 Clarinda	0.17Lamoni			
13	0.83	3.59	-6.54	12	0.55 Seymour	0.28 Clarinda	0.17 Lamoni			
14	0.85	2.24	-9.61	12	0.48 Seymour	0.30 Lamoni	0.22 Clarinda			
15	0.72	1.88	-10.43	12	0.35 Lamoni	0.31 Clarinda	0.29 Seymour	0.05 Alluvial		
Field w/ strips 3										
16	5.67	6.48	0.01	7	0.35 Arispe	0.33 Grundy	0.18 Bucknell	0.06 Haig	0.05 Seymour	0.03 Pershing
17	4.62	6.64	0.39	7	0.46 Pershing	0.26 Grundy	0.11 Armstrong	0.09 Arispe	0.08 Bucknell	
18	1.58	6.70	0.53	7	0.55 Pershing	0.36 Armstrong	0.09 Grundy			
Field w/ strips 4										
19	0.43	7.61	2.61	3	0.89 Seymour	0.11 Clarinda				
20	0.57	9.56	7.03	3	0.90 Seymour	0.10 Clarinda				
21	0.57	8.66	4.98	3	0.85 Seymour	0.15 Edina				
22	0.56	7.23	1.72	3	0.51 Seymour	0.28 Edina	0.21 Clarinda			
23	0.56	8.53	4.68	3	0.57 Seymour	0.27 Edina	0.16 Clarinda			

Table II.11. Area, switchgrass yield, stand age, and soil series found in the 45 yield strips from 1999, Lake Rathbun Watershed, IA.

	Area	Average yield	Normal yield	Age	Proportion of area per series (given in decreasing order)				
	ha	Mg/ha							
24	0.57	7.93	3.31	3	0.97 Seymour	0.03 Clarinda			
25	0.50	10.26	8.61	3	0.86 Seymour	0.14 Clarinda			

continued

	Area	Average yield	Normal yield	Age	Proportion of area per series (given in decreasing order)				
Field w/ strips 5									
26	0.60	5.44	-2.34	12	0.86 Seymour	0.14 Kniffen			
27	0.58	5.65	-1.86	12	0.68 Seymour	0.27 Clarinda	0.05 Kniffen		
28	0.52	8.75	5.19	12	0.94 Seymour	0.06 Clarinda			
29	0.45	8.19	3.92	12	0.56 Seymour	0.35 Kniffen	0.09 Clarinda		
30	0.39	9.43	6.73	12	0.56 Kniffen	0.28 Clarinda	0.16 Seymour		
Field w/ strips 6									
31	1.02	4.80	-3.79	10	0.57 Seymour	0.23 Adair	0.18 Shelby	0.02 Edina	
32	0.72	4.13	-5.32	10	0.38 Seymour	0.35 Adair	0.27 Shelby		
Field w/ strips 7									
33	1.36	3.94	-5.75	7	0.86 Lamoni	0.08 Grundy	0.05 Alluvial	0.01 Arispe	
34	0.52	3.65	-6.41	7	0.48 Arispe	0.46 Lamoni	0.06 Grundy		
35	1.83	3.53	-6.69	7	0.42 Lamoni	0.29 Arispe	0.18 Adair	0.05 Grundy	0.05 Allluvial
36	1.62	4.43	-4.63	7	0.46 Arispe	0.33 Grundy	0.21 Lamoni		
37	1.33	3.69	-6.33	7	0.66 Grundy	0.24 Arispe	0.10 Lamoni		
38	1.52	3.35	-7.10	7	0.44 Arispe	0.27 Clarinda	0.19 Lamoni	0.10 Grundy	
Field w/ strips 8									
39	1.85	5.15	-3.01	7	0.39 Shelby	0.21 Adair	0.20 Arispe	0.20 Alluvial	
40	1.70	5.13	-3.04	7	0.56 Adair	0.35 Shelby	0.05 Alluvial	0.04 Arispe	
41	1.62	5.15	-2.99	7	0.55 Armstrong	0.18 Alluvial	0.14 Pershing	0.13 Shelby	
42	1.13	7.86	3.17	7	0.54 Adair	0.43 Shelby	0.02 Arispe	0.01 Alluvial	
43	0.98	7.93	3.32	7	0.38 Shelby	0.35 Adair	0.27 Arispe		
44	1.04	7.90	3.26	7	0.54 Adair	0.25 Arispe	0.21 Shelby		
45	1.33	7.90	3.25	7	0.33 Shelby	0.26 Lamoni	0.25 Arispe	0.16 Grundy	
Average standard deviation variance									
	1.01	6.47	0.00	8.02					
	1.03	2.95	6.71	2.98					
	1.05	8.70	45.00	8.89					

Table II.11. Area, switchgrass yield, stand age, and soil series found in the 45 yield strips from 1999, Lake Rathbun Watershed, IA.

Area	Average yield	Normal yield	Age	Proportion of area per series (given in decreasing order)
ha	Mg/ha			
45	45	45	45	

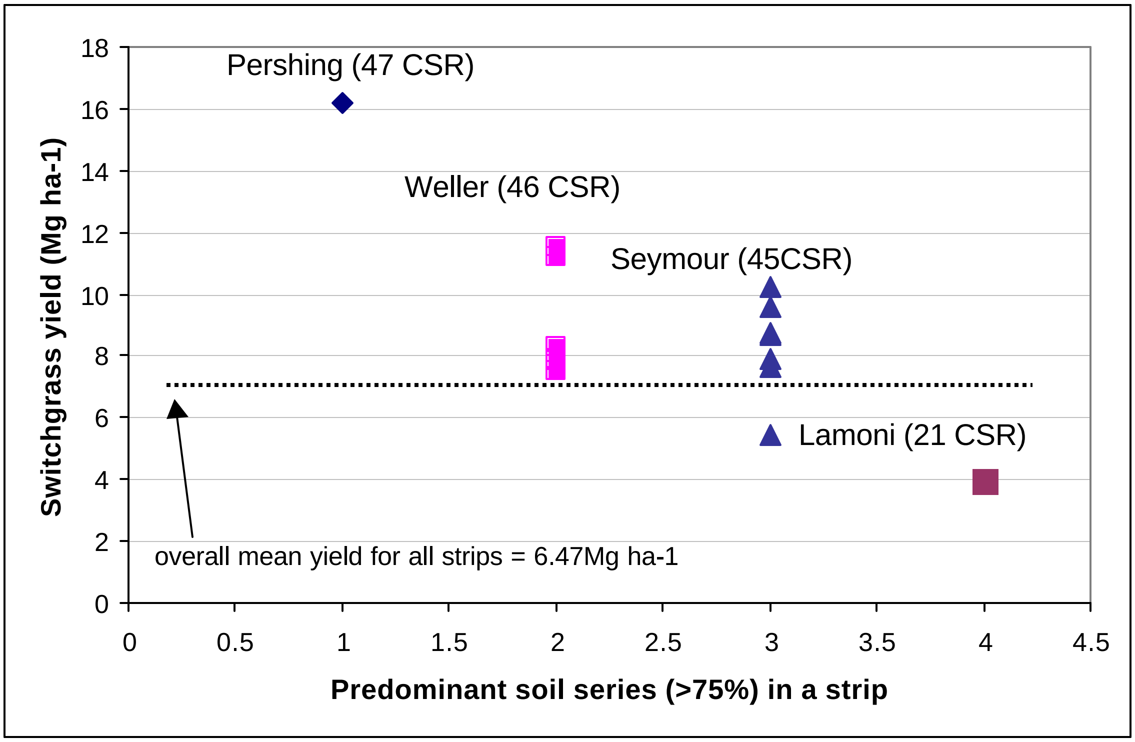


Figure II.3. Switchgrass yield versus soil series (with average CSR in paranthesis) from strips where the soil series shown comprises at least 75% of that strip, Lake Rathbun Watershed, IA.

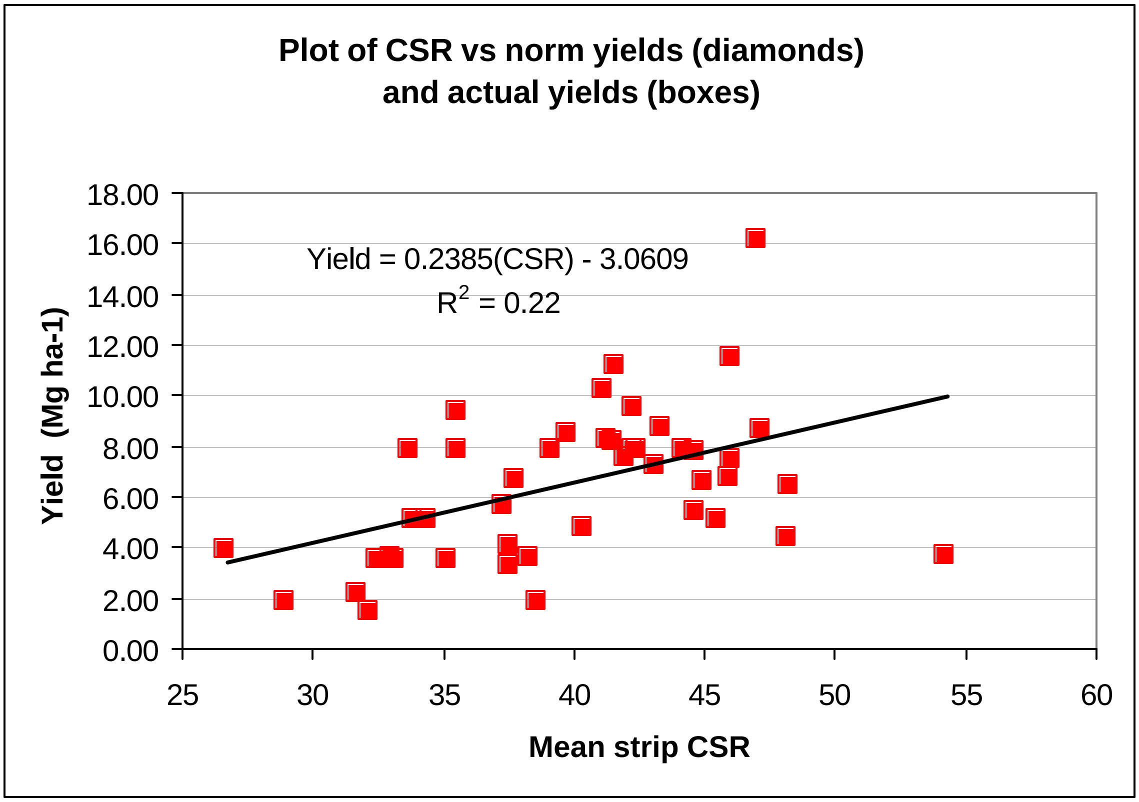


Figure II.4. Relationship between switchgrass yield and corn suitability ratings for 45 strips, Lake Rathbun Watershed, IA.

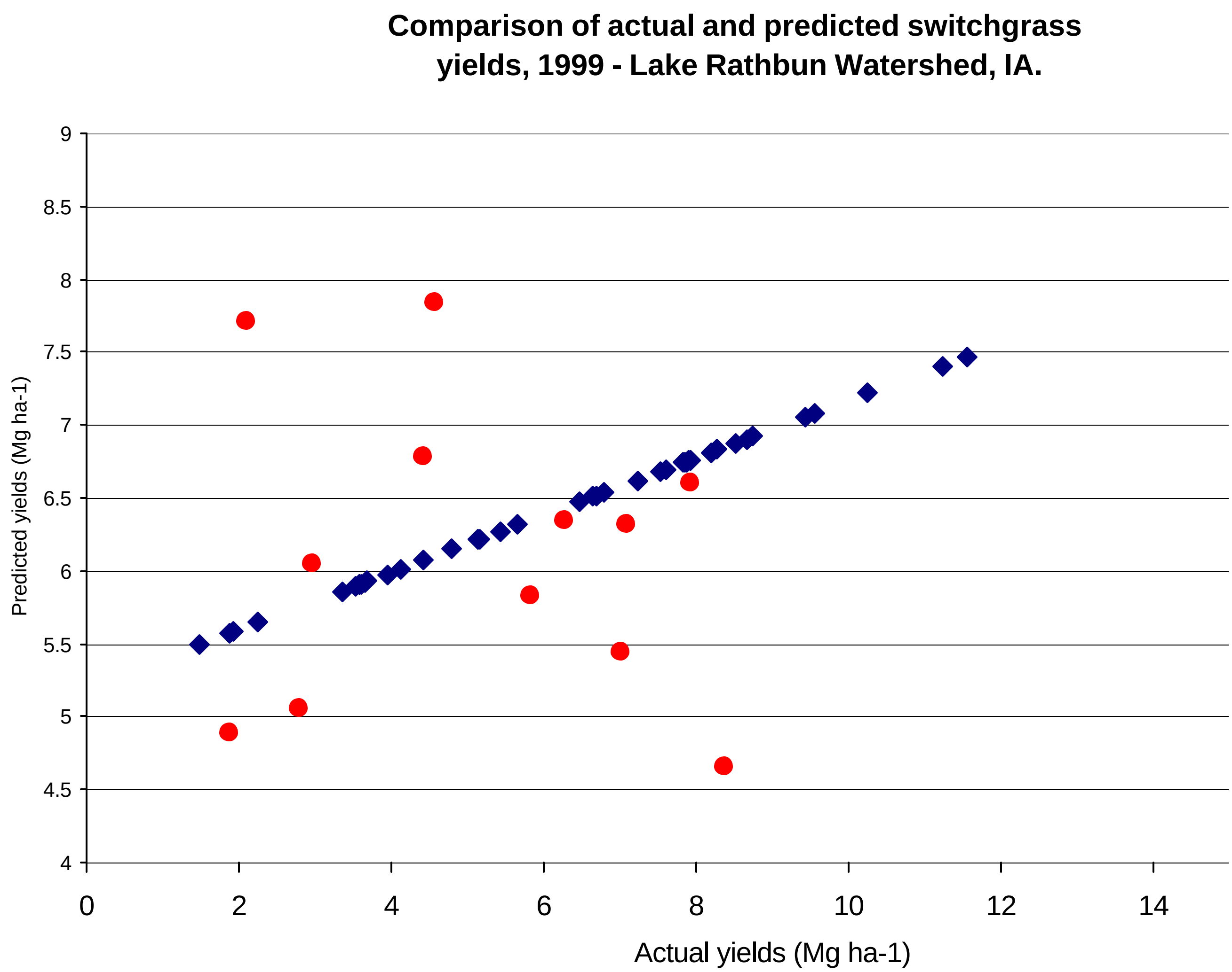


Figure I.5. Comparison of actual switchgrass yields to the yields predicted using the regression developed from age of stands and normalized yields from the 45 strips. (Diamonds indi values; Dots indicate field values).

Table II.12. Regression statistics wherein normalized switchgrass yields were regressed against soil series present within a strip and the age of the stand.

Regression statistics						Factor	Coefficient
Multiple R	0.87					Haig	187.65
R Square	0.75					Kniffen	23.57
Adjusted R Square	0.61					Pershing	16.50
Standard Error	4.21					Shelby	7.75
Observations	45.00					Weller	7.72
						Seymour	3.93
ANOVA						Arispe	-0.39
	df	SS	MS	F	Significance F	Stand age	-0.95
Regression	16.00	1483.39	92.71	5.23	<0.001	Adair	-2.71
Residual	28.00	496.77	17.74			Edina	-3.30
Total	44.00	1980.16				Lamoni	-5.61
						Armstrong	-6.17
						Grundy	-7.87
						Clarinda	-9.37
						Alluvial	-23.61
						Bucknell	-47.60
						Intercept	6.01

Conclusion

The common stratigraphy-based model of soil variability for hillslopes in the Lake Rathbun Watershed was not validated in this study. Rather, considerable overlap in soil properties across hillslopes was found. This overlap is the a product of all hillslope soil parent materials being clayey and generally poorly drained as well as natural and human-induced hillslope sediment having buried paleosol and till derived soils. The secondary hypothesis that epipedon morphology will reflect the impact of long-term farming was validated. The most obvious change was that about one-half of all soils have been eroded to the point where now have ochric rather than mollic epipedons. The localized nature of this long-term erosion resulted in considerable within pedon variability. Increased stable aggregate content was a product of conversion of row cropped fields into switchgrass fields.

Notwithstanding the first paragraph of this section, switchgrass yields do appear to be related to inherent soil properties inclusive of landscape position. The best evidence for this came from the 20 fields although Lemus (1999) and Molstad (2000) also documented the importance of landscapes in the four intensively studied fields. Analysis of the 20 fields showed that mean series CSR values accounted for 20% of the yield variability occurring across them. It is speculated that an additional 20 or 30% of the yield variability could be accounted for by use of county-specific soil map unit CSR values, which tend to be highly landscape position dependent. The remaining 50% or so of yield variability is thought to be due to current and past management of switchgrass fields. The basis of this is the findings of Lemus (1999) and Molstad (2000). Thus, future studies relating soils and switchgrass productivity in the Lake Rathbun Watershed will need to examine CSR in greater detail as well as to focus more on actual management regimens such as comprehensive fertility amendments. It is also speculated such studies will likely be able to more completely evaluate the environmental impacts of switchgrass production.

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.'

Methods

We planted 20 entries, including released cultivars and experimental germplasms from IA, NE, and OK, in a replicated field experiment on 13 May 1997 at the McNay Research Farm in Lucas County. The experiment was a randomized complete block design with four replications. The plots were 10' x 15' with a 5' alley separating plots. Plots were fertilized with 78 N ha^{-1} in May 1998, April 1999, April 2000, and April 2001. The plots were harvested for biomass in November 1998 and October 1999 using a flail-type forage harvester. A 3' section through the middle of the plot was harvested and weighed. A subsample was taken from the harvested material to determine moisture content and the weights were adjusted to a dry matter basis. The subsample was subsequently ground and used for biomass quality analysis. No yield data were taken in 2000 due to wet conditions in early November followed by early snowfall and continual snow cover until mid-March 2001. However, a subsample was taken from all plots in November 2000, which was used for cell wall analysis, and for 'Alamo,' 'Kanlow,' and Cave-In-Rock, proximate, ultimate, and elemental analyses were also conducted.

Results and Discussion

No yield data were taken in 1997 due to weed competition. In 1998, yellow foxtail was problematic in plots with weak stands. Stands were uneven in 1998, but by 1999, all stands had thickened acceptably. The study is continuing in 2001, with excellent growth of all plots; harvest will be done in September or early October to avoid the possibility of inclement weather as encountered in 2000.

Yields were considerably higher in 1999 than 1998, probably due to the improved stands (Table III.1). The lowland varieties 'Alamo', 'Kanlow', and 'Carthage' had among the highest yields both years; the germplasm, NU94-2CH, an upland selection from Oklahoma also performed well. Height of these lowland entries was higher than the upland germplasm, and may be the reason for their higher yields (Table III.1). Cave-In-Rock, the most widely recommended cultivar for Iowa, may not be the best for use as a biofuel crop. We are still concerned about the survival of lowland cultivars in Iowa. The plants have now experienced four winters, and stands of all varieties are acceptable. No winterkill of the lowland cultivars has occurred. However, of the four winters, three (1997-1999) were relatively mild (for Iowa) and the last (2000) was marked by continual snow cover from November through March, buffering the plots from cold temperatures. Further experimentation with the lowland ecotypes is warranted in southern Iowa.

When averaged across the three years, the 20 germplasms did not differ for ADF, ADL, or ash content, but did differ for height, NDF, nitrogen, and IVDMD (Table III.1). Although some variation for cell-wall content and composition is evident, the differences among entries does not appear to be large and selection to alter these characteristics, even though it may be successful, would not be expected to change biofuel quality substantially. Selection for higher yield would seem to be a more logical point to improve switchgrass destined for fuel use since all the cultivars have roughly similar quality profiles when averaged across three years of data.

Chemical constituents differed among entries, suggesting some germplasm may be more suited to co-firing than others, but none of the values is unacceptably high (Table III.2). A substantial reduction in Cl, P, and S anions occurred between November and March. This may affect harvest managements if the fall levels are unsatisfactory. Interestingly, stems had significantly more of these minerals than leaves in the fall. Because leaves may be expected to deteriorate over winter, the decline in these constituents during that time must be related to leaching from the stems.

Disease scores did not show major differences among cultivars for 1998 or 1999 (data not shown). Lodging did not differ substantially among entries either year (data not shown) and was not severe enough to affect harvest.

In summary, the germplasm evaluated differed for yield, cell-wall composition, and mineral concentration. For biomass production, the lowland ecotypes appear superior, but winter hardiness still needs to be assessed since every winter that this test has been established has either had good snow cover or been mild. Selecting for high yield and good biofuel quality appears possible.

Table III.1. Switchgrass germplasm yield (1998 and 1999 only), height, cell wall and nitrogen contents, digestibility, and ash averaged across three years (1998, 1999, and 2000).

Germplasm	Ecotype†	Yield 1998	Yield 1999	Yield Mean	Height	NDF	ADF	ADL	N	IVDMD	ASH
		Mg ha^{-1}			cm	%					
Alamo	LL	6.3	17.5	11.9	221	83.0	50.1	6.0	0.45	26.4	3.9
Blackwell	UL	7.0	9.9	8.4	155	80.3	46.7	6.0	0.52	25.1	5.5
Caddo	UL	5.1	11.4	8.3	161	81.2	48.1	6.1	0.52	24.5	4.5
Carthage	UL	6.8	14.2	10.5	169	79.5	45.8	5.5	0.63	25.2	6.0
Cave-In-Rock	I	6.3	12.5	9.4	181	82.8	49.3	6.5	0.45	21.5	4.8
Forestburg	LL	4.9	8.8	6.8	152	79.5	45.4	5.3	0.57	24.1	5.9
HDMDC3	UL	7.6	13.5	10.5	158	79.9	46.1	5.7	0.58	24.8	5.7
HYLDC3	UL	5.7	11.4	8.6	170	79.4	45.9	5.7	0.60	24.6	5.4
IA-GT	UL	6.6	10.5	8.5	172	77.2	44.9	5.7	0.51	24.9	5.8
IA-LM	UL	7.1	11.0	9.1	171	79.2	45.8	5.7	0.48	24.2	5.6
Kanlow	LL	8.4	16.3	12.4	221	83.9	49.6	5.8	0.38	26.1	3.8
NL93-2HC	LL	5.5	11.5	8.5	204	79.9	45.7	4.8	0.47	28.4	4.8
NU94-2HC	UL	7.2	15.0	11.1	202	79.4	43.9	4.3	0.61	29.6	5.9
Pathfinder	UL	5.5	9.4	7.5	160	81.7	47.6	5.9	0.57	24.2	5.1
Shawnee	UL	5.8	13.1	9.5	184	80.4	47.8	6.3	0.51	23.1	4.8
Shelter	LL	7.3	10.2	8.7	174	80.4	48.3	6.3	0.54	23.6	5.4
SU92-ISO	LL	7.2	11.2	9.2	158	79.7	46.0	5.8	0.50	23.4	5.6
SU94-2CH	LL	6.8	10.7	8.7	165	80.7	47.9	6.1	0.63	24.0	4.8
Sunburst	UL	5.3	8.2	6.7	162	79.9	46.2	5.7	0.54	23.1	5.2
Trailblazer	UL	5.5	10.5	8.0	149	81.5	47.3	5.9	0.58	24.8	5.3
Mean		6.4	11.8	9.1	175	80.5	47.0	5.8	0.53	24.8	5.2
LSD (5%)		2.1	4.3	2.7	17	1.2	ns	ns	0.06	1.7	ns

†Ecotypes: LL= lowland, UP= upland, and I= intermediate.

Table III.2. Proximate and ultimate analyses of switchgrass biomass from three cultivars harvested in October 2000 at Lucas, IA.

Cultivar	BTU	Ash	Volatile matter	Fixed carbon	C	H	N	O	S
		---% Dry weight --- --------							
Alamo	7807	3.4	83.0	13.6	47.0	5.66	0.28	43.5	0.19
CIR	7838	4.4	81.8	13.8	46.6	5.56	0.44	42.9	0.17
Kanlow	7917	3.3	83.0	13.8	47.5	5.72	0.27	43.0	0.24
Mean	7834	3.8	82.5	13.7	46.9	5.63	0.37	43.0	0.20
LSD (5%)	ns	ns	ns	ns	ns	ns	0.05	ns	ns

Table III.3. Elemental analyses of switchgrass biomass from three cultivars harvested in October 2000 at Lucas, IA.

		Overall		Three switchgrass varieties			
Variable	Units	Mean	Std dev	Alamo	CIR	Kanlow	LSD
Constituents determined using INAA on dry vegetation							
Au	ppb	-0.10	0.00	-0.10	-0.10	-0.10	ns
Ba	ppm	17.00	7.38	15.00	25.00	11.00	9.08
Br	ppm	1.64	0.38	1.97	1.30	1.67	ns
Ca	%	0.41	0.13	0.33	0.52	0.38	ns
Co	ppm	-0.10	0.00	-0.10	-0.10	-0.10	ns
Cr	ppm	0.72	0.19	0.63	0.80	0.73	ns
Fe	%	0.01	0.00	0.01	0.01	0.01	ns
K	%	0.11	0.03	0.09	0.11	0.12	ns
Mo	ppm	0.92	0.15	0.94	0.82	1.02	ns
Na	ppm	104.04	57.47	145.13	40.90	126.10	72.65
Rb	ppm	1.78	0.44	2.00	1.67	1.67	ns
Sr	ppm	6.00	15.48	1.00	18.00	-1.00	ns
Zn	ppm	16.22	4.24	18.33	15.67	14.67	ns
La	ppm	0.10	0.05	0.07	0.13	0.10	ns
Constituents determined using ICP on fused and acid-digested vegetation							
SiO2	%	63.06	2.00	63.57	62.42	63.17	ns
Al2O3	%	0.67	0.21	0.53	0.71	0.76	ns
Fe2O3	%	0.41	0.11	0.36	0.45	0.44	ns
MnO	%	0.05	0.02	0.04	0.05	0.07	ns
MgO	%	4.50	0.99	5.29	3.39	4.81	1.17
CaO	%	13.06	2.16	11.90	14.74	12.54	ns
Na2O	%	0.36	0.26	0.57	0.07	0.44	0.32
K2O	%	3.67	0.76	3.72	3.24	4.06	ns
TiO2	%	0.04	0.01	0.04	0.05	0.05	ns
P2O5	%	4.41	0.63	4.76	4.14	4.33	ns
LOI	%	9.82	1.21	9.40	10.56	9.49	ns
Ba	ppm	523.00	155.99	500.67	696.67	371.67	150.37
Sr	ppm	408.89	49.87	394.67	463.67	368.33	59.66
Y	ppm	1.11	1.36	0.33	2.00	1.00	ns
Zr	ppm	21.78	2.33	20.33	22.67	22.33	ns

Table III.3. Elemental analyses of switchgrass biomass from three cultivars harvested in October 2000 at Lucas, IA.

		Overall		Three switchgrass varieties			
Variable	Units	Mean	Std dev	Alamo	CIR	Kanlow	LSD
V	ppm	4.89	3.98	1.67	6.33	6.67	ns
Cu	ppm	62.00	22.48	59.67	82.33	44.00	ns
Ni	ppm	12.33	2.55	14.67	9.33	13.00	2.21
Pb	ppm	2.67	3.35	0.67	2.67	4.67	ns
Zn	ppm	274.56	76.21	302.67	257.00	264.00	ns
Constituents determined using ICP on aqua-regia digested vegetation							
Cl	ppm	470.78	263.16	569.67	192.00	650.67	359.67

continued

Constituents determined using INAA on ashed vegetation							
Au	ppb	1.56	6.35	-1.00	2.67	3.00	ns
Ag	ppm	-2.00	0.00	-2.00	-2.00	-2.00	ns
As	ppm	3.64	1.30	4.17	3.93	2.83	ns
Ba	ppm	426.67	110.57	426.67	540.00	313.33	117.44
Br	ppm	18.11	7.66	19.33	11.33	23.67	ns
Ca	%	10.24	1.69	9.73	10.67	10.33	ns
Co	ppm	2.89	0.60	2.33	3.33	3.00	ns
Cr	ppm	20.22	4.84	20.00	16.33	24.33	ns
Cs	ppm	0.19	0.66	-0.13	0.80	-0.10	ns
Fe	%	0.31	0.08	0.28	0.32	0.31	ns
K	%	3.74	0.90	3.34	3.53	4.35	ns
Mo	ppm	30.33	7.31	34.00	22.00	35.00	8.71
Na	ppm	3419.67	2572.92	5460.00	645.67	4153.33	3239.10
Rb	ppm	48.33	6.84	49.67	44.33	51.00	ns
Sb	ppm	0.39	0.20	0.47	0.33	0.37	ns
Sc	ppm	0.53	0.15	0.47	0.57	0.57	ns
Se	ppm	0.44	3.00	2.33	-2.00	1.00	ns
Sr	ppm	321.11	373.71	206.67	543.33	213.33	ns
Th	ppm	0.52	0.13	0.60	0.50	0.47	ns
U	ppm	0.09	0.23	0.03	0.20	0.03	ns
W	ppm	0.22	1.86	0.33	1.33	-1.00	ns
Zn	ppm	521.11	149.37	646.67	406.67	510.00	ns
La	ppm	3.13	0.65	3.07	3.30	3.03	ns
Ce	ppm	4.89	1.54	4.00	5.33	5.33	ns
Sm	ppm	0.53	0.14	0.50	0.53	0.57	ns
Eu	ppm	0.02	0.10	0.06	-0.03	0.01	ns
Yb	ppm	0.10	0.18	0.05	0.07	0.18	ns

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 C_4 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 are currently available in North America.

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 August if sufficient growth was available. No data were taken in establishment year.

Results

In general, yields in 2001 were approximately 50-75% of 2000 (Table III.4), due to a combined dry spring and fall. Across the three locations, the SF harvest system produced higher yields than F (Table III.4). However, at Arlington, SF produced lower yields than F in 2000. The hay treatment, not included at Ames, was equivalent to SF in Arlington in 1999, because the dry autumn prevented a third harvest. In 2000, H yielded similarly to F. 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.

Dry matter content of biomass (two-year averages) declined from ~30% in June to ~60% in October. 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).

Proximate analysis of the 2000 biomass produced at Ames shows fairly high ash contents (Table III.8), similar to the 1999 data (see 2000 annual report). The spring harvest appears to have the lowest ash content in dry matter. Interestingly, ash content determined during the elemental analysis (conducted by a different laboratory) was lower (Table III.10); the reason for the disparity is unclear, since ashing in both cases was done near 500°C. Nevertheless, ash content needs to be monitored closely. Harvest timing had no effect on BTU content in 2000. Otherwise, harvest management did not have a big effect on BTU.

Ultimate analysis indicated that N content was much higher in the spring harvested material (Table III.9), not surprising since fertilizer was applied in April and no leaves had senesced to return N to the soil. Other harvests were similar in N content. Sulfur, an important element for co-firing, did not differ among the harvests. Silica is also 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.10). K_2O and P_2O_5 declined sharply after spring. Most other elements differed between the harvest managements. Chloride concentration was also higher than switchgrass at both Ames and McNay; however, spring concentrations were lower at McNay than Ames.

In summary, reed canarygrass can produce good 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.

Table III.4. Reed canarygrass biomass yields under several harvest treatments at Ames and McNay, IA and Arlington, WI. No data was collected in 1998 at Arlington or in 1998 or 1999 in McNay.

Location	Mgmt	6/98	10/ 98	3/99	Total	6/99	10/99	3/00	Total	6/00	7/00	10/00	3/01	Total
		--------------------------------------Tons dry matter per acre ---												
Ames	Fall	-	3.76	-	3.76	-	3.37	-	3.37	-	-	1.42	-	1.42
	Spr+Fall	2.63	2.69	-	5.33	3.52	1.01	-	4.52	0.74	-	1.48	-	2.21
	Winter	-	-	2.10	2.10	-	-	1.81	1.81	-	-	-	0.00	0.00
	LSD (5%)		*		0.40		*		0.71			ns		0.15
Arlington	Fall	-	-	-	-	-	2.62	-	2.63	-	-	2.03	-	2.03
	Hay	-	-	-	-	2.20†	0.93	-	3.14	0.94	0.93	0.40	-	2.28
	Spr+Fall	-	-	-	-	2.31	0.83	-	3.15	0.95	-	0.68	-	1.63
	Spr+Win	-	-	-	-	2.18	-	0.00	2.19	1.24	-	-	0.47	1.71
	Winter	-	-	-	-	-	-	0.00	0.00	-	-	-	1.71	1.71
	LSD (5%)					ns	0.22	ns	0.43	0.18		0.22	*	0.36
McNay	Fall	-	-	-	-	-	-	-	-	-	-	1.46	-	1.46
	Hay	-	-	-	-	-	-	-	-	1.18	1.32	-	-	2.49
	Spr+Fall	-	-	-	-	-	-	-	-	1.29	-	1.61	-	2.90
	Spr+Win	-	-	-	-	-	-	-	-	1.12	-	-	0.00	1.11
	Winter	-	-	-	-	-	-	-	-	-	-	-	0.00	0.00
	LSD (5%)									ns		*	ns	0.24

†No summer cut taken due to limited regrowth; thus, hay management was equal to a spring + fall management.

Table III.5. Reed canarygrass yields at two Midwestern locations, Ames, IA and Arlington, WI, under two harvest management treatments in 1999.

	Fall only		Winter only		Spring and Fall					
Location	10/99	10/00	3/00	3/01	6/99	10/99	1999	6/00	10/00	2000
	---Tons dry matter per acre --									
Ames	3.37	1.42	1.81	0.00	3.94	1.01	4.52	0.74	1.48	2.21
Arlington	2.62	2.03	0.00	1.71	2.43	0.83	3.15	0.95	0.68	1.63
McNay	-	1.46	-	0.00	-	-	-	1.29	1.61	2.90
LSD/contrast	*	*	*	*	*	ns	*	0.10	0.09	0.08

Table III.6. Reed canarygrass variety yields averaged across two Midwestern locations, Ames, IA and Arlington, WI, under three harvest management treatments in 1999 and 2000.

	Fall		Winter		Spring and Fall					
Variety	10/99	10/00	3/00	3/01	6/99	10/99	1999	6/00	10/00	2000
	---Tons dry matter per acre--									
Bellevue	3.26	1.77	0.86	0.45	3.13	0.91	4.01	1.03	1.31	2.33
Common	3.35	1.75	0.93	0.52	3.09	0.94	4.03	1.04	1.30	2.35
PSC1142	3.72	1.80	1.03	0.63	3.30	1.09	4.39	1.27	1.53	2.80
Palaton	3.31	1.76	1.00	0.65	3.19	1.03	4.23	1.06	1.32	2.38
Rival	3.23	1.62	0.79	0.50	3.01	0.82	3.81	0.85	1.10	1.94
Vantage	3.57	1.67	0.88	0.59	3.23	0.96	4.20	0.94	1.25	2.18

Table III.6. Reed canarygrass variety yields averaged across two Midwestern locations, Ames, IA and Arlington, WI, under three harvest management treatments in 1999 and 2000.

	Fall		Winter		Spring and Fall					
Variety	10/99	10/00	3/00	3/01	6/99	10/99	1999	6/00	10/00	2000
	---Tons dry matter per acre-- ----------									
Venture	3.48	1.76	0.85	0.65	3.36	1.03	4.41	1.01	1.25	2.25
Mean	3.42	1.73	0.90	0.57	3.19	0.97	4.15	1.03	1.29	2.32
LSD (5%)	ns	0.13	ns	0.13	ns	ns	0.22	0.15	0.13	0.13

Table III.7. Reed canarygrass variety heights averaged across two Midwestern locations, Ames, IA and Arlington, WI, under three harvest management treatments in 1999 and 2000.

	Fall		Spring and Fall or Winter				
Variety	10/99	10/00	6/99	10/99	6/00	10/00	4/01
Bellevue	115	143	135	49	105	65	30
Common	115	154	135	49	105	57	29
PSC1142	120	147	135	49	112	65	27
Palaton	113	148	131	51	110	62	32
Rival	116	154	134	46	105	62	24
Vantage	117	151	136	48	106	63	21
Venture	118	140	130	51	104	59	30
Mean	116	148	134	49	107	62	27
LSD (5%)	ns	5	ns	ns	ns	5	9

Table III.8. Proximate, ultimate, and elemental analyses of reed canarygrass biomass averaged across seven cultivars and harvested in spring, fall, or winter 2000 at Ames and Lucas, IA.

		Ames				Lucas (McNay)				
		Two harvests		One harvest		Two harvests		One harvest		
Variable	Units	Spring 00	Fall 00	Winter 00	Fall 00	Spring 00	Fall 00	Fall 00	Mean	LSD
Ultimate and Proximate Analyses										
Ash	%	10.50	8.77	9.83	10.70	10.30	10.03	11.50	10.23	0.58
Vol. matter	%	70.70	73.43	76.33	72.97	72.27	71.97	72.03	72.81	0.50
Fixed C	%	18.80	17.80	17.07	16.33	17.43	18.00	16.47	17.41	ns
BTU		7322.67	7471.33	7406.00	7342.67	7377.67	7365.67	7260.33	7363.76	ns
C	%	43.63	43.91	44.43	43.61	43.65	43.52	42.77	43.64	0.39
H	%	5.39	5.46	5.07	5.31	5.22	5.50	5.23	5.31	0.08
N	%	1.44	0.83	0.47	0.84	0.81	0.91	0.92	0.89	0.09
O	%	38.82	40.85	40.11	39.31	39.84	39.86	39.44	39.75	ns
S	%	0.22	0.18	0.09	0.23	0.18	0.18	0.14	0.18	0.04
Constituents determined using INAA on dry vegetation										
Au	ppb	1.47	0.03	4.73	0.30	0.57	-0.10	-0.10	0.99	1.22
Ba	ppm	18.67	14.67	18.33	23.00	33.00	24.33	28.67	22.95	3.19
Br	ppm	5.57	5.87	2.77	2.60	7.43	8.73	7.00	5.71	0.58
Ca	%	0.44	0.33	0.25	0.38	0.39	0.37	0.38	0.36	0.04
K	%	1.80	0.99	0.15	0.62	1.10	1.20	0.58	0.92	0.08
Mo	ppm	1.73	2.07	0.91	1.97	0.58	1.13	1.17	1.36	0.41
Na	ppm	33.73	40.73	240.67	79.27	54.53	41.90	48.27	77.01	9.84
Rb	ppm	10.33	7.00	1.00	3.00	17.00	20.33	11.67	10.05	1.83
Zn	ppm	22.33	34.00	32.33	42.00	40.33	39.33	51.67	37.43	3.66
Constituents determined using ICP on fused and acid-digested vegetation										

Table III.8. Proximate, ultimate, and elemental analyses of reed canarygrass biomass averaged across seven cultivars and harvested in spring, fall, or winter 2000 at Ames and Lucas, IA.

		Ames				Lucas (McNay)				
		Two harvests		One harvest		Two harvests		One harvest		
Variable	Units	Spring 00	Fall 00	Winter 00	Fall 00	Spring 00	Fall 00	Fall 00	Mean	LSD
SiO_2	%	53.47	63.67	73.53	75.23	49.04	44.13	53.68	58.96	ns
Al_2O_3	%	0.30	0.43	0.96	0.79	0.59	0.32	0.36	0.54	0.12
Fe_2O_3	%	0.19	0.17	0.40	0.30	0.16	0.11	0.14	0.21	0.07
MnO	%	0.06	0.10	0.09	0.14	0.06	0.06	0.08	0.08	ns
MgO	%	2.54	2.78	1.03	1.87	1.58	1.74	0.97	1.79	0.18
CaO	%	4.35	4.99	2.84	4.53	3.53	3.27	2.85	3.77	0.39
Na_2O	%	0.02	0.03	0.30	0.11	0.62	0.02	0.03	0.16	0.19
K_2O	%	16.63	12.07	1.72	7.42	5.99	9.14	4.62	8.23	0.89
P_2O_5	%	5.02	6.10	2.04	4.64	3.24	3.70	2.23	3.85	0.66
LOI	%	17.77	10.01	16.42	5.28	35.18	36.94	34.76	22.34	9.43

continued

Ba	ppm	167.00	178.33	187.00	245.00	262.33	188.00	193.00	202.95	27.64
Sr	ppm	52.67	64.67	51.67	67.33	133.00	114.33	94.00	82.52	9.69
Zr	ppm	8.00	13.00	22.67	23.67	12.33	10.33	11.33	14.48	ns
Cu	ppm	44.33	62.67	60.67	69.67	38.33	39.33	37.67	50.38	7.19
Ni	ppm	15.67	10.67	11.00	13.33	13.33	9.67	9.00	11.81	1.42
Pb	ppm	-1.00	1.00	2.67	3.00	0.00	-1.00	4.00	1.24	ns
Zn	ppm	166.33	281.67	260.00	333.00	254.00	249.33	298.67	263.29	35.43
Constituents determined using ICP on aqua-regia digested vegetation										
Cl	ppm	8419.33	5084.33	231.67	3374.67	4519.00	5250.33	3176.33	4293.67	1072.20
Constituents determined using INAA on ashed vegetation										
Au	ppb	12.33	-5.00	43.67	8.00	-1.00	-5.00	-5.00	6.86	14.92
As	ppm	1.03	2.47	2.37	2.30	2.03	1.33	1.37	1.84	0.50
Ba	ppm	140.00	119.67	121.33	166.67	180.00	130.00	150.00	143.95	ns
Br	ppm	48.00	39.33	4.33	14.33	32.00	34.00	17.00	27.00	5.04
Ca	%	3.50	3.30	2.07	2.77	2.30	2.23	2.03	2.60	ns
Co	ppm	2.00	3.00	3.33	2.33	2.33	1.67	2.00	2.38	ns
Cr	ppm	-1.00	1.33	6.67	5.00	4.00	2.33	-1.00	2.48	2.42
Cs	ppm	-0.50	0.43	0.47	1.40	1.57	-0.10	0.33	0.51	ns
Fe	%	0.09	0.13	0.27	0.21	0.12	0.09	0.11	0.14	0.04
K	%	19.00	13.33	2.39	8.55	9.70	11.23	5.73	9.99	1.16
Mo	ppm	18.33	27.00	8.67	24.67	2.33	10.33	10.00	14.48	5.07
Na	ppm	117.67	292.33	2740.00	819.67	327.67	194.00	252.33	677.67	369.19
Rb	ppm	85.00	64.33	9.33	28.67	106.33	133.33	62.33	69.90	15.89
Sb	ppm	0.00	0.20	0.20	0.23	0.17	0.03	0.07	0.13	ns
Sc	ppm	-0.10	0.20	0.60	0.47	0.33	0.20	0.23	0.28	0.08
Th	ppm	-0.10	0.03	0.50	0.37	0.20	0.00	0.23	0.18	0.17
W	ppm	5.67	6.67	7.67	4.00	-1.00	-0.33	-1.00	3.10	ns
Zn	ppm	220.00	396.67	326.67	450.00	296.67	293.33	360.00	334.76	53.80
La	ppm	0.33	0.83	2.70	1.83	1.37	0.90	1.03	1.29	0.42
Ce	ppm	-3.00	-3.00	2.67	2.00	-3.00	-3.00	1.67	-0.81	ns
Sm	ppm	-0.10	0.07	0.40	0.30	0.23	0.17	0.17	0.18	0.07
Yb	ppm	-0.05	-0.05	0.18	0.01	0.08	-0.05	0.03	0.02	0.05

†INAA=Instrumental neutron activation analysis; ICP=Inductively coupled plasma emission spectrometry.
‡LOI=Loss on Ignition.

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.11). 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. 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 may formalize the collection next year with colleagues from South Dakota and Wisconsin) 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.9. Biomass yield and height of reed canarygrass accessions measured at Ames, IA and Arlington, WI in 1999 and 2000.

Entry	By year 1999	By year 2000	By location IA	By location WI	By harvest Harv 1	By harvest Harv 2	Ht at harvest 1 IA	Ht at harvest 1 WI	Ht at harvest 2 IA	Ht at harvest 2 WI
	---------------------------------g plant^{-1} --------------------------------------						-------------------------cm-----------------------			
172443	237	217	286	169	129	97	109	154	86	74
206463	.	.	.	.	120	.	84	.	65	.
209979	294	226	313	206	132	127	107	157	90	76
225116	290	236	324	203	132	132	118	159	92	79
227670	246	227	253	221	125	113	108	122	75	68
234694	227	183	270	140	94	112	83	114	69	55
234695	269	245	317	197	127	131	106	156	91	79
234696	317	284	382	220	140	159	93	139	82	75
234698	264	239	301	202	133	118	106	149	86	84
234780	290	245	307	228	140	128	106	142	89	80
234790	288	231	302	216	131	128	104	151	83	74
235023	282	237	314	204	132	129	96	140	81	70
235482	352	241	359	234	114	182	103	124	79	77
235484	270	269	337	202	137	134	100	136	91	71

continued

235485	282	241	302	221	136	126	110	154	94	86
235546	300	272	355	217	147	138	107	139	94	81
235547	340	303	370	.	147	171	98	.	83	.
235551	275	227	299	.	130	124	103	.	79	.
236525	212	185	222	175	75	124	78	128	67	73
241064	295	291	341	.	134	155	98	.	96	.
241065	289	194	290	.	107	133	98	.	82	.
251426	297	259	358	198	135	141	114	143	87	81
251531	359	331	330	361	171	176	108	134	88	84
251841	276	260	307	229	135	132	105	153	90	77
251841	276	260	307	229	135	132	105	153	90	77
251842	295	228	361	162	121	142	109	145	90	77
253315	367	294	379	.	156	175	110	.	97	.
253316	449	345	445	.	184	214	103	.	97	.
253317	303	254	306	251	143	136	114	145	90	87
255887	299	231	311	220	132	134	103	159	92	90
269728	313	260	354	219	135	150	104	126	90	82
272122	296	277	334	240	145	142	103	141	92	78
272123	250	253	274	229	137	114	106	158	89	76
278706	326	247	335	.	132	154	106	.	95	.
284179	216	194	226	183	71	135	69	120	72	64
297362	188	168	191	165	93	85	79	106	81	54
314102	242	207	273	177	118	107	121	153	95	91
314581	219	192	249	161	106	102	101	137	79	74
314726	250	212	291	171	122	108	123	158	103	94
314727	245	218	270	193	124	108	110	131	91	72
314728	278	241	317	202	136	124	114	139	86	82
315486	285	249	310	224	142	123	119	160	92	81
315487	191	162	187	166	90	87	100	132	88	86
316329	277	236	.	208	43	178	63	122	.	76
316330	216	141	160	197	67	111	79	129	60	71
319825	247	224	271	200	123	112	96	136	63	64
329243	.	.	.	.	39	.	32	140	.	62
337718	261	212	282	191	121	116	119	156	92	72
344557	300	250	350	200	124	152	95	135	89	74

345662	250	200	259	191	119	106	111	148	90	87
346015	290	226	307	209	120	141	102	138	86	76
357645	276	244	333	187	136	124	113	128	89	83
368980	259	246	297	207	126	125	121	163	95	83
369290	207	179	227	159	110	84	101	135	76	76
369291	252	243	322	173	133	115	109	155	87	77
369292	225	194	231	188	114	94	106	149	88	85
371754	274	221	305	190	123	123	111	141	88	76
372558	327	257	370	215	143	150	106	143	90	72
380963	212	169	250	130	100	89	110	111	80	75
380965	287	228	344	171	120	138	108	131	84	69
383726	217	184	225	176	101	98	100	122	82	70
387928	238	216	248	206	120	106	97	128	80	72
387929	185	154	188	151	89	80	97	139	79	72
392389	231	198	263	166	124	90	108	146	79	82
406316	251	209	289	171	119	113	101	138	80	75
422030	312	256	362	206	132	154	107	153	102	86
422031	234	214	272	175	90	134	89	122	88	71

continued

433725	296	279	323	251	143	144	106	145	84	75
435294	254	191	266	179	117	106	104	151	86	83
435295	260	223	300	182	123	118	100	138	80	75
435296	284	216	323	176	127	124	98	136	80	69
435297	224	205	278	151	117	100	106	138	79	72
435298	265	217	298	184	125	116	103	136	88	69
435299	221	217	265	173	109	108	101	130	76	71
435300	266	230	287	209	133	116	111	143	80	80
435301	294	222	308	209	139	120	112	148	87	75
435302	247	212	282	176	130	100	114	146	78	80
435303	245	199	251	194	130	93	120	149	95	79
435304	240	207	273	174	117	105	101	127	86	74
435305	252	222	265	209	131	106	103	148	88	84
435307	228	188	264	151	104	106	94	119	72	74
435308	223	226	265	184	111	113	96	126	80	81
435309	231	208	255	184	112	107	104	147	62	78
435311	256	188	262	182	119	102	108	138	81	74
435312	289	279	382	186	147	138	98	130	76	88
440584	217	185	235	167	114	90	99	126	77	74
440585	206	188	248	146	105	92	102	142	71	66
505892	261	223	289	194	127	114	110	144	80	74
505893	307	229	326	210	132	135	106	153	88	79
539029	238	218	266	190	125	104	105	154	87	81
539030	301	223	326	198	133	129	108	150	88	80
557461	220	186	242	164	104	100	96	129	79	71
578789	276	226	305	196	128	124	109	145	95	81
578790	218	169	190	169	64	115	70	129	75	65
578791	322	245	365	203	131	153	104	147	95	81
578792	182	203	.	144	59	116	44	118	.	62
578793	313	251	349	215	141	140	116	159	90	83
578795	177	186	.	133	51	114	53	122	85	69
578796	268	225	297	196	127	119	113	153	91	82
578797	301	278	330	249	149	141	116	162	111	99
597488	220	177	220	176	101	97	109	149	93	83
Bellevue	274	230	298	206	126	126	105	144	81	85
Flare	298	222	308	.	121	141	107	.	97	.
Fraser	317	275	344	.	140	156	110	.	92	.

High_SLW	390	280	383	.	150	184	113	.	96	.
Lo_SLW	326	197	310	.	124	136	103	.	94	.
Palaton	315	298	376	237	131	127	106	.	96	.
PS-3	298	221	307	212	140	125	108	165	96	82
PSC_1142	294	232	311	.	149	155	107	144	101	84
RC-11	319	260	338	.	139	149	104	.	89	.
RC-5	292	314	351	.	150	154	105	.	89	.
RC-6	355	275	363	.	146	169	112	.	94	.
RC-7	273	259	314	.	134	130	98	.	91	.
RH33	286	278	331	.	130	157	88	.	80	.
RH47	275	215	293	.	125	120	109	.	93	.
RH50	138	122	178	.	63	68	80	.	52	.
RH78	103	66	133	.	27	59	55	.	57	.
RH85	206	181	242	.	95	102	86	.	73	.
Rival	294	210	325	179	128	123	101	151	95	73
Vantage	251	207	261	197	116	111	102	154	87	85
Venture	275	221	302	195	131	117	113	147	97	85
Mean	268	226	296	194	121	125	101	141	85	77
LSD (5%)	72	64	73	37	46	60	16	30	15	14
Maximum	449	345	445	361	184	214	123	165	111	99
Minimum	103	66	133	130	27	59	32	106	52	54

continued

Table III.10. Biomass quality trait means for all reed canarygrass accessions for spring and autumn harvests averaged across two years at Ames, IA.

	IVDMD†		NDF		ADF		ADL		CP	
Entry	Harv 1	Harv 2	Harv 1	Harv 2	Harv 1	Harv 2	Harv 1	Harv 2	Harv 1	Harv 2
	---				%--					
172443	59.7	52.5	56.9	61.2	31.9	33.9	3.6	4.2	12.9	9.3
206463	61.8	57.4	55.1	57.3	30.3	30.7	3.2	3.5	13.4	9.6
209979	62.3	57.2	53.9	59.6	28.9	32.3	3.1	3.6	13.2	9.9
225116	60.2	54.9	54.3	58.9	30.0	32.3	3.4	3.8	12.2	9.7
227670	57.0	51.9	57.0	61.2	32.0	33.7	3.8	4.0	13.5	9.0
234694	63.3	57.0	51.0	58.1	26.4	30.0	2.8	3.3	16.6	13.4
234695	62.9	56.4	52.8	60.7	29.0	34.2	3.0	3.6	14.4	10.7
234696	61.7	56.5	52.5	58.7	28.5	32.8	3.0	3.6	15.0	10.2
234698	61.5	55.9	55.8	58.6	30.2	32.2	3.1	3.6	13.0	10.4
234780	62.3	55.1	54.2	60.6	29.8	33.4	3.1	3.7	12.9	8.7
234790	60.8	52.0	54.3	61.9	29.6	34.3	3.3	4.1	13.6	8.7
235023	62.2	54.0	52.5	59.3	28.5	32.3	3.0	3.7	14.6	10.4
235482	58.0	56.0	54.9	58.0	29.5	31.4	3.5	3.8	12.1	9.2
235484	63.7	54.7	53.1	59.7	28.9	32.3	2.9	3.8	14.9	8.7
235485	62.4	56.0	53.1	59.2	28.8	31.9	3.0	3.7	13.8	8.7
235546	61.6	58.2	54.2	58.2	29.9	31.6	3.3	3.6	13.3	11.3
235547	61.1	54.9	56.1	60.4	30.5	33.3	3.3	4.1	13.8	10.6
235551	62.4	57.0	54.3	57.4	29.3	30.9	3.0	3.4	14.0	9.4
236525	63.3	56.7	52.9	60.7	29.0	33.4	3.0	3.5	16.6	9.8
241064	64.6	59.8	53.2	56.1	28.5	29.3	3.1	3.3	13.7	11.8
241065	57.7	60.2	56.6	59.2	30.9	32.5	3.6	3.2	11.5	11.4
251426	62.8	55.4	54.2	60.1	29.9	34.4	3.2	3.9	14.7	9.1
251531	59.4	54.0	55.8	60.4	30.0	32.7	3.4	3.9	12.5	8.3
251841	62.4	55.5	53.2	60.4	28.3	33.1	3.0	3.9	14.6	9.4
251842	61.6	55.6	55.0	59.7	29.8	32.4	3.2	3.7	13.2	10.1

Table III.10. Biomass quality trait means for all reed canarygrass accessions for spring and autumn harvests averaged across two years at Ames, IA.

	IVDMD†		NDF		ADF		ADL		CP	
Entry	Harv 1	Harv 2	Harv 1	Harv 2	Harv 1	Harv 2	Harv 1	Harv 2	Harv 1	Harv 2
	----------------------------------%----------------------------------									
253315	61.4	53.9	54.7	59.7	29.6	33.0	3.1	3.9	12.1	8.7
253316	63.3	55.9	53.8	60.5	29.0	33.3	3.1	3.8	13.9	9.2
253317	61.0	54.3	55.0	61.4	29.9	34.3	3.1	4.0	12.5	8.6
255887	64.0	57.8	53.6	58.7	28.4	32.4	2.9	3.6	13.7	9.7
269728	59.2	57.1	53.3	59.6	30.2	32.4	3.3	3.6	13.9	9.8
272122	65.6	55.2	53.0	58.9	28.4	32.5	2.8	3.8	14.8	9.9
272123	64.1	56.1	53.0	60.8	28.3	33.1	3.0	3.8	14.6	9.9
278706	59.8	57.2	55.1	59.6	30.1	32.1	3.2	3.7	13.5	10.5
284179	65.6	55.2	51.0	62.7	26.8	34.4	2.7	3.7	16.3	9.1
297362	63.9	60.3	51.5	54.6	27.0	28.1	2.7	3.1	17.0	14.0
314102	60.8	52.3	55.3	64.2	30.2	35.1	3.4	4.1	13.1	7.8
314581	60.9	56.0	54.7	59.5	28.5	30.6	3.2	3.4	15.4	10.5
314726	57.2	53.7	58.2	61.6	31.9	33.3	3.7	3.8	11.9	9.0
314727	62.2	57.8	54.6	58.8	29.8	31.3	3.2	3.6	13.7	11.5
314728	58.6	52.4	56.0	59.2	31.1	32.7	3.5	4.2	13.0	10.8
315486	60.5	56.2	54.6	59.4	29.8	32.9	3.2	3.8	12.8	8.4
315487	58.4	52.5	55.5	61.7	30.2	33.8	3.4	4.0	13.6	9.7
316329	66.5	60.4	51.7	58.3	28.1	31.9	2.9	3.1	16.0	11.5
316330	61.4	53.2	54.5	61.8	29.7	33.6	3.1	3.9	17.1	11.5
319825	63.8	55.2	52.6	60.6	27.8	33.2	2.9	3.8	15.8	10.8
329243	51.6	.	62.0	.	32.6	.	4.8	.	4.3	.
337718	58.9	53.7	58.1	63.4	31.9	34.6	3.6	3.9	11.5	7.9
338666	46.5	.	66.0	.	36.5	.	5.2	.	2.8	.
344557	61.4	57.4	54.9	59.2	29.6	32.0	3.2	3.5	12.3	8.5
345662	59.4	53.1	55.2	63.7	30.3	35.4	3.3	4.1	12.9	8.7
346015	61.6	55.6	54.0	59.4	28.9	32.3	3.1	3.7	14.0	9.5
357645	59.8	53.9	55.1	61.0	29.8	33.2	3.4	4.1	13.6	9.6
368980	58.5	54.9	57.2	61.3	31.5	33.7	3.5	3.9	11.7	6.9
369290	61.8	57.9	54.4	60.0	29.0	32.1	3.2	3.4	14.0	10.9
369291	60.4	56.4	55.7	60.9	30.4	33.3	3.2	3.6	14.3	10.0
369292	60.4	53.6	56.8	62.5	31.1	34.2	3.3	4.0	14.6	10.4
371754	62.0	57.8	53.8	58.6	29.1	31.3	3.1	3.5	13.3	9.9
372558	60.8	54.0	54.0	58.7	29.5	32.9	3.2	4.0	13.2	9.0
380963	58.0	54.0	58.1	62.0	32.5	34.5	3.8	4.1	14.5	11.2
380965	59.5	55.3	56.3	61.2	31.1	32.8	3.5	3.8	14.6	11.0
383726	59.7	58.5	56.9	61.9	30.7	32.7	3.3	3.3	14.4	13.0
387928	61.0	54.9	54.2	62.4	29.3	33.5	3.0	3.8	13.3	10.3
387929	60.4	53.7	56.0	61.8	29.2	32.3	3.0	3.8	13.5	10.5
392389	58.8	54.5	56.4	61.8	30.9	33.3	3.5	3.8	13.5	9.9
406316	58.7	55.8	56.1	59.7	30.6	33.0	3.5	3.6	12.6	8.7
422030	61.7	54.1	54.7	61.3	30.3	34.4	3.2	4.0	12.9	8.7
422031	60.2	51.8	56.0	64.0	30.2	35.6	3.1	4.1	13.9	7.5
433725	60.6	57.2	55.0	56.9	30.3	31.1	3.3	3.5	11.5	9.4
435294	58.5	55.0	57.0	60.6	30.9	33.3	3.3	3.7	12.9	9.9
435295	61.5	56.7	54.5	57.5	29.5	30.3	3.3	3.5	14.0	10.1
435296	63.1	55.6	51.8	59.5	27.6	31.4	2.8	3.7	15.1	9.6
435297	60.1	54.9	55.4	58.7	30.4	32.1	3.2	3.5	13.6	9.6
435298	62.4	56.9	52.3	58.2	28.5	32.0	2.9	3.5	15.2	11.2

continued

Table III.10. Biomass quality trait means for all reed canarygrass accessions for spring and autumn harvests averaged across two years at Ames, IA.

	IVDMD†		NDF		ADF		ADL		CP	
Entry	Harv 1	Harv 2	Harv 1	Harv 2	Harv 1	Harv 2	Harv 1	Harv 2	Harv 1	Harv 2
	--%--									
435299	61.8	57.6	53.7	59.6	29.0	32.6	3.1	3.6	16.1	11.3
435300	60.5	54.9	55.9	60.2	30.1	32.7	2.9	3.7	12.5	9.7
435301	59.7	53.9	56.4	61.4	30.7	33.5	3.5	4.1	14.7	9.7
435302	58.7	55.0	57.2	62.0	31.0	33.5	3.6	3.8	13.6	10.5
435303	57.5	54.2	58.1	61.8	32.5	33.9	3.5	3.6	12.4	8.8
435304	61.2	54.7	55.6	60.3	30.2	33.2	3.1	3.8	14.9	10.6
435305	60.6	56.4	55.9	59.3	29.9	31.3	3.2	3.6	14.0	10.1
435307	61.6	57.2	52.3	57.9	27.8	29.5	3.0	3.4	15.9	11.6
435308	61.9	55.1	52.0	56.1	27.6	29.2	3.1	3.8	15.8	9.0
435309	62.1	57.2	53.4	58.3	28.6	30.6	3.2	3.6	15.6	11.9
435311	59.5	55.4	55.9	60.5	30.6	31.8	3.4	3.7	13.7	10.0
435312	60.4	56.8	54.2	59.5	29.1	30.6	3.2	3.6	14.9	11.3
440584	57.3	56.0	57.5	60.3	32.0	32.1	3.6	3.6	14.1	11.0
440585	58.2	55.2	56.4	59.1	30.6	30.5	3.4	3.6	13.2	11.2
505892	60.0	56.4	55.6	58.6	29.8	31.2	3.2	3.6	14.6	11.0
505893	61.9	55.4	53.9	59.5	28.9	31.2	3.2	3.6	13.6	10.6

continued

539029	60.0	55.8	55.4	59.1	30.2	32.0	3.3	3.5	14.0	10.0
539030	57.9	53.6	54.5	58.9	29.5	32.1	3.4	3.9	11.0	10.7
557461	58.5	54.1	57.0	61.3	31.5	33.2	3.4	3.8	12.7	9.4
578789	59.4	55.3	56.0	60.2	30.6	33.4	3.2	3.7	12.7	8.9
578790	63.0	53.9	52.9	61.8	29.5	34.5	3.2	3.9	16.1	10.2
578791	61.0	53.2	55.7	61.5	30.5	34.3	3.3	4.0	12.9	7.9
578792	.	65.8	.	61.0	.	32.0	.	2.7	.	18.5
578793	60.2	56.6	55.1	59.8	30.4	33.2	3.3	3.7	12.4	9.1
578795	66.0	64.1	53.1	61.1	28.8	33.0	2.9	2.6	17.1	15.8
578796	59.4	56.5	56.5	59.3	31.0	31.7	3.4	3.5	12.3	8.7
578797	60.7	56.6	56.0	61.3	30.8	34.5	3.4	3.8	13.3	9.1
597488	58.3	55.1	56.1	60.9	30.5	33.6	3.4	3.9	13.6	9.4
Bellevue	60.1	52.6	55.2	62.3	30.4	34.6	3.3	4.1	13.1	8.0
Flare	61.5	54.4	55.0	61.5	29.8	34.7	3.1	3.9	13.3	8.2
Fraser	62.0	56.7	52.6	59.0	28.8	32.2	3.0	3.7	13.8	8.4
High_SLW	63.1	54.1	52.4	58.9	28.1	33.1	3.0	3.8	13.3	9.2
Lo_SLW	61.6	55.8	53.5	60.6	29.2	33.3	3.2	3.7	14.2	10.1
PS-3	63.1	52.7	54.0	62.9	29.4	35.6	2.9	3.9	13.7	7.9
PSC_1142	61.8	54.9	52.9	59.9	29.2	33.1	3.3	4.0	12.5	7.7
Palaton	61.0	56.9	56.1	60.2	30.9	32.7	3.2	3.7	12.1	9.2
RC-11	63.1	57.5	52.1	59.3	28.1	31.8	3.0	3.7	14.2	10.3
RC-5	61.3	56.5	54.7	60.8	30.0	33.0	3.0	3.6	10.9	8.9
RC-6	61.5	54.2	54.0	60.3	29.1	33.7	3.0	3.8	14.0	8.3
RC-7	64.1	55.7	50.4	60.1	27.6	32.9	2.8	3.8	15.8	11.4
RH33	62.2	57.6	51.5	55.7	27.6	29.3	2.9	3.3	16.2	11.9
RH47	61.5	54.4	54.2	60.7	28.8	34.0	3.0	3.9	13.9	9.1
RH50	63.3	60.5	54.8	58.0	27.9	29.8	3.0	3.1	16.0	12.0
RH78	68.1	60.2	47.5	54.3	23.2	27.0	2.4	3.0	19.8	15.4
RH85	62.4	60.9	55.1	57.8	29.3	29.4	3.3	3.1	11.9	11.8
Rival	62.6	57.8	53.8	62.0	29.4	34.1	3.1	3.4	14.2	11.4
Vantage	60.7	56.3	55.1	60.6	29.4	34.0	3.1	3.7	12.4	8.1

Table III.10. Biomass quality trait means for all reed canarygrass accessions for spring and autumn harvests averaged across two years at Ames, IA.

	IVDMD†		NDF		ADF		ADL		CP	
Entry	Harv 1	Harv 2	Harv 1	Harv 2	Harv 1	Harv 2	Harv 1	Harv 2	Harv 1	Harv 2
	---%--									
Venture	60.0	54.4	56.8	61.6	31.1	33.8	3.4	3.7	12.1	9.4
Mean	61.0	55.8	54.8	60.0	29.7	32.6	3.2	3.7	13.7	10.0
LSD (5%)	ns	ns	5.2	4	3.4	3.5	ns	ns	ns	ns
Maximum	68.1	65.8	66.0	64.2	36.5	35.6	5.2	4.2	19.8	18.5
Minimum	46.5	51.8	47.5	54.3	23.2	27.0	2.4	2.6	2.8	6.9

†IVDMD = In vitro dry matter disappearance; NDF = Neutral detergent fiber (hemicellulose + cellulose + lignin); ADF = Acid detergent fiber (cellulose + lignin); ADL = Acid detergent lignin (lignin); CP = crude protein.

Acknowledgments

We thank Mark Downing and Sandy McLaughlin at Oak Ridge National Laboratory, 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.

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RC-11	63.1	57.5	52.1	59.3	28.1	31.8	3.0	3.7	14.2	10.3
RC-5	61.3	56.5	54.7	60.8	30.0	33.0	3.0	3.6	10.9	8.9
RC-6	61.5	54.2	54.0	60.3	29.1	33.7	3.0	3.8	14.0	8.3
RC-7	64.1	55.7	50.4	60.1	27.6	32.9	2.8	3.8	15.8	11.4
RH33	62.2	57.6	51.5	55.7	27.6	29.3	2.9	3.3	16.2	11.9
RH47	61.5	54.4	54.2	60.7	28.8	34.0	3.0	3.9	13.9	9.1
RH50	63.3	60.5	54.8	58.0	27.9	29.8	3.0	3.1	16.0	12.0
RH78	68.1	60.2	47.5	54.3	23.2	27.0	2.4	3.0	19.8	15.4
RH85	62.4	60.9	55.1	57.8	29.3	29.4	3.3	3.1	11.9	11.8
Rival	62.6	57.8	53.8	62.0	29.4	34.1	3.1	3.4	14.2	11.4
Vantage	60.7	56.3	55.1	60.6	29.4	34.0	3.1	3.7	12.4	8.1
Venture	60.0	54.4	56.8	61.6	31.1	33.8	3.4	3.7	12.1	9.4
Mean	61.0	55.8	54.8	60.0	29.7	32.6	3.2	3.7	13.7	10.0
LSD (5%)	ns	ns	5.2	4	3.4	3.5	ns	ns	ns	ns
Maximum	68.1	65.8	66.0	64.2	36.5	35.6	5.2	4.2	19.8	18.5
Minimum	46.5	51.8	47.5	54.3	23.2	27.0	2.4	2.6	2.8	6.9

†IVDMD = In vitro dry matter disappearance; NDF = Neutral detergent fiber (hemicellulose + cellulose + lignin); ADF = Acid detergent fiber (cellulose + lignin); ADL = Acid detergent lignin (lignin); CP = crude protein.

Acknowledgments

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APPENDIX I. DETAILED ESTABLISHMENT YEAR COST ESTIMATES FOR SEVEN PRODUCTION SCENARIOS DESCRIBED IN SECTION I.1, AND EXPECTED COSTS OF RESEEDING UNDER ALTERNATIVE SEEDING TIMINGS.

Table 1.1. Estimated establishment budgets for frost seeded switchgrass on croplands, and on grasslands.

Preharvest machinery operations	Switchgrass on cropland	Switchgrass on grassland
	Cost per acre*	Cost per acre*
Disc	$8.00	-
Harrow	$3.85	-
Mowing	-	$6.80
Airflow spreader (seed and fertilizers)	$4.50	$4.50
Spraying Roundup™	-	$4.30
Spraying Atrazine and 2,4 D	$4.30	$4.30
Total machinery cost	$20.65	$19.90

Operating Expenses	Unit	Price/Unit	Amount	Switchgrass cropland	Switchgrass grassland
				Cost Per Acre	Cost Per Acre
Seed	lb of PLS				
Fertilizer	(0-30-40)**	$4.00	$10.00	$40.00	$40.00
Lime (including its application)	ton	$11.50	$3.00	$13.70	$13.70
Herbicide				$34.50	$34.50
Atrazine	qt.	$2.93	$1.50	$4.40	$4.40
2,4 D	pt.	$1.63	$1.50	$2.45	$2.45
Roundup™	qt.	$9.39	$2.00	-	$18.77
Total operating cost	$/acre			$95.04	$113.81
Land charge (cash rent equivalent)	$/acre			$75.00	$50.00
Total establishment cost				$190.69	$183.71
Prorated establishment costs (11 yrs. @ 8%)				$26.71	$25.73

* Source: 2000 Iowa Farm Custom Rate Survey, FM-1698, March 2000.
** Phosphorus price = $.27/lb; potassium price = $.14/lb.

Table I.2. Reseeding estimated costs for frost seeded switchgrass (25, 15, and 10% probability of reseeding).

Switchgrass on cropland and grassland	Cost per acre*
Preharvest machinery operations	
Airflow spreader (seed and fertilizers)	$4.50
Spraying chemicals	$4.30
Total machinery cost	$8.80

Operating Expenses	Unit	Price/Unit	Amount	Cost Per Acre
Seed	lb of PLS	$4.00	$7.00	$28.00
Fertilizer	(0-30-40)**			$3.70
Herbicide				
Atrazine	qt.	$2.93	$1.50	$4.40
2,4 D	pt.	$1.63	$1.50	$2.45
Total operating cost	$/acre			$48.54

25% reseeding probability	Unit	Switchgrass on cropland	Switchgrass on grassland
Land charge (cash rent equivalent)	$/acre	$75.00	$50.00
Total reseeding cost	$/acre	$132.34	$107.34
Expected reseeding costs (25%)		$33.09	$26.84
Prorated reseeding cost (10 yrs. @ 8%)		$4.93	$4.00

15% reseeding probability		Switchgrass on cropland	Switchgrass on grassland
Land charge (cash rent equivalent)	$/acre	$75.00	$50.00
Total reseeding cost	$/acre	$132.34	$107.34
Expected reseeding costs (15%)		$19.85	$16.10
Prorated reseeding cost (10 yrs. @ 8%)		$2.96	$2.40

10% reseeding probability		Switchgrass on cropland	Switchgrass on grassland
Land charge (cash rent equivalent)	$/acre	$75.00	$50.00
Total reseeding cost	$/acre	$132.34	$107.34
Expected reseeding costs (10%)		$13.23	$10.73
Prorated reseeding cost (10 yrs. @ 8%)		$1.97	$1.60

* Source: 2000 Iowa Farm Custom Rate Survey, FM-1698, March 2000.

** Phosphorus price = $.27/lb; potassium price = $.14/lb.

Table I.3a. Estimated production year budgets for frost seeded switchgrass (yield: 1.5 tons/acre and 25% probability of reseeding).

Switchgrass on cropland and grassland	Cost per acre*
Preharvest Machinery Operations	
Spreading liquid nitrogen	$4.35
Applying P&K	$3.15
Spraying chemicals	$4.30
Total machinery cost	$11.80

Switchgrass on cropland and grassland	Unit	Price/Unit	Amount	Cost per acre
Operating Expenses				
Nitrogen	lb.	$.21	$100.00	$21.00
P	lb.	$.27	$2.91	$.79
K	lb.	$.14	$34.20	$4.79
Herbicide				
Atrazine	qt.	$2.93	$1.50	$4.40
2,4 D	pt.	$1.63	$1.50	$2.45
Total operating cost	$/acre			$33.42
Interest on operating expenses (9%)	$/acre			$1.50

Switchgrass on cropland and grassland	Cost/Ton	Cost per acre
Harvesting and Storing Expenses		
Mowing/conditioning	$5.80	$8.70
Raking	$2.73	$4.10
Baling (large square bales)	$16.34	$24.51
Staging and loading	$6.51	$9.77
Total harvesting cost	$31.39	$47.08

	Switchgrass on cropland	Switchgrass on grassland
Land charge (cash rent equivalent)	$75.00	$50.00
Prorated establishment costs (11 yrs. @ 8%)	$26.71	$25.73
Prorated reseeding costs (10 yrs. @ 8%)	$4.93	$4.00
Total production costs per acre	$200.44	$173.53
Total costs per bale	$57.27	$49.58
Total costs per ton	$133.63	$115.69

* Source: 2000 Iowa Farm Custom Rate Survey, FM-1698, March 2000.

Table I.3b. Estimated production year budgets for frost seeded switchgrass (yield: 3 tons/acre and 25% probability of reseeding).

Switchgrass on cropland and grassland				Cost per acre*
Preharvest machinery operations				
Spreading liquid nitrogen				$4.35
Applying P&K				$3.15
Spraying chemicals				$4.30
Total machinery cost				$11.80
Switchgrass on cropland and grassland	**Unit**	**Price/Unit**	**Amount**	**Cost per acre**
Operating expenses				
Nitrogen	lb.	$.21	$100.00	$21.00
P	lb.	$.27	$5.82	$1.57
K	lb.	$.14	$68.40	$9.58
Herbicide				
Atrazine	qt.	$2.93	$1.50	$4.40
2,4 D	pt.	$1.63	$1.50	$2.45
Total operating cost	$/acre			$38.99
Interest on operating expenses (9 %)	$/acre			$1.75

Switchgrass on cropland and grassland	Cost/Ton	Cost per acre
Mowing/conditioning	$2.90	$8.70
Raking	$1.37	$4.10
Baling (large square bales)	$16.34	$49.03
Staging and loading	$6.51	$19.53
Total harvesting cost	$27.12	$81.36

	Switchgrass on cropland	Switchgrass on grassland
Land charge (cash rent equivalent)	$75.00	$50.00
Prorated establishment costs (11 yrs. @ 8%)	$26.71	$25.73
Prorated reseeding costs (10 yrs. @ 8%)	$4.93	$4.00
Total production costs per acre	$240.55	$213.64
Total costs per bale	$34.36	$30.52
Total costs per ton	$80.18	$71.21

* Source: 2000 Iowa Farm Custom Rate Survey, FM-1698, March 2000.

Table I.3c. Estimated production year budgets for frost seeded Switchgrass (Yield: 4 tons/acre and 25% probability of reseeding).

Switchgrass on cropland and grassland	Cost per acre*
Preharvest machinery operations	
Spreading liquid nitrogen	$4.35
Applying P&K	$3.15
Spraying chemicals	$4.30
Total machinery cost	$11.80

Switchgrass on cropland and grassland	Unit	Price/Unit	Amount	Cost per acre
Operating expenses				
Nitrogen	lb.	$.21	$100.00	$21.00
P	lb.	$.27	$7.76	$2.10
K	lb.	$.14	$91.20	$12.77
Herbicide				
Atrazine	qt.	$2.93	$1.50	$4.40
2,4 D	pt.	$1.63	$1.50	$2.45
Total operating cost	$/acre			$42.71
Interest on operating expenses (9 %)	$/acre			$1.92

Switchgrass on cropland and grassland	Cost/ton	Cost per acre
Mowing/conditioning	$2.18	$8.70
Raking	$1.03	$4.10
Baling (large square bales)	$16.34	$65.37
Staging and loading	$6.51	$26.04
Total harvesting cost	$26.05	$104.21

	Switchgrass on cropland	Switchgrass on grassland
Land charge (cash rent equivalent)	$75.00	$50.00
Prorated establishment costs (11 yrs. @ 8%)	$26.71	$25.73
Prorated reseeding costs (10 yrs. @ 8%)	$4.93	$4.00
Total production costs per acre	$267.28	$240.37
Total costs per bale	$28.65	$25.76
Total costs per ton	$66.82	$60.09

* Source: 2000 Iowa Farm Custom Rate Survey, FM-1698, March 2000.

Table I.3d. Estimated production year budgets for frost seeded Switchgrass (Yield: 6 tons/acre and 25% probability of reseeding).

Switchgrass on cropland and grassland	Cost per acre*
Preharvest machinery operations	
Spreading liquid nitrogen	$4.35
Applying P&K	3.15
Spraying chemicals	4.30
Total machinery cost	$11.80

Switchgrass on cropland and grassland	Unit	Price/Unit	Amount	Cost per acre
Operating expenses				
Nitrogen	lb.	$.21	$100.00	$21.00
P	lb.	$.27	$11.65	$3.15
K	lb.	$.14	$136.80	$19.15
Herbicide				
Atrazine	qt.	$2.93	$1.50	$4.40
2,4 D	pt.	$1.63	$1.50	$2.45
Total operating cost	$/acre			$50.14
Interest on operating expenses (9 %)	$/acre			$2.26

Switchgrass on cropland and grassland	Cost/Ton	Cost per acre
Mowing/conditioning	$1.45	$8.70
Raking	$.68	$4.10
Baling (large square bales)	$16.34	$98.06
Staging and loading	$6.51	$39.06
Total harvesting cost	$24.99	$149.92

	Switchgrass on cropland	Switchgrass on grassland
Land charge (cash rent equivalent)	$75.00	$50.00
Prorated establishment costs (11 yrs. @ 8%)	$26.71	$25.73
Prorated reseeding costs (10 yrs. @ 8%)	$4.93	$4.00
Total production costs per acre	$320.76	$293.85
Total costs per bale	$22.91	$20.99
Total costs per ton	$53.46	$48.97

* Source: 2000 Iowa Farm Custom Rate Survey, FM-1698, March 2000.

Table I.4a. Estimated production year budgets for frost seeded Switchgrass (Yield: 1.5 tons/acre) and four levels of reseeding probabilities (25, 15, 10, and 0%).

25% reseeding probability	Switchgrass on cropland	Switchgrass on grassland
Land charge (cash rent equivalent)	$75.00	$50.00
Prorated establishment costs (11 yrs. @ 8%)	$26.71	$25.73
Prorated reseeding costs (10 yrs. @ 8%)	$4.93	$4.00
Total production costs per acre	$200.44	$173.53
Total costs per bale	$57.27	$49.58
Total costs per ton	$133.63	$115.69
15% reseeding probability	**Switchgrass on cropland**	**Switchgrass on grassland**
Land charge (cash rent equivalent)	$75.00	$50.00
Prorated establishment costs (11 yrs. @ 8%)	$26.71	$25.73
Prorated reseeding costs (10 yrs. @ 8%t)	$2.96	$2.40
Total production costs per acre	$198.47	$171.93
Total costs per bale	$56.71	$49.12
Total costs per ton	$132.31	$114.62
10% reseeding probability	**Switchgrass on cropland**	**Switchgrass on grassland**
Land charge (cash rent equivalent)	$75.00	$50.00
Prorated establishment costs (11 yrs. @ 8%)	$26.71	$25.73
Prorated reseeding costs (10 yrs. @ 8%)	$1.97	$1.60
Total production costs per acre	$197.48	$171.13
Total costs per bale	$56.42	$48.90
Total costs per ton	$131.66	$114.09
0% reseeding probability	**Switchgrass on cropland**	**Switchgrass on grassland**
Land charge (cash rent equivalent)	$75.00	$50.00
Prorated establishment costs (11 yrs. @ 8 %)	$26.71	$25.73
Prorated reseeding costs (10 yrs. @ 8%)	$0.00	$0.00
Total production costs per acre	$195.51	$169.53
Total costs per bale	$55.86	$48.44
Total costs per ton	$130.34	$113.02

* Source: 2000 Iowa Farm Custom Rate Survey, FM-1698, March 2000.

Table I.4b. Estimated production year budgets for frost seeded switchgrass (Yield: 3 tons/acre) and four levels of reseeding probabilities (25, 15, 10, and 0%).

25% reseeding probability	Switchgrass on cropland	Switchgrass on grassland
Land charge (cash rent equivalent)	$75.00	$50.00
Prorated establishment costs (11 yrs. @ 8%)	$26.71	$25.73
Prorated reseeding costs (10 yrs. @ 8%)	$4.93	$4.00
Total production costs per acre	$240.55	$213.64
Total costs per bale	$34.36	$30.52
Total costs per ton	$80.18	$71.21
15% reseeding probability	**Switchgrass on cropland**	**Switchgrass on grassland**
Land charge (cash rent equivalent)	$75.00	$50.00
Prorated establishment costs (11 yrs. @ 8%)	$26.71	$25.73
Prorated reseeding costs (10 yrs. @ 8%t)	$2.96	$2.40
Total production costs per acre	$238.57	$212.04
Total costs per bale	$34.08	$30.29
Total costs per ton	$79.52	$70.68
10% reseeding probability	**Switchgrass on cropland**	**Switchgrass on grassland**
Land charge (cash rent equivalent)	$75.00	$50.00
Prorated establishment costs (11 yrs. @ 8%)	$26.71	$25.73
Prorated reseeding costs (10 yrs. @ 8%)	$1.97	$1.60
Total production costs per acre	$237.59	$211.24
Total costs per bale	$33.94	$30.18
Total costs per ton	$79.20	$70.41
0% reseeding probability	**Switchgrass on cropland**	**Switchgrass on grassland**
Land charge (cash rent equivalent)	$75.00	$50.00
Prorated establishment costs (11 yrs. @ 8 %)	$26.71	$25.73
Prorated reseeding costs (10 yrs. @ 8%)	$0.00	$0.00
Total production costs per acre	$235.62	$209.64
Total costs per bale	$33.66	$29.95
Total costs per ton	$78.54	$69.88

* Source: 2000 Iowa Farm Custom Rate Survey, FM-1698, March 2000

Table I.4c. Estimated production year budgets for frost seeded switchgrass (Yield: 4 tons/acre) and four levels of reseeding probabilities (25, 15, 10, and 0%).

25% reseeding probability	Switchgrass on cropland	Switchgrass on grassland
Land charge (cash rent equivalent)	$75.00	$50.00
Prorated establishment costs (11 yrs. @ 8%)	$26.71	$25.73
Prorated reseeding costs (10 yrs. @ 8%)	$4.93	$4.00
Total production costs per acre	$267.28	$240.37
Total costs per bale	$28.65	$25.76
Total costs per ton	$66.82	$60.09
15% reseeding probability	**Switchgrass on cropland**	**Switchgrass on grassland**
Land charge (cash rent equivalent)	$75.00	$50.00
Prorated establishment costs (11 yrs. @ 8%)	$26.71	$25.73
Prorated res eeding costs (10 yrs. @ 8%t)	$2.96	$2.40
Total production costs per acre	$265.31	$238.77
Total costs per bale	$28.44	$25.59
Total costs per ton	$66.33	$59.69
10% reseeding probability	**Switchgrass on cropland**	**Switchgrass on grassland**
Land charge (cash rent equivalent)	$75.00	$50.00
Prorated establishment costs (11 yrs. @ 8%)	$26.71	$25.73
Prorated reseeding costs (10 yrs. @ 8%)	$1.97	$1.60
Total production costs per acre	$264.32	$237.97
Total costs per bale	$28.33	$25.51
Total costs per ton	$66.08	$59.49
0% reseeding probability	**Switchgrass on cropland**	**Switchgrass on grassland**
Land charge (cash rent equivalent)	$75.00	$50.00
Prorated establishment costs (11 yrs. @ 8 %)	$26.71	$25.73
Prorated reseeding costs (10 yrs. @ 8%)	$0.00	$0.00
Total production costs per acre	$262.35	$236.37
Total costs per bale	$28.12	$25.33
Total costs per ton	$65.59	$59.09

* Source: 2000 Iowa Farm Custom Rate Survey, FM-1698, March 2000.

Table I.4d. Estimated production year budgets for frost seeded switchgrass (Yield: 6 tons/acre) and four levels of reseeding probabilities (25, 15%, 10, and 0%).

25% reseeding probability	Switchgrass on cropland	Switchgrass on grassland
Land charge (cash rent equivalent)	$75.00	$50.00
Prorated establishment costs (11 yrs. @ 8%)	$26.71	$25.73
Prorated reseeding costs (10 yrs. @ 8%)	$4.93	$4.00
Total production costs per acre	$320.76	$293.85
Total costs per bale	$22.91	$20.99
Total costs per ton	$53.46	$48.97
15% reseeding probability	**Switchgrass on cropland**	**Switchgrass on grassland**
Land charge (cash rent equivalent)	$75.00	$50.00
Prorated establishment costs (11 yrs. @ 8%)	$26.71	$25.73
Prorated reseeding costs (10 yrs. @ 8%t)	$2.96	$2.40
Total production costs per acre	$318.78	$292.25
Total costs per bale	$22.77	$20.87
Total costs per ton	$53.13	$48.71
10% reseeding probability	**Switchgrass on cropland**	**Switchgrass on grassland**
Land charge (cash rent equivalent)	$75.00	$50.00
Prorated establishment costs (11 yrs. @ 8%)	$26.71	$25.73
Prorated reseeding costs (10 yrs. @ 8%)	$1.97	$1.60
Total production costs per acre	$317.80	$291.45
Total costs per bale	$22.70	$20.82
Total costs per ton	$52.97	$48.57
0% reseeding probability	**Switchgrass on cropland**	**Switchgrass on grassland**
Land charge (cash rent equivalent)	$75.00	$50.00
Prorated establishment costs (11 yrs. @ 8 %)	$26.71	$25.73
Prorated reseeding costs (10 yrs. @ 8%)	$0.00	$0.00
Total production costs per acre	$315.83	$289.85
Total costs per bale	$22.56	$20.70
Total costs per ton	$52.64	$48.31

*Source: 2000 Iowa Farm Custom Rate Survey, FM-1698, March 2000.

APPENDIX II. PRELIMINARY BUDGETS FOR REED CANARYGRASS

Table II.1. Estimated establishment budget for reed canarygrass on cropland.

Preharvest machinery operations		Cost per acre*		
No till grass seed drill		$10.85		
Mowing weeds		$7.05		
Spreading fertilizers		$3.25		
Spraying 2,4 D		$4.60		
Total machinery cost		$25.75		
Operating expenses	**Unit**	**Price/Unit**	**Amount**	**Cost per acre**
Seed	lb of PLS	$3.25	$11.00	$35.75
Fertilizer	(0-30-40)**			$13.70
Lime (including its application)	ton	$12.00	$3.00	$36.00
Herbicide (2,4 D)	pt.	$1.63	$1.50	$2.45
Total operating cost	$/acre			$87.90
Land charge (cash rent equivalent)	$/acre			$75.00
Total establishment costs				$188.65
Prorated establishment costs (11 yrs. @ 8%)				$26.43

* Source: 2001 Iowa Farm Custom Rate Survey, FM-1698, March 2001.
** Phosphorus price = $.27/lb; potassium price = $.14/lb.

Table II.2a. Estimated establishment budget of reed canarygrass on grassland (1) (using a burn down herbicide) preharvest machinery operations cost per acre*.

Preharvest machinery operations		Cost per acre*		
No till grass seed drill		$10.85		
Mowing weeds		$7.05		
Spreading fertilizers		$3.25		
Spraying 2,4 D		$4.60		
Spraying Roundup ™ to kill sods		$4.60		
Total machinery cost		$30.35		
Operating expenses	**Unit**	**Price/Unit**	**Amount**	**Cost per acre**
Seed	lb of PLS	$3.25	$11.00	$35.75
Fertilizer	(0-30-40)**			$13.70
Lime (including its application)	ton	$12.00	$3.00	$36.00
Herbicide				
2,4 D	pt.	$1.63	$1.50	$2.45
Roundup™	qt.	$9.39	$2.00	$18.77
Total operating cost	$/acre			$106.67
Land charge (cash rent equivalent)	$/acre			$50.00
Total establishment costs				$187.02
Prorated establishment costs (11 yrs. @ 8%)				$26.20

* Source: 2001 Iowa Farm Custom Rate Survey, FM-1698, March 2001.
** Phosphorus price = $.27/lb; potassium price = $.14/lb.

Table II.2b. Estimated establishment budget of reed canarygrass on grassland (2) (plow and disk).

Preharvest machinery operations	Cost per acre*
Grass seed drill	$10.85
Plowing	$11.05
Disking	$7.75
Mowing weeds	$7.05
Spreading fertilizers	$3.25
Spraying 2,4 D	$4.60
Total machinery cost	$42.95

Operating expenses	Unit	Price/Unit	Amount	Cost per acre
Seed	lb of PLS	$3.25	$11.00	$35.75
Fertilizer	(0-30-40)**			$13.70
Lime (including its application)	ton	$12.00	$3.00	$36.00
Herbicide (2,4 D)	pt.	$1.63	$1.50	$2.45
Total operating cost	$/acre			$87.90
Land charge (cash rent equivalent)				$50.00
Total establishment costs				$180.85
Prorated establishment costs (11 yrs. @ 8%)				$25.33

* Source: 2001 Iowa Farm Custom Rate Survey, FM-1698, March 2001.
** Phosphorus price = $.27/lb; potassium price = $.14/lb.

Table II.3. Estimated production year budgets for reed canarygrass on cropland and on grassland. Expected Yield: 3 tons/acre, approximately 5 large square bales: 1100 Pounds/bale reed canarygrass on cropland and grassland.

Preharvest machinery operations			Cost per acre*	
Spreading liquid nitrogen (2x)			$9.10	
Applying P&K			$3.25	
Spraying chemicals			$4.60	
Total machinery cost			$16.95	
	Unit	Price/Unit	Amount	Cost per acre
Nitrogen	lb.	$.21	$90.00	$18.90
P	lb.	$.27	$30.00	$8.10
K	lb.	$.14	$40.00	$5.60
Herbicide (2,4 D)	pt.	$1.63	$1.50	$2.45
Total operating cost	$/acre			$35.05
Interest on operating expenses (9%)	$/acre			$1.58
Harvesting and storing expenses			Cost/Ton	Cost per acre
Mowing/conditioning (2x)			$5.93	$17.80
Raking (2x)			$2.60	$7.80
Baling (large square bales) (2x)***			$12.91	$38.73
Staging and loading (2x)***			$6.51	$19.53
Total harvesting cost			$27.95	$83.86
	Reed canarygrass on cropland		Reed canarygrass on grassland (1) and (2)	
Land charge (cash rent equivalent)	$75.00		$50.00	$50.00
Prorated establishment costs (11 yrs. @ 8%)	$26.43		$26.20	$25.33
Total production costs per acre	$238.86		$213.63	$212.76
Total costs per bale	$47.77		$42.73	$42.55
Total costs per ton	$79.62		$71.21	$70.92

* Source: 2001 Iowa Farm Custom Rate Survey, FM-1698, March 2001.

** Phosphorus price = $.27/lb; potassium price = $.14/lb.

*** The cost of baling is on per bale basis. For the first baling, 3 bales (60% of production) and for the second baling, 2 bales (40% of production). The staging and loading is on per ton basis. For first staging, 1.8 tons (60% of production), for second staging, 1.2 tons (40% production).

Table II.4. Estimated production year budgets for reed canarygrass on cropland and on grassland. Expected Yield: 4 tons/acre, approximately 7 large square bales: 1100 Pounds/bale.

Preharvest machinery operations			Cost per acre*	
Spreading liquid nitrogen (2x)			$9.10	
Applying P&K			$3.25	
Spraying chemicals			$4.60	
Total machinery cost			$16.95	
	Unit	Price/Unit	Amount	Cost per acre
Nitrogen	lb.	$.21	$90.00	$18.90
P	lb.	$.27	$30.00	$8.10
K	lb.	$.14	$40.00	$5.60
Herbicide (2,4 D)	pt.	$1.63	$1.50	$2.45
Total operating cost	$/acre			$35.05
Interest on operating expenses (9%)	$/acre			$1.58
Harvesting and storing expenses			Cost/Ton	Cost per acre
Mowing/conditioning (2x)			$4.45	$17.80
Raking (2x)			$1.95	$7.80
Baling (large square bales) (2x)***			$12.91	$51.64
Staging and loading (2x)***			$6.51	$26.04
Total harvesting cost			$25.82	$103.28
	Reed canarygrass on cropland		Reed canarygrass on grassland (1) and (2)	
Land charge (cash rent equivalent)	$75.0		$50.00	$50.00
Prorated establishment costs (11 yrs. @ 8%)	$26.43		$26.20	$25.33
Total production costs per acre	$258.28			$232.18
			$233.05	
Total costs per bale	$36.90		$33.29	$33.17
Total costs per ton	$64.57		$58.26	$58.04

* Source: 2001 Iowa Farm Custom Rate Survey, FM-1698, March 2001

** Phosphorus price = $.27/lb; potassium price = $.14/lb

*** The cost of baling is on per bale basis. For first baling, 4 bales (60% of production) and for the second baling, 3 bales (40% of production). The staging and loading is on per ton basis. For first staging, 2.4 tons (60% of production), for second staging, 1.6 tons (40% production).

Table II.4. Estimated production year budgets for reed canarygrass on cropland and on grassland. Expected Yield: 6 tons/acre, approximately 11large square bales: 1100 pounds/bale.

Preharvest machinery operations			Cost per acre*	
Spreading liquid nitrogen (2x)			$9.10	
Applying P&K			$3.25	
Spraying chemicals			$4.60	
Total machinery cost			$16.95	
	Unit	Price/Unit	Amount	Cost per acre
Nitrogen	lb.	$.21	$90.00	$18.90
P	lb.	$.27	$30.00	$8.10
K	lb.	$.14	$40.00	$5.60
Herbicide (2,4 D)	pt.	$1.63	$1.50	$2.45
Total operating cost	$/acre			$35.05
Interest on operating expenses (9%)	$/acre			$1.58
Harvesting and storing expenses			Cost/Ton	Cost per acre
Mowing/conditioning (2x)			$2.97	$17.80
Raking (2x)			$1.30	$7.80
Baling (large square bales) (2x)***			$12.91	$77.45
Staging and loading (2x)***			$6.51	$39.06
Total harvesting cost			$23.69	$142.11
	Reed canarygrass on cropland		Reed canarygrass on grassland (1) and (2)	
Land charge (cash rent equivalent)	$75.00		$50.00	$50.00
Prorated establishment costs (11 yrs. @ 8%)	$26.43		$26.20	$25.33
Total production costs per acre	$297.12			$271.02
			$271.89	
Total costs per bale	$27.01			$24.64
			$24.72	
Total costs per ton	$49.52			$45.17
			$45.31	

* Source: 2001 Iowa Farm Custom Rate Survey, FM-1698, March 2001.

** Phosphorus Price = $.27/lb; Potassium Price = $.14/lb.

*** The cost of baling is on per bale basis. For first baling, 7 bales (60% of production) and for the second baling, 4 bales (40% of production). The staging and loading is on per ton basis. For first staging, 3.6 tons (60% of production), for second staging, 2.4 tons (40% production).

Appendix Table III.1. Names and origins of accessions planted in the reed canarygrass germplasm trials at Ames, IA and Arlington, WI in 1998.

Accession	Origin	Germplasm name	Test
PI 172443	Turkey		IA & WI
PI 206463	Turkey		IA & WI
PI 209979	Former Soviet Union		IA & WI
PI 225116	Germany		IA & WI
PI 227670	Iran		IA & WI
PI 234694	Denmark		IA & WI
PI 234695	Denmark		IA & WI
PI 234696	Denmark		IA & WI
PI 234698	Denmark		IA & WI
PI 234780	Germany		IA & WI
PI 234790	Sweden		IA & WI
PI 235023	Germany		IA & WI
PI 235482	Switzerland		IA & WI
PI 235484	Switzerland		IA & WI
PI 235485	Switzerland		IA & WI
PI 235546	Sweden		IA & WI
PI 236525	Portugal		IA & WI
PI 251426	Yugoslavia		IA & WI
PI 251531	Yugoslavia		IA & WI
PI 251841	Austria		IA & WI
PI 251842	Austria		IA & WI
PI 253317	Yugoslavia		IA & WI
PI 255887	Poznan, Poland		IA & WI
PI 269728	Iowa, United States		IA & WI
PI 272122	Poland	Motycka	IA & WI
PI 272123	Poland	Nakielska	IA & WI
PI 284179	France	CPI 6764	IA & WI
PI 297362	Ostfold, Norway		IA & WI
PI 314102	Former Soviet Union	75	IA & WI
PI 314581	Former Soviet Union	304	IA & WI
PI 314726	Former Soviet Union	339	IA & WI
PI 314727	Former Soviet Union	380	IA & WI
PI 314728	Former Soviet Union	492	IA & WI
PI 315486	Former Soviet Union	33923	IA & WI
PI 315487	Former Soviet Union	34003	IA & WI
PI 316329	Austr. Capital Terr., Australia	CPI 7594	IA & WI
PI 316330	Portugal	CPI 10446	IA & WI
PI 319825	Akershus, Norway	239	IA & WI
PI 329243	Argentina	CPI 27961	IA & WI
PI 337718	Former Soviet Union		IA & WI
PI 338666	Morocco	107	IA & WI
PI 344557	East Slovakia, Slovakia	60	IA & WI
PI 345662	Former Soviet Union	Donskoi 18	IA & WI
PI 346015	Norway	1828	IA & WI
PI 357645	Ontario, Canada	Grove	IA & WI
PI 368980	Portugal	NS 589	IA & WI
PI 369290	Former Soviet Union	1697	IA & WI
PI 369291	Former Soviet Union	1698	IA & WI
PI 369292	Former Soviet Union	1720	IA & WI

Appendix Table III.1. Names and origins of accessions planted in the reed canarygrass germplasm trials at Ames, IA and Arlington, WI in 1998.

Accession	Origin	Germplasm name	Test
PI 371754	Alaska, United States	PN-609	IA & WI
			continued
PI 372558	Ontario, Canada		IA & WI
PI 380963	Iran	308	IA & WI
PI 380965	Iran	439	IA & WI
PI 383726	Turkey	188	IA & WI
PI 387928	Canada	360	IA & WI
PI 387929	British Columbia, Canada	367	IA & WI
PI 392389	Former Soviet Union	62	IA & WI
PI 406316	Former Soviet Union	Priekul'skij 15	IA & WI
PI 422030	Missouri, United States	Ioreed	IA & WI
PI 422031	Missouri, United States	Auburn	IA & WI
PI 433725	Germany		IA & WI
PI 435294	Russian Federation		IA & WI
PI 435295	Russian Federation		IA & WI
PI 435296	Russian Federation		IA & WI
PI 435297	Russian Federation		IA & WI
PI 435298	Russian Federation		IA & WI
PI 435299	Russian Federation		IA & WI
PI 435300	Ukraine		IA & WI
PI 435301	Kazakhstan		IA & WI
PI 435302	Kazakhstan		IA & WI
PI 435303	Kazakhstan		IA & WI
PI 435304	Russian Federation		IA & WI
PI 435305	Russian Federation		IA & WI
PI 435307	Russian Federation		IA & WI
PI 435308	Russian Federation		IA & WI
PI 435309	Russian Federation		IA & WI
PI 435311	Russian Federation		IA & WI
PI 435312	Russian Federation		IA & WI
PI 440584	Former Soviet Union	D-1827	IA & WI
PI 440585	Former Soviet Union	D-1828	IA & WI
PI 505892	Former Soviet Union	Pervence	IA & WI
PI 505893	Former Soviet Union	Kievskij	IA & WI
PI 539029	Russian Federation	AJC-481	IA & WI
PI 539030	Russian Federation	AJC-482	IA & WI
PI 557461	Canada	S-8986	IA & WI
PI 578789	Missouri, United States	MI 4694 Ioreed	IA & WI
PI 578790	Arkansas, United States	Arkansas Upland	IA & WI
PI 578791	Wisconsin, United States	Syn 4 Loreed	IA & WI
PI 578792	Oregon, United States	Superior	IA & WI
PI 578793	Minnesota, United States	NCRC1	IA & WI
PI 578795	California, United States	Cana	IA & WI
PI 578796	Iowa, United States	Rise	IA & WI
PI 578797	Minnesota, United States	MN-76	IA & WI
PI 597488	Saskatchewan, Canada	S-8799	IA & WI
Bellevue	Canadian cultivar		IA & WI
Palaton	US cultivar		IA & WI
PSC 1142	US cultivar		IA & WI
Rival	Canadian cultivar		IA & WI
Vantage	US cultivar		IA & WI

Appendix Table III.1. Names and origins of accessions planted in the reed canarygrass germplasm trials at Ames, IA and Arlington, WI in 1998.

Accession	Origin	Germplasm name	Test
Venture	US cultivar		IA & WI
			continued
Fraser	Collected on Brummer Farm, IA		IA only
RH33	From M. Sahramaa, Finland collections		IA Only
RH47	From M. Sahramaa, Finland collections		IA Only
RH50	From M. Sahramaa, Finland collections		IA Only
RH78	From M. Sahramaa, Finland collections		IA Only
RH85	From M. Sahramaa, Finland collections		IA Only
PI 235547	Sweden		IA only
PI 235551	Denmark		IA only
PI 241064	Maryland, United States		IA only
PI 241065	Maryland, United States		IA only
PI 253315	Yugoslavia		IA only
PI 253316	Yugoslavia		IA only
PI 278706	Canada	Ames 85	IA only
High SLW	ISU germplasm		IA only
Lo SLW	ISU germplasm		IA only
Flare	US cultivar		IA only
RC-5	ISU germplasm		IA only
RC-6	ISU germplasm		IA only
RC-7	ISU germplasm		IA only
RC-11	ISU germplasm		IA only
PS-3	ISU germplasm		IA only
Not Included—Poor Germ			
PI 234697	Denmark		
PI 235483	Switzerland		
PI 237724	Germany	Weihenstephaner	
Jericho	Collected in Jericho, VT		
Not Available From PI Station:			
PI 378124	Alberta, Canada	Castor	
PI 379611	England, United Kingdom		
PI 410388	South Africa	1949	
PI 435306	Russian Federation		
PI 435310	Russian Federation		
PI 531088	Iowa, United States	Palaton	
PI 531089	Iowa, United States	Venture	
PI 547387	Iran	KJ-98	
PI 578794	Iowa, United States	Vantage	
PI 587092	Quebec, Canada	Bellevue	
PI 587193	Hungary	Szarvasi 50	
W6 19694	Mongolia	96N-201	
W6 19801	Mongolia	96N-325	