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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Technical Assistance

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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. Economic Potential of Switchgrass as a Biofuel Crop

I.1. Estimating the Costs of Producing Switchgrass

This section examines the costs of producing switchgrass in the Chariton Valley. The data used for these cost estimates comes from a variety of sources. Actual production practices are used whenever possible.

From the outset several differences of switchgrass compared to other agronomic crops should be noted. First, switchgrass is a relatively new commercial crop in the Chariton Valley. As such, not all of the practices have been standardized. Other components of this study (particularly Objective II) examine the optimum agronomic practices in the hope of improving recommendations to the farmers. As these practices are identified, the budgets presented here may need to be refined.

When farmer practices were examined considerable differences in practices and costs were identified. We have been working with producers, and similar to other, established crops, costs can range considerably.

Estimating costs of production needs to be divided into two segments: (1) the establishment period and (2) the production phase. Costs from the establishment period must be prorated over the life of the stand and allocated each year to obtain a cost of producing switchgrass.

Finally, not all switchgrass plantings are successful. There are a variety of agronomic reasons for planting failures and these are being examined. Regardless of the reason, planting failure has to be factored into the estimate of the cost of production.

To estimate the cost of switchgrass production in the Chariton Valley seven alternative scenarios were examined. These scenarios represent alternative planting strategies used by farmers. The *alternative scenarios* were:

1) frost seeding on cropland
2) frost seeding on grassland
3) spring seeding on cropland with airflow planter
4) spring seeding on cropland with a drill
5) spring seeding on cropland with a no-till drill
6) spring seeding on grassland with a drill
7) spring seeding on grassland with a no-till drill

The scenarios were established based on the time of year when planting occurred. The primary difference with the timing of planting is the amount of seed used and the assumption regarding the need for reseeding. It was assumed that spring seeding would need to be reseeded 50 percent of the time, whereas, frost seeding would require reseeding only 25 percent of the time.

The designation "on cropland" or "on grassland" describes the previous crop. This designation determines the land charge associated with the scenario. Some of the land in the Chariton Valley is better suited for crop production. This land will have a higher land charge when compared to land that is pasture or grassland.

For each scenario, costs of production were calculated assuming four different yield levels: 1.5, 3, 4, and 6 tons per acre. These yield levels were determined to be within the range possible in the Chariton Valley.

For each scenario and yield the following procedure was used to estimate the costs of production. First, the establishment costs were estimated, including the machinery operations, fertilizer, seed, and chemicals. The appropriate land charge is also included. These total establishment costs are then prorated at 8 percent over 11 years to determine the yearly charge.

The second step is to estimate the costs of reseeding. The machinery operations, seed, fertilizer and chemical costs are estimated and the land charge is added. The total reseeding cost is then multiplied by the probability of needing to reseed. Finally, this expected reseeding cost is prorated over 10 years at 8 percent.

The third step is to estimate the yearly costs of production. These costs include the costs for fertilizers, chemicals, and the machinery to apply them. The major expense in the production year is harvesting. Harvesting is assumed to be in large square bales and the costs include mowing, raking, baling, and hauling to the edge of the field. Each production year also includes a land charge and an yearly interest charge on the money used for the variable inputs.

The yearly prorated establishment costs plus the prorated expected reseeding costs plus the annual production costs comprise the total cost of switchgrass. The costs are then divided by the expected yield to obtain the estimated costs of switchgrass per ton.

The machinery operations will vary depending on the farm and farmer preference. For this estimation, we used machinery operations that varied by the type of seeding and the timing of the seeding.

For all machinery costs we used the average custom rate charge. These are the average values reported by the Iowa State Extension Service (1999 Custom Rate Guide, ISU Extension Pub., FM 1698, Mar. 1999). Custom rate charges would include a cost of labor. Additionally, they would include a return to the custom operator. This would tend to over estimate the cost to the individual operator, but we used the custom charge to provide an equal charge for all operators.

Switchgrass harvest is a somewhat different operation than harvesting alfalfa or hay. The switchgrass is taller and less dense than a typical hay cutting. To estimate impact of the differences on harvest we analyzed data reported by custom harvesting crews hired for the project. There were two separate crews who harvested 16 different switchgrass fields. One crew used a large round baler and the other used a large square baler.

The reported time for mowing averaged 9.4 minutes per acre. There was little difference between the two crews, 9.9 minutes and 8.8 minutes per acre. This time estimate compares to the ISU engineering estimate of 10.2 minutes for a 12 foot mower/conditioner (Estimating Field Capacity of Farm Machines, ISU Ext. Pub PM-696, Jan. 1986)

Raking times varied significantly between the two crews. This was due to the differences in the types of rakes being used. In the one case the average time was 8.7 minutes per acre whereas the other crew averaged only 2.9 minutes per acre. The ISU estimate for a 14 foot rake is 8.3 minutes and 6.7 minutes per acre for an 18 foot rake. The time for raking decreases dramatically as the width of the rake increases.

The baling times were not as comparable between the ISU estimates and the custom crews. The single ISU estimate is 7.5 tons per hour. The two custom crews averaged 18.4 and 20.3 tons per hour. This difference may be due to different equipment sets or, most likely, it is due to differences in the two materials, hay and switchgrass.

Moving bales to the edge of the field, staging, also varied considerably between ISU and the custom crews. The custom crews averaged 9 and 9.3 tons per hour, while the ISU estimate is 4.8 tons.

Some differences exist between the times reported for the 16 fields in this study and the standard estimates. However, we choose to use the ISU Custom Rate as our guide for estimating harvesting costs for two reasons. First, it is a readily available cost estimate. Second, and more important, the cost estimate for raking and mowing is on a per acre basis and here the estimates do not vary greatly. The baling and staging estimates vary but because the custom charges are on a per ton basis this should help mitigate some of the differences.

We also examined the relationship between harvest times and the size of the fields. The field size average 19.1 acres, ranging from 4 to 50 acres. We found the time to rake or mow, per acre, did not vary with the field size. The correlation coefficients between size and mowing and raking were 0.17 and 0.24, respectively. Scatter plots of the time and size confirmed there was no discernable relation between size of field and the time required, per acre, for mowing and raking.

Baling time per acre is a function of the yield per acre not the size. We found no correlation between the size of the field and the yield per acre.

Harvesting differences between switchgrass and hay are an area that deserves further research. Not only are the materials different but so too is the time of year when harvest occurs. This will influence not only the cost but the time required for harvest. As more switchgrass is grown, harvest crews should become more familiar with the process and differences will be minimized.

The seeding rates used are recommended rates from the Iowa State University Extension Service. Analysis of on farm records revealed differences among farmers and the seeding rate used. Other components of this project are trying to determine the optimum seeding rates.

Fertilizer needs will depend on the current level of fertility and the removal rate. In this cost estimation, bulk fertilizer is applied with the seed in the establishment year. During production the amount of phosphorus and potassium applied is a function of the yield. Phosphorus and potassium are applied a the rate they are removed with the switchgrass harvested. Nitrogen fertilizer is applied at 100 pounds per acre (112 kg ha^{-1}) during the production years.

Lime is included in the budget. Again, the need for lime depends on the individual soil. However, it was assumed that sometime during the life of the switchgrass stand lime would need to be added. Therefore, lime is considered a cost in the establishment year.

A basic herbicide program is followed. It is designed to remove any broadleaf weeds that may be present. It is assumed to be a prophylactic program. No insecticides are used.

The detailed presentation of the establishment year cost estimates for each of the scenarios is provided in Appendix I.1. Appendix I.1 also provides a detailed cost estimate for the expected cost of reseeding under the alternative seeding timing.

Appendix I.2 presents the yearly production cost estimates for each of the scenarios. Additionally, Appendix I.2 is further divided by the assumed yield.

Table I.1 presents a summary of the switchgrass cost of production estimates. This table is a summary of the information provided in Appendix I.1 and Appendix I.2.

Table I.1 shows that the biggest difference in the estimated cost of production comes from the different yield assumptions. The second biggest impact comes from the type of land on which the switchgrass is planted. These results are consistent with other published cost estimates of switchgrass.

Notice that within a yield category the impact of the land charge can cause significant differences. For 4 ton yields, costs of production are estimated between $66 and $67 per ton on cropland (land charge $75 per acre) and $59 and $60 on grassland (land charge $50 per acre).

It is also interesting to note from Table I.1 that the impact of the difference in land charge diminishes as the assumed yield increases. The average cost of production on cropland with 1.5 ton yield is 14 percent higher than the average grassland cost of production. When the yield increases to 6 tons per acre the average difference between cropland and grassland drops to 9 percent.

Table I.2 presents the costs of production with varying land charges. In Table I.2 grassland charges are $25 and $50 per acre and cropland charges are $50, $75 and $100 per acre. This table clearly illustrates the impact of the higher land charge. For example, with a 4 ton yield and a $25 per acre land charge the cost per ton is $51.94 with scenario 2. Using the same yield and $100 per acre land charge the cost per ton increases to $74.92 with scenario 4. If the yield increases to 6 tons per acre the cost per ton with a $25 per acre charge drops to $43.98 and $59.30 with the $100 per acre charge.

Costs of production for switchgrass will vary depending on the farmer and the practices used. The most important factors in determining the costs of production are the land charge and the yield.

Comparison with Corn

The cost of production for switchgrass reported in Table I.1 appear to be greater than the expected price for switchgrass in the area. This would seem to indicate that the likelihood of adopting switchgrass is reduced unless the costs can be lowered. While this is true, the soils in the area are not especially productive and the costs of production for other crops also appear to be above the price received. In spite of this there is still considerable row crop production in the area.

Another way to examine switchgrass is to estimate the price for switchgrass necessary to produce a return equal to other crops in the area. In some cases this may be estimating the price that would produce the same level of loss. Continuous corn is used as an example. It is assumed that the costs of production would be similar to those reported by the Iowa State Extension Service. (Estimated Costs of Crop Production, 1999, ISU, Ext. Pub. FM1712, Jan. 1999).

To estimate the price necessary to equate returns, it is necessary to estimate the revenue to the corn. Corn revenue is price times the yield minus the costs. This produces the corn net revenue. Then we set the switchgrass net revenue equal to the corn net revenue. In other words, the corn net revenue plus the cost of producing the switchgrass divided by the switchgrass yield will give the switchgrass price necessary for equal returns.

The costs for 100 bushel per acre corn without a land charge are $212.66 per acre. The switchgrass costs are those reported in Table I.1. For simplicity this examination only includes costs for frost seeded switchgrass on cropland.

Table I.3 shows the price necessary for switchgrass returns to equal corn returns with varying switchgrass yields and corn prices. This table assumes a $75 per acre land charge. Notice that the price necessary for switchgrass ranges from a high of $140 to $43 depending on the corn price and the switchgrass yield. Notice too that the difference in the price for switchgrass is a constant within a yield group and for a given corn yield. For example, with 100 bushel corn yield and a 1.5 ton switchgrass yield, the price for switchgrass must increase by $13.33 to equal the effects of a $0.10 increase in corn. Similarly with an 80 bushel corn yield and a 6 ton switchgrass yield the switchgrass price must increase by $2.67 a ton for every $0.10 increase in corn price.

It is important when comparing alternative land uses that all relevant factors are considered. On first blush it does not appear that switchgrass could be competitive. However, switchgrass costs will decrease as we learn more about growing and harvesting the crop. And, perhaps more important, it is critical to remember the costs and returns of the alternatives available when examining switchgrass or any other alternative land use.

Table I.1. Summary of costs of producing switchgrass.

Scenario	Yield (tons)	Annual Production Costs	Total Costs per Acre	Total Costs per Ton
1	1.5	$165.07	$194.22	$129.48
	3	207.17	236.32	78.77
	4	235.25	264.40	66.10
	6	291.37	320.54	53.42
2	1.5	$140.08	$167.01	$111.34
	3	182.19	209.12	69.71
	4	210.25	257.19	59.30
	6	266.40	393.33	48.89
3	1.5	$165.07	$198.74	$132.49
	3	207.17	240.86	80.28
	4	235.25	268.92	67.23
	6	291.37	325.07	54.18
4	1.5	$165.07	$198.74	$132.75
	3	207.17	241.33	80.41
	4	235.25	269.31	67.33
	6	291.37	325.45	54.24
5	1.5	$165.07	$199.13	$131.79
	3	207.17	239.79	84.75
	4	235.25	267.86	66.96
	6	291.37	323.98	54.00
6	1.5	$140.07	$170.99	$114.00
	3	182.19	213.10	71.03
	4	210.24	241.70	60.29
	6	266.40	297.32	49.55
7	1.5	$140.07	$171.18	$114.12
	3	182.18	213.29	71.10
	4	210.24	241.37	60.34
	6	266.40	297.51	49.59

Table I.2. Summary of switchgrass production costs per ton with varying land charges.

		Land Charge			
Scenario	Yield	$25	$50	$75	$100
	(tons)				
1	1.5	*	$109.85	$129.48	$149.10
	3	*	68.96	78.77	88.59
	4	*	58.74	66.10	73.46
	6	*	48.52	53.42	58.33
2	1.5	$91.72	$111.34	*	*
	3	59.89	69.71	*	*
	4	51.94	59.30	*	*
	6	43.98	48.89	*	*
3	1.5	*	$112.25	$132.49	$152.74
	3	*	70.16	80.28	90.41
	4	*	59.64	67.23	74.82
	6	*	49.12	54.18	59.24
4	1.5	*	$112.51	$132.75	$153.00
	3	*	70.29	80.41	90.53
	4	*	59.74	67.33	74.92
	6	*	49.18	54.24	59.30
5	1.5	*	$111.54	$131.79	$152.03
	3	*	69.81	79.93	90.05
	4	*	59.37	66.96	74.56
	6	*	48.94	54.00	59.06
6	1.5	$93.75	$114.00	*	*
	3	60.91	71.03	*	*
	4	52.70	60.29	*	*
	6	44.49	49.55	*	*
7	1.5	$93.88	$114.12	*	*
	3	51.41	71.10	*	*
	4	52.75	60.34	*	*
	6	44.52	49.59	*	*

* Out of Range of Possibilities.

Table I.3. Switchgrass price necessary to equal corn returns with varying corn prices

				Switchgrass yield (tons/acre)			
Corn Yield	Corn Price	Return	Net	1.5	3	4	6
---bu---	---$/bu---	---------$---------		----------------------Switchgrass $/ton ----------------------			
100	1.80	180	-107.66	57.71	42.88	39.19	35.48
	2.00	200	-87.66	71.04	49.55	44.19	38.81
	2.20	220	-67.66	84.37	56.22	49.19	42.14
	2.40	240	-47.66	97.71	62.88	54.19	45.48
	2.60	260	-27.66	111.04	69.55	59.19	48.81
	2.80	280	-7.66	124.37	76.22	64.19	52.14
	3.00	300	12.34	137.71	82.88	69.19	55.48
90	1.80	162	-120.41	49.21	38.63	36.00	33.35
	2.00	180	-102.41	61.21	44.63	40.50	36.35
	2.20	198	-84.41	73.21	50.63	45.00	39.35
	2.40	216	-66.41	85.21	56.63	49.50	42.35
	2.60	234	-48.41	97.21	62.63	54.00	45.35
	2.80	252	-30.41	109.21	68.63	58.50	48.35
	3.00	270	-12.41	121.21	74.63	63.00	51.35
80	1.80	144	-133.16	40.71	34.38	32.81	31.23
	2.00	160	-117.16	51.37	39.72	36.81	33.89
	2.20	176	-101.16	62.04	45.05	40.81	36.56
	2.40	192	-85.16	72.71	50.38	44.81	39.23
	2.60	208	-69.16	83.37	55.72	48.81	41.89
	2.80	224	-53.16	94.04	61.05	52.81	44.56
	3.00	240	-37.16	104.71	66.38	56.81	47.23
70	1.80	126	-145.91	32.21	30.13	29.62	29.10
	2.00	140	-131.91	41.54	34.80	33.12	31.44
	2.20	154	-117.91	50.87	39.47	36.62	33.77
	2.40	168	-103.91	60.21	44.13	40.12	36.10
	2.60	182	-89.91	69.54	48.80	43.62	38.44
	2.80	196	-75.91	78.87	53.47	47.12	40.77
	3.00	210	-61.91	88.21	58.13	50.62	43.10
60	1.80	108	-158.66	23.71	25.88	26.44	26.98
	2.00	120	-146.66	31.71	29.88	29.44	28.98
	2.20	132	-134.66	39.71	33.88	32.44	30.98
	2.40	144	-122.66	47.71	37.88	35.44	32.98
	2.60	156	-110.66	55.71	41.88	38.44	34.98
	2.80	168	-98.66	63.71	45.88	41.44	36.98
	3.00	180	-86.66	71.71	49.88	44.44	38.98

I.2. The Regional Economic Impacts of Switchgrass Production

This report is an economic analysis of different levels of switchgrass production in a six-county region of southern Iowa. the region consists of the counties Lucas, Appanoose, Monroe, Decatur, Clarke, and Wayne. These counties are all part of the Chariton River-Lake Rathbun watershed. The analysis is conducted using an input-output (I-O) model of the economy of the six-county region.

Switchgrass is a possible alternative crop for the region. It can be used for haying and grazing but the primary use for switchgrass in this study would be for biomass production. The switchgrass would be used to replace coal for electricity generation at the Ottumwa power plant.

Input-Output Modeling and its Limits

Input-Output models are highly detailed accounts of inter-industrial transactions in a region. Any industry's output (its gross sales) requires employees, materials, capital investments, financing, maintenance, equipment, and service inputs. the probability that a firm purchases its inputs locally is estimated in the I-O model. These estimates are based on national and regional industrial surveys to identify the overall production 'recipes' for the firms in the study region. Once we know the kinds of inputs that a firm requires and the availability of those inputs within the region that we are studying, we are able to identify the expected transactions that the firm has with the remainder of the economy in the area. When these industrial linkages are identified and the model is constructed, we can simulate how the regional economy responds to or otherwise demonstrates dependence on the industry we are studying.

There are up-front limitations to these studies that must be acknowledged. First and foremost, absent highly detailed and costly local industry surveys we must rely on national and regional averages when determining major input categories and the likelihood of a local purchase of inputs for the industries that we are studying. The model that we employ contains detailed information for up to 537 industrial, governmental, and household sectors. This detail is regionally adjusted to reflect actual production and payroll characteristics in the study area. The data are updated annually and rely on U.S. Bureau of Economic Analysis, County Business Patterns, and U.S. Department of Labor ES 202 data on quarterly employee withholdings to zero-in on characteristics of local production, wages and industry types. The I-O program that we use, along with the annual data sets for the states and counties that we study, has a historically respectable research and production foundation along with an equally respectable client base nationwide. Whenever possible, we modify the data in the model based on information that is provided to us by our clients or based on our own more detailed research activity in a region.

Other limits in these types of models include:

1) difficulties in capturing economies of scale (the current input values or production functions are, therefore, initially constant),
2) an inability to identify input substitutes - especially new technologies,
3) the models occasionally contain dated data on industrial performance and purchases (to this we can add an absence of detailed information on emerging industries, especially those associated with communications, software, and computer industries),
4) in-state and out-of-state purchases of commodities are fixed (unless we manually adjust regional purchasing coefficients), and
5) an implicit assumption that input commodity supply is infinite and perfectly elastic.

These considerations duly noted, carefully conducted I-O studies give us reasonably good simulation of the current industrial inter-dependencies in the economy. I-O models are useful for simulating how an economy is currently performing rather than how an economy is expected to perform in the future. They help to define the relative linkages of an institution under study with the industries and households in the region at the present time. It is important to remember that these models give us localized or regionalized estimates of economic interactions, and that as the scope of analysis changes, i.e., statewide or nationwide, the kinds and extents of economic interactions change, accordingly.

The Study Scenario

The purpose of the regional study is to estimate the impact producing switchgrass would have on the entire region. This was a difficult task to know where to start regarding reasonable assumptions.

As a base we assumed that the acres in switchgrass would be comparable to the acres currently enrolled in the Conservation Reserve Program (CRP). In the 6 county area there are 212,000 acres in the CRP. For this analysis we are assuming that 50,000 of these acres would be converted to switchgrass.

Another issue addressed concerned the assumption of what would switchgrass replace. Obviously production of switchgrass produces both income and expenses. These expenses are income elsewhere in the region.

We choose to look at the switchgrass impacts in two ways. First, we look at the impact of switchgrass production in isolation. This would be equivalent to assuming that the CRP land would leave the CRP program and be retired from any kind of production. While this is not a likely scenario it does provide some insights into the impacts of switchgrass alone.

The second scenario evaluated looks at what would happen if the CRP was discontinued and the land shifted to switchgrass production. The average CRP payment in the 6 counties is $69.97. Switchgrass net income will be compared to that income to estimate the net impact.

The per acre switchgrass costs in excess of the CRP maintenance costs are presented in Table I.4. These costs are divided into the four yield categories used throughout this report. The costs represent the expenditures for fertilizer and herbicide material and application. The costs also include the cost of harvesting. These are the costs found in Appendix I.1. However, the costs in Table I.4 show two fewer operations for mowing to reflect that mowing would occur regardless of whether or not the land was in switchgrass.

The Economic Impacts

Table I.5 shows the regional impact if switchgrass were planted on 50,000 acres of the land now in CRP (212,000 acres) in the 6 county region. The table assumes switchgrass is the only use for the land. This table shows the summary of the total economic impact with different yield and price assumptions. The impacts are divided into three categories and they are summarized for all sectors of the economy including secondary effects. Sales is the summary of all the direct and secondary sales generated from switchgrass. The value-added column is a measure of all income plus profits and indirect tax payments to state and local governments. And, finally, the employment column shows the number of jobs that would be created throughout the region.

Table I.6 presents a detailed summary of the direct and secondary impact for the 50,000 acres of the current CRP program. These 50,000 acres generate approximately $4.7 million in value added to the agricultural sector. They would also add approximately 37 jobs in the region. Table I.7 compares what would happen if the 50,000 CRP acres, with a $69.97 payment per acre, were replaced by switchgrass at various yields and with three price levels. The three price levels were chosen to show a range of possible prices for switchgrass. Table I.7 uses the same costs as shown in Table I.4.

Prices of $30 or $50 per ton and a 1.5 ton yield generate a loss to the region compared to CRP. With yields this low the increased economic activity due to switchgrass production is still not enough to offset the loss of the CRP income. Yields at three ton or above produce positive value added to the region. With a three ton yield and a price of $30 per ton the farmer is losing money compared to the CRP payment. However, the increased activity due to producing switchgrass offset the losses to the individual farmer so there was a net increase in value added for the region. At all the yield levels there would be a positive impact on employment in the area. The range is from a low of 4 new jobs with a 1.5 ton yield and $30 a ton to a high of 103 new jobs with 6 ton yield and $70 per ton.

Concluding Comments

Switchgrass production involves greater input usage than CRP. This increase in input use can lead to an increase in economic activity in the region even if the returns to the farmers are lower than the returns under CRP. In some instances it is a distributional problem but the 'winners' could offset the 'losers' and the region would be better off. In other cases the yield is so low that there is a net loss.

The results of the regional analysis show again how sensitive the impact of switchgrass would be to the yield. Changing to switchgrass under a low yield scenario would produce negative returns not only for the farmer but in some cases even the region if the prices were also low.

This analysis has not considered the potential for added benefits to the region that could occur with a change to switchgrass production. Electricity generated with a local fuel source would reduce the amount of money leaving the region for that purpose. Switchgrass could provide additional wildlife benefits as well. Neither of these impacts nor any other of the potential benefits from switchgrass were considered in this estimation.

At high yield levels switchgrass would produce enough return to quite possibly induce farmers to change to switchgrass on their own. At the lower levels there would have to be some subsidy available in order to justify the production of switchgrass. At the intermediate levels, as shown in Table I.4, a more favorable condition could be reached but some way for the gainers to offset the losers would have to be devised.

Switchgrass is better than nothing on the CRP acres. However, many of the 212,000 acres may return to row crops. How many is not known but the level of erosion would increase and the wildlife benefits achieved with CRP would be lost. If 50,000 acres could be shifted into switchgrass the results would be favorable at all but the lowest yield levels.

Table I.4. Per Acre Switchgrass Production Costs in Excess of CRP Maintenance Costs

	Yield (tons/acre)			
	1.5	3.0	4.0	6.0
	--------------------------Production Cost ($/acre)------------------------------			
Fertilizer Material	23.16	30.32	35.09	44.63
Machinery	7.20	7.20	7.20	7.20
Herbicide Material	6.94	6.94	6.94	6.94
Machinery	4.25	4.25	4.25	4.25
Harvesting, Baling	24.86	49.71	66.28	99.43
TOTAL	66.41	98.42	119.76	162.45

Table I.5 Summary of Total Economic Impacts Under Different Yield Scenarios

Switchgrass Price	Yield	Sales	Income	Value Added	Employment
$/ton	tons/acre	------------------------------	$	------------------------------	
30	1.5	6,737,734	162,310	3,589,670	41
	3.0	9,922,538	239,032	8,554,432	65.3
	4.0	12,045,740	290,179	10,384,890	90.6
	6.0	14,612,739	352,017	12,597,955	103.9
50	1.5	9,014,099	882,295	4,443,980	48
	3.0	13,274,898	1,299,339	10,590,312	76.4
	4.0	16,115,430	1,577,369	12,856,404	106.1
	6.0	19,549,698	1,913,513	15,596,159	121.6
70	1.5	12,060,864	1,131,102	5,501,647	55.4
	3.0	17,761,813	1,665,753	13,110,806	88.1
	4.0	21,562,446	2,022,187	15,916,228	122.3
	6.0	26,157,496	2,453,124	19,308,044	140.2

Table I.6. Farm Operation and Family Spending Impacts

	Sales	Personal Income	Value Added	Employment
Agriculture	42,266	3,468,173	3,494,345	0.5
Mining	8	3	5	-
Construction	26,373	11,220	11,930	0.4
Manufacturing	143,155	21,884	33,838	0.8
Trans., Comm., and Utilities	175,571	40,156	113,032	1.1
Trade	581,312	277,187	423,458	18.1
Fin., Ins., & Real Estate	290,003	34,618	211,363	1.7
Services	500,665	229,655	258,194	13.3
Government	23,835	11,540	12,838	0.3
Other	6,444	6,444	6,444	1
Total	1,789,632	4,100,880	4,565,447	37.3

Table I.7. Regional Returns with CRP Income Offsets

Switchgrass Price	Yield	Sales	Income	Value Added	Employment
$/ton	tons/acre				
30	1.5	4,794,197	-3,924,884	-975,777	3.7
	3.0	8,744,428	-1,921,046	3,988,984	28
	4.0	11,376,707	-587,914	5,819,443	53.4
	6.0	16,754,155	6,054,963	8,032,508	66.6
50	1.5	7,097,254	-3,732,734	-121,467	10.7
	3.0	12,136,144	-1,638,664	6,024,864	39.1
	4.0	15,494,095	-244,524	8,290,956	68.8
	6.0	21,749,703	6,471,705	11,030,711	84.3
70	1.5	9,400,310	-3,540,583	936,200	18.1
	3.0	15,527,859	-1,356,283	8,545,358	50.8
	4.0	19,611,483	98,866	11,350,780	85.1
	6.0	26,745,251	6,888,447	14,742,597	102.9

I.3. Energy Use in Switchgrass Production

Switchgrass in the Chariton Valley is being grown as a biomass crop. The purpose of biomass crops is to save fossil fuels. Changes in production practices are another source of differences in fossil fuel use. This section provides a brief examination of the use of fossil fuels in switchgrass production and compares this with typical corn and soybean production.

Energy use in crop production is a complex subject. One of the complexities is knowing what energy to include and what level of detail is necessary. Some studies have even included the energy required to manufacture the machinery while other studies have simply included the fuel used. Another issue in examining the energy use in crop production is the conflicting energy use estimates for the various inputs. This is especially an issue for fertilizer.

An example of the discrepancies and complexities can be found when examining the literature on the energy balance for ethanol. There have been literally hundreds of different studies and papers written on this subject. Some of the discrepancies are due to including different aspects of the inputs and some are due simply to using different numbers.

For purposes here we will examine the energy used in three broad categories: machinery operations, pesticides, and fertilizers. These are the variable areas and the ones where the changes in the farmers' practices have the most impact.

The energy used for machinery operations only includes the fuel used. Fuel use will vary considerably depending on the operation, the soil conditions, the farmer and other factors. The Iowa State Extension Service has provided a general fuel use estimate for many field operations. This publication, Fuel Required for Field Operations, Ext. Pub. PM 709, will serve as the basis for the machinery estimates used here.

The fossil fuel used to produce pesticides varies considerably with formulation. For simplicity, this section assumes that there is the equivalent of a gallon of diesel fuel used for each pound of active ingredient. It is further assumed that each of the pesticides will be applied at the rate of a half pound of active ingredient per acre.

The other major source of estimates for this section comes from the Department of Energy (Energy in Synthetic Fertilizers and Pesticides: Revisited, M.G. Bhat, et al., Univ of TN, Knoxville, Dept of Ag Econ and Rur Soc, Report for U.S. Dept. of Energy, Oak Ridge, TN, Report No. ORNL/Sub/90-00732/2, Jan. 1994). Specifically, the energy for fertilizer reported in a study commissioned by the Department will be used. The energy for a pound of nitrogen is 27,540 BTUs, for a pound of phosphorus is 6,160 BTUs and for potassium is 5,200 BTUs. These will be converted to gallons of diesel fuel equivalents using 138,000 BTUs per gallon.

Energy use will be discussed in gallons of diesel fuel equivalents to allow easier comparisons and a familiar unit of measure. Fertilizers and pesticides are made from fossil fuels so such a comparison is not unrealistic because they are all fossil fuel derived.

The energy use in switchgrass production will be divided into machinery, pesticides, and fertilizer. The energy will be calculated for the establishment and for the production and will be presented on a yearly use basis. The establishment energy use is divided by 10 to reflect the general assumption of a 10 year life to a switchgrass stand. The energy for reseeding was calculated based on the energy used, the probability of having to reseed, and the expected life of a stand.

Table I.8 shows the energy use for switchgrass production based on the scenarios used to estimate the costs of production. Again, Table I.8 has been converted to gallons of diesel fuel equivalents for easier comparisons. There is very little energy use variation across the scenarios. The largest variation is less than a half a gallon. The largest source of variation in energy use is due to the changes in yields. Going from 1.5 to 6 ton yield add approximately 5 gallons of diesel fuel equivalent to the total use. This increase is due primarily to the increase in potassium removed as the yields increase. Total energy use for 1.5 tons is approximately 25 gallons per acre, while the total energy use for 6 tons is approximately 30 gallons per acre.

Nitrogen fertilizer is the single largest use of energy in switchgrass production. Nitrogen accounts for approximately three-fourths of the total energy use regardless of the scenario or yield. The 100 pounds of nitrogen applied is the equivalent to approximately 20 gallons of diesel fuel.

A recent survey in Iowa, conducted in 1998, examined corn and soybean cropping practices for energy use (1998 Iowa Cropping Practices, M. Duffy & M. Ernst, Proceedings 11th Annual ICM Conference, ISU Extension, Ames, IA, pp 211-230, Nov. 1999). This study used the same assumptions for energy use as presented here for switchgrass. The study found that soybeans used 6.83 gallons of diesel fuel equivalent energy per acre, rotated corn used 42.85, and continuous corn used 41.15.

Soybean energy use is so low relative to corn and switchgrass because soybeans do not receive nitrogen fertilizer and because some of the phosphorus and potassium intended for soybeans are applied to the rotated corn. Switchgrass production uses less energy than corn production. The decrease in energy use is primarily in lower fertilizer use although machinery operation energy use is also lower.

Assuming a corn/soybean rotation uses half the energy of soybeans plus half the energy in corn following soybeans, the rotation would use approximately 24.84 gallons of diesel fuel equivalents per acre. This rotation would be quite similar in total switchgrass energy use. However, there would be differences in the composition of the energy division. In a corn/soybean rotation approximately 50 percent of the energy would be in fertilizer whereas with switchgrass approximately 85 percent of the energy would be in fertilizer.

Switchgrass production requires most of its energy for fertilizer and the majority of this energy is for nitrogen. Switchgrass has lower energy use than continuous corn but approximately the same energy use as a corn/soybean rotation.

Table I.8. Energy Use in Switchgrass Production in Gallons of Diesel Fuel Equivalent

	Production Scenario						
	#1	#2	#3	#4	#5	#6	#7
	Gallons Diesel Fuel Equivalent						
Machinery	1.84	1.75	1.86	1.88	1.74	1.79	1.81
Pesticide	1.10	1.15	1.10	1.10	1.10	1.15	1.15
Fertilizer without P&K	20.24	20.24	20.24	20.24	20.24	20.24	20.24

Total Use by Yield and Scenario

Yield	#1	#2	#3	#4	#5	#6	#7
1.5	24.83	24.80	24.86	24.87	24.73	24.84	24.85
3	26.48	26.45	26.51	26.52	26.38	26.49	26.50
4	27.59	27.55	27.61	27.63	27.49	27.59	27.61
6	29.79	29.76	29.82	29.83	29.69	29.80	29.81

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.

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

Map Unit	*Series & Great Group Classification*	*Field No. & estimated MU area (%)*			
		1	*2*	*3*	*4*
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	

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

To determine the effects of locations, years, harvest dates, landscape positions (summit, backslope, swale/footslope) and nitrogen levels on switchgrass yield and biomass quality traits.

Methods

Plant materials:	Mature, established switchgrass fields; primarily ‘Cave-In-Rock’.
Harvest treatments:	October or November after killing frost–cut and bale whole plots Subsampling throughout the year with a 1 m^2 quadrat
Plot locations:	Lucas County, near Derby; Wayne County, near Millerton
Experimental design:	Randomized complete block design, six replications at Derby, five reps 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. 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 the analyses shown here.)
Plot size:	200’ x 100’ to 400’ depending on slope length; summit, backslope, and swale in each plot
Nitrogen treatments:	Within each plot, four fertility treatments: 0, 56, 112, and 224 kg N/ha (as ammonium nitrate), 50’ wide through plot using
Landscape positions:	Each plot encompassed a summit, a backslope, and a footslope.
Soil testing:	‘A’ horizons sampled at five points along each the landscape for each N level 30 1-m cores were taken across all plots and will be analyzed in 1999.

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 percent.

Results and Discussion

Biomass yield improved in 1999 over 1998 (Table II.2), which is partly a reflection of better management and partly due to a different growing season. The fact that we had applied nitrogen two years in a row and were harvesting the material suggests that our management played a key role in the increased yields. Stands were still thin in some areas of the plots, accounting for the still low biomass yields observed. Note that the subsample yields improved more than the plot yields. Since the subsamples could not be taken from areas with no plants, this data may indicate that yields could rise more if the stands were more uniformly dense. Yields of at least 5 Mg/ha could be expected in southern Iowa, even under moderate nitrogen fertilizer regimes. We speculate that the measured yields were low due to a combination of weather, site limitations (e.g., the fields consist of soils with severe B horizon limitations), fertility and/or stand problems, and inappropriate switchgrass cultivars for southern Iowa. Differences between years could also be observed for most other traits analyzed, including plant height, lodging, and various biomass quality indicators (Table II.2).

The two locations in Lucas and Wayne Counties were generally quite comparable for most traits measured, so only selected data from individual locations is presented. Significantly, several minerals (Cl, N, P, and S) were substantially higher at Lucas than at Wayne, as measured using ion chromatography (Table II.4) or instrumental neutron activation analysis (INAA, Table II.8) on whole plant samples. This variation could be important for the end uses of the material, although none of these levels should interfere with a co-firing operation.

Biomass yields increased linearly in both years to increasing nitrogen fertilization (Table II.4). In addition, lodging and plant height also increased at higher N rates. Differences in cell wall components or mineral composition were either negligible or not evident, with the exception of ash content, which declined slightly (data not shown).

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 (Tables II.5a,b).

In general, summits had higher yields 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.

Large differences for most traits were observed among sampling dates (Tables II.6a,b). 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 the fall 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.

Proximate analysis of biomass samples showed little difference among nitrogen levels for the traits examined (Table II.7). Slightly higher C and lower ash were observed with 224 kg ha^{-1} compared to 0 kg ha^{-1} applied N. BTU content of the biomass did not change. More differences were observed across sampling dates. The March 1999 sample had higher BTU content compared to November 1998; ash was also lower. 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.

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.2. Comparison between 1998 and 1999 for switchgrass biomass yield, canopy height, lodging, NDF, ADF, ADL, hemicellulose, cellulose, total N, and ash, across two southern Iowa locations, four nitrogen fertilization levels, three landscape positions, and two locations, except as noted.

		Year			
Trait	Unit	1998	1999	Mean	LSD (5%)[†]
Biomass Yield					
Total plot yield	Mg ha^{-1}	2.9	3.9	3.4	0.2
July subsample	g m^{-2}	139a[‡]	452a	296a	52
August subsample	g m^{-2}	494b	566b	529b	ns
Morphological Components[§]					
Leaves	%	29b[‡]	--	--	
Stems	%	71a	--	--	
Canopy Height					
July	cm	72a[‡]	96a	84a	3
August	cm	114b	144b	129b	5
Lodging	%	6	11	8	5
Fibers[¶]					
NDF	g kg^{-1}	648	710	680	9
ADF	g kg^{-1}	358	414	386	10
ADL	g kg^{-1}	56	71	63	2
Hemicellulose	g kg^{-1}	290	296	293	2
Cellulose	g kg^{-1}	302	343	322	9
Total N	g kg^{-1}	7.3	5.5	6.4	0.5
Ash	g kg^{-1}	65	56	60	2

[†] Comparisons should be made between years within rows for each variable.
[‡] Values followed by different letters within columns for each trait are different at $P<0.05$.
[§] Leaf:Stem ratio based on mass of samples collected on November 98 harvest.
[¶] Fiber comparisons are based on September harvest.

Table II.3. Comparison between two southern Iowa locations for mineral composition as determined by ion chromatography. Values are averaged across four nitrogen levels and three harvests (Nov 98, Mar 99, Sept 99).

Location	Cl	N	P	S
	ppm			
Lucas	803	547	107	240
Wayne	1293	388	41	98
LSD	ns	89	60	95

Table II.4. Mean switchgrass biomass yield, canopy height, and lodging at four nitrogen fertilization rates in southern Iowa averaged across two locations, three landscape positions, and two years, except as noted.

	Nitrogen Rate (kg ha^{-1})					
	0	56	112	224	Mean	LSD (5%)†
Yield (total plot)			Mg ha^{-1}			
1998	2.3a‡	2.6a	3.1a	3.6a	2.9a	0.5
1999	3.5b	3.7b	4.3b	4.1b	3.9b	0.5
Mean	2.9	3.1	3.7	3.9	3.4	0.4
Yield (subsample)			g m^{-2}			
July	251a	267a	322a	344a	295a	45
August	445b	449b	542b	683b	529b	143
Canopy Height			cm			
July	76a	81a	88a	92a	84a	4
August	119b	126b	133a	138a	129a	5
Lodging			%			
November 1998	4.5	6.8	14.2	20.3	11	6
August 1999	1.8	3.5	8.9	10.4	6	3

† Comparisons should be made among values within rows for each variable.
‡ Values followed by different letters within columns for each trait are different at P<0.05.

Table II.5a. Variation among landscape positions for yield and plant height measured in July and August averaged over two locations in southern Iowa and four nitrogen levels.

	Subsample Yield			Height		
Landscape	1998	1999	Mean	1998	1999	Mean
		g m^{-2}			cm	
Backslope	373	479	396	101	119	105
Footslope	375	484	396	102	118	105
Summit	392	564	447	105	122	109
LSD (5%)	ns	54	40	ns	3.3	ns

Table II.5b. Variation among landscape positions for total nitrogen, *in vitro* digestibility, and cell wall components measured in July and August averaged over two locations in southern Iowa and four nitrogen levels.

	Total N†	IVDMD	Hemicellulose	Cellulose	Lignin
Landscape	1998	1998	1998	1998	1998
			g kg^{-1}		
Backslope	7.3	520	462	335	63
Footslope	7.5	532	469	337	62
Summit	7.5	522	463	333	64
LSD (5%)	ns	ns	ns	3	1.6

† N by Kjeldahl determination.

Table II.6a. Mean switchgrass biomass NDF, ADF, ADL, hemicellulose, and cellulose sampled at nine dates in 1998 and 1999, averaged across two southern Iowa locations, four N application rates, and three landscape positions.

	Fibers					
Season	NDF	ADF	ADL	Hemicellulose	Cellulose	Leaf:Stem
	--g kg^{-1}		--			ratio
1998-1999						
Jul	657	326	36	331	290	0.73
Aug	657	348	48	309	299	0.50
Sep	649	355	57	294	298	0.33
Nov	776	450	75	336	376	0.21
Feb	790	438	79	352	358	--
Mar	912	471	84	340	388	--
1999-2000						
Jul	656	343	50	313	293	--
Aug	665	364	58	301	306	--
Sep	710	414	71	297	343	--
Overall Mean	677	374	60	303	314	0.44
LSD(0.05)	22	22	7	14	18	0.03

Table II.6b. Mean switchgrass biomass total N (Kjeldahl), ash, Cl, P, and S concentration (determined by ion chromatography) sampled at nine dates in 1998 and 1999, averaged across two southern Iowa locations, four N application rates, and three landscape positions.

			Minerals		
Season	Total N	Ash	Cl	P	S
	----------------g kg^{-1}	----------------	---------------------------mg kg^{-1} ---------------------------		
1998-1999					
July	17.4	62	--	--	--
August	9.9	64	--	--	--
September	7.1	62	--	--	--
November	3.4	43	622	242	100
February	3.5	40	--	--	--
March	3.3	35	149	76	66
1999-2000					
July	12.2	58	--	--	--
August	9.2	56	--	--	--
September	5.5	56	931	614	188
Overall Mean	8.9	57	657	311	118
LSD (5%)	2.0	8	110	83	31

Table II.7. Proximate and ultimate analyses of switchgrass biomass. Analyses were conducted on samples collected in November 1998, March 1999, and September 1999. Data are reported averaged over sampling dates for each N level and averaged over N levels for each sampling date.

	Nitrogen level (kg ha^{-1})				Sample Date				
	0	112	224	LSD†	11/98	3/99	9/99	LSD†	Mean
	--------------------				% dry wt.‡			--------------------	
Ultimate analysis									
C	47.4	47.8	48.2	0.4	42.5	48.3	46.9	0.4	47.8
H	5.4	5.4	5.4	ns	5.3	5.3	5.5	0.1	5.4
N	0.27	0.26	0.3	ns	0.24	0.32	0.25	ns	0.28
O	42.4	42.4	42.5	ns	42.1	42.8	42.4	0.3	42.4
S	0.07	0.06	0.06	ns	0.06	0.07	0.06	ns	0.07
Cl§ (units = ppm)	1071	951	987	ns	--	--	--	--	1003
Proximate analysis									
Ash	4.4	4.0	3.7	0.4	4.1	3.1	4.8	0.3	4.0
Volatile Matter	80.3	80.8	80.8	ns	80.6	83	78.4	0.3	80.6
Fixed C	15.3	15.2	15.6	0.3	15.3	13.9	16.7	0.3	15.3
BTU	7968	8001	7991	ns	7950	8067	7943	39	7987

† LSD (5%)= Least Significant Difference; ns = not different at the 5% probability level. Comparisons should be made among values within rows for either nitrogen treatment or harvest period.

‡ Analyses made on dry matter basis.

§ Cl based on samples harvested in September 1999 only.

Table II.8. Elemental analysis of switchgrass samples from September 1999 at two southern locations and three nitrogen levels. Only three replications at each location are included.

		Overall		By Location			By Nitrogen Level (kg ha^{-1})			
	Units	Mean	Std Dev	Lucas	Wayne	LSD–5%	0	112	224	LSD–5%
Constituents determined using INAA† on dry vegetation										
Cl	ppm	1003	312	1228	777	221	1070	951	986	NS
Au	ppb	4.39	1.46	3.96	4.83	NS	5.08	4.63	3.47	NS
Ba	ppm	19.83	6.00	22.56	17.11	NS	16.33	19.33	23.83	5.00
Br	ppm	16.24	5.93	13.49	19.00	NS	18.12	17.50	13.12	NS
Ca	%	0.32	0.05	0.31	0.33	NS	0.33	0.33	0.30	NS
Co	ppm	0.36	0.11	0.30	0.41	NS	0.33	0.42	0.32	NS
Cr	ppm	0.45	0.32	0.36	0.54	NS	0.43	0.48	0.43	NS
Fe	%	0.01	0.00	0.01	0.01	NS	0.01	0.01	0.01	NS
K	%	0.56	0.09	0.59	0.53	NS	0.54	0.57	0.56	NS
Mo	ppm	0.61	0.40	0.29	0.93	0.17	0.66	0.68	0.50	NS
Na	ppm	33.4	4.1	32.7	34.0	NS	32.2	36.3	31.5	NS
Zn	ppm	18.72	3.66	17.78	19.67	NS	19.17	18.50	18.50	NS
La	ppm	0.10	0.03	0.10	0.10	NS	0.11	0.11	0.09	NS
Constituents determined using INAA on ashed vegetation										
Au	ppb	65.89	22.80	53.67	78.11	NS	62.67	72.00	63.00	NS
Ba	ppm	272.22	79.52	283.33	261.11	NS	231.67	245.00	340.00	88.11

Br	ppm	151.39	70.23	112.78	190.00	NS	150.83	160.83	142.50	NS
Ca	%	5.60	0.82	5.00	6.20	0.58	5.17	5.63	6.00	NS
Co	ppm	5.67	2.52	4.67	6.67	NS	5.33	6.33	5.33	NS
Cr	ppm	7.00	1.71	6.44	7.56	NS	7.33	7.17	6.50	NS
Fe	%	0.09	0.02	0.09	0.09	NS	0.08	0.09	0.09	NS
K	%	11.35	1.55	11.14	11.56	NS	10.80	11.21	12.05	NS
Mo	ppm	10.33	7.13	4.11	16.56	2.50	11.50	9.83	9.67	NS
Na	ppm	264.61	53.78	271.56	257.67	NS	251.17	301.33	241.33	NS
Rb	ppm	53.00	16.24	48.89	57.11	NS	49.00	62.33	47.67	NS
Zn	ppm	352.22	87.82	307.78	396.67	NS	345.00	340.00	371.67	NS
La	ppm	1.71	0.40	1.60	1.81	NS	1.75	1.63	1.73	NS
Sm	ppm	0.22	0.07	0.19	0.26	NS	0.23	0.20	0.23	NS
Ash	% dry wt.	9.24	1.41	8.93	9.54	NS	9.43	9.52	8.76	NS
Constituents determined using ICP on fused and acid-digested vegetation										
SiO_2	%	57.97	3.98	57.21	58.72	NS	59.54	58.83	55.52	3.13
Al_2O_3	%	0.20	0.07	0.21	0.20	NS	0.18	0.26	0.17	0.06
Fe_2O_3	%	0.17	0.07	0.17	0.17	NS	0.13	0.15	0.22	NS
MnO	%	0.25	0.07	0.23	0.26	NS	0.23	0.25	0.26	NS
MgO	%	4.39	0.68	3.99	4.79	NS	4.32	4.50	4.35	NS
CaO	%	7.48	0.86	6.86	8.11	0.60	7.08	7.46	7.91	NS
Na_2O	%	0.31	0.37	0.35	0.26	NS	0.17	0.48	0.29	NS
K_2O	%	10.83	1.91	10.44	11.22	NS	10.23	10.90	11.37	NS
TiO_2	%	0.01	0.01	0.01	0.01	NS	0.01	0.01	0.01	NS
P_2O_5	%	3.45	1.09	4.31	2.58	0.34	3.77	3.48	3.09	0.42
LOI‡	%	14.05	3.80	15.36	12.75	NS	13.45	12.83	15.88	NS
Ba	ppm	418.56	129.03	443.89	393.22	NS	327.67	403.00	525.00	140.00
Sr	ppm	253.22	39.42	275.22	231.22	NS	227.17	255.83	276.67	25.80
Zr	ppm	13.22	1.77	12.56	13.89	NS	13.83	12.67	13.17	NS
Constituents determined using ICP on aqua-regia digested vegetation										
Ag	ppm	0.52	0.13	0.57	0.47	NS	0.52	0.55	0.48	NS
Cu	ppm	4.67	1.53	4.11	5.22	NS	4.00	5.17	4.83	NS
Mn	ppm	110.11	23.16	115.56	104.67	NS	108.00	117.00	105.33	NS
Zn	ppm	20.67	6.44	21.44	19.89	NS	19.83	22.83	19.33	NS
Ba	ppm	26.56	9.68	31.67	21.44	9.18	22.17	29.33	28.17	NS
Ca	%	0.33	0.09	0.35	0.31	NS	0.32	0.37	0.31	NS
K	%	0.53	0.14	0.58	0.47	NS	0.50	0.60	0.49	NS
Mg	%	0.17	0.04	0.18	0.17	NS	0.18	0.19	0.15	NS
Na	%	0.03	0.01	0.04	0.03	NS	0.03	0.04	0.03	NS
P	ppm	894.89	495.75	1255.11	534.67	398.00	978.67	989.83	716.17	NS
Sr	ppm	15.28	6.04	18.67	11.89	5.93	14.00	17.33	14.50	NS
S	ppm	364.11	76.05	366.11	362.11	NS	393.33	388.67	310.33	NS

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

II.2: Environmental Impact of Switchgrass Production

To quantify soil erosion, tilth, and runoff in switchgrass fields of the Chariton River watershed and to assess soil quality using qualitative comparisons of expected and actual soil profile descriptions.

Methods

Soil sampling in these fields consisted of two types: shallow (thickness of the A horizon) and deep (120 cm) coring. The 180 shallow samples were analyzed using standard soil fertility tests at the Iowa State University (ISU) Soil Testing Laboratory. The 93 deep cores were analyzed by the ISU Pedometrics Laboratory using standard pedological methodologies.

In order to assess the extent of gullying in switchgrass fields, preliminary walking transects were completed across 13 established switchgrass fields (including the four used in the fertility testing). Subsequently, 12 gullies were examined in more detail. In an attempt to measure ongoing rill and sheet erosion associated with each of these 12 gullies, 30-cm long metal pins were driven into the soil along a transect consisting of six sites spaced 15 m apart and oriented more or less perpendicular to the gully.

Results & Discussion

The importance of landscape position to switchgrass yield is thought to derive from two internal soil properties as well as simply the position itself. The first internal property is effective rooting volume, which is indicated by A horizon thickness (Figure 6). The second is limitations in the B horizon (e.g., strongly developed argillic horizon, seasonally high water table, etc.). Important components of the landscape position include the relative wetness caused by runoff-infiltration ratios, erosivity, effective light interception, etc. These factors will be evaluated and discussed in Mr. Molstad's thesis.

A variety of other fertility analyses (available P, K, Zn; pH and buffer pH) were completed on 180 soil samples from the A horizons throughout fields 1 through 4. The relationship between these and yields by landscapes will be discussed in the forthcoming theses. Preliminary interpretations show available P to differ from field to field (2.7 to 25.4 mg/kg). Fields 3 and 4 had the lowest amount of available P (2.7 and 6.8 mg/kg, respectively), which suggests switchgrass yield would have benefited from P fertilization. Potassium concentrations were high or very high in all four fields. In summary, the fertility status of each of the study fields varied considerably, which is thought to have had a marked effect on total switchgrass yield. All of the fields contained high amounts of total carbon, total nitrogen, organic matter, and plant available zinc, but varied in their amounts of plant available phosphorus, plant available potassium and pH values. These differences make a direct overall fertility comparison between fields difficult. However, in general Field 2 contained adequate to excessive amounts of plant nutrients, and thus yielded the largest amount of switchgrass. Future studies on specific fertility regimes will be necessary in order to pinpoint the conditions for optimal switchgrass growth.

The environmental impact of switchgrass production was evaluated by examining gullies, quantifying aggregate stability of A horizons, and comparing expected and actual soil profiles across landscapes. The characteristics of the A horizons, such as thickness, are evaluated using field morphology and laboratory descriptions. Eight of the 13 established switchgrass fields examined had gullies (Table II.9). A total of 15 active gullies were found in the eight fields although some gullies were likely missed simply due to the difficulties associated with field exploration in tall, dense switchgrass. The gullies recorded are each a trunk gully - some had several smaller tributaries. The gullies noted were each at least 50 m long and had maximum depths and widths typically exceeding 1 m.

Table II.9 suggests about one-half of all established switchgrass fields develop gullies. In the fields where gullies develop, it is common to have multiple trunk gullies – each of which may have a series of tributary rills. Interestingly, there does not appear to be any correlation between switchgrass stand quality and the presence of gullies. Mr. Molstad's thesis will include an analysis of the soil and landscape features present in the gullied and nongullied switchgrass fields. This analysis will indicate what conditions are most conducive to gully initiation, which in turn can become the basis for gully prevention.

Additional data is being collected to precisely quantify the amount of soil eroded from these gullies. Very preliminary calculations suggest serious erosion rates and correlated degradation of soil and water quality even under good switchgrass stands. A preliminary calculation indicates that 225 m^3 of soil have been lost from the 13 fields studied if one assumes the average gully is 60-m long and has a V-shaped cross-section that averages being 1-m wide at the land surface and is 0.5-m deep. This translates into about 1 m^3/ha of eroded soil, which is approximately equivalent to 1 to 2 Mg/ha of gully erosion. On the plus side, the average age of each switchgrass field included in this study was probably 5 years. Consequently, the average annual rate of gully erosion is less than 0.5 Mg/ha.

However, three important concerns remain. First, this calculation does not take into account the amount of rill and sheet erosion occurring in switchgrass fields. Evidence for both was commonly observed in most fields of switchgrass. Thus, the total rate of erosion likely approaches, and possibly even exceeds, T in some fields. Second, the field dissection caused by these gullies has serious ramifications for future agronomic management as well as even simply the sustainability of switchgrass production itself. Third, stream and lake quality are being adversely affected from the gully sediment.

An attempt was made to monitor rill and sheet erosion associated with 12 gullies by using 25 cm long pins in transects. This attempt was a failure. The pins were routinely displaced by shrink-swell as these soils wetted and dried due to precipitation events and evapotranspiration. In retrospect, it is not surprising that severe shrink-swell disrupted this study because all of the soils studied have high smectitic clay contents (e.g., see Laird et al., 1988). Future studies will use photographs and “sediment seeding” to quantify rill and sheet erosion.

Aggregate stability within A-horizons of the four switchgrass fields used in the nitrogen fertilizer trials is commonly around 70% (Table II.10), about twice what Patton (1999) found in row cropped fields in Minnesota and Ohio that have comparable soils to the Chariton Valley. There are significant differences in amount of aggregate stability between fields, landscape positions, and nitrogen fertilizer treatments. The differences between fields and landscape positions are thought to reflect soil properties largely controlled by parent material and slope differences. The decrease in aggregate stability as nitrogen fertilizer rates increase is somewhat perplexing. It may reflect better protection of the less stable aggregates under the more extensive vegetative cover in sites that have been heavily fertilized. Alternatively, it may reflect less organic matter being available to stabilize aggregates as microorganisms more aggressive decompose residue because nitrogen is non-limiting.

Use of soil profile descriptions was the final approach to assess the environmental quality impact of switchgrass production in the Chariton Valley. Specifically, 93 profiles were described – 81 of these came from transects within the four fields used for the nitrogen fertility trials. The other 12 came from the long-term row crop field adjacent to fertility trial field 1. Most of the soil profiles described are Mollisols although 1/3 are Alfisols and more than 10% are Inceptisols (Table II.11). In itself, anyone but a pedologist would generally find this boring. However, comparison of Table II.9 to the taxonomic classification of the series represented by map units in Table II.1 as well as to the descriptions shown in Lockridge (1971) and Prill (1960) suggest a significant shift in soil properties has occurred. These fields were thought to be entirely Mollisols (or at least almost entirely Mollisols) when cultivation began in the mid- to late-1800’s. Now about 40% of their area is Alfisols and Inceptisols, which indicates long-term erosion and A horizon (Mollic epipedon) degradation.

Most or all of this degradation likely occurred prior to switchgrass production although ongoing rill, sheet and gully erosion suggests degradation is not been completely stopped by adoption of switchgrass. The backslopes and footslopes are most susceptible to this degradation (Figures 7 and 8). Thus, a question arises: *Does switchgrass adequately protect the whole soil?* Answering this question is pertinent to this study as well as to carbon sequestration research. A more in-depth analysis of the soil profiles and the impact of switchgrass production will be completed by Mr. Molstad. Subsequently, Lee Burras and Julie McLaughlin will make a thorough report on carbon sequestration trends across the Chariton Valley.

The combination of Figures 7 through 10 and Table II.11 help explain why yields were very low across these landscapes, especially on backslopes. The backslopes of these fields have been significantly eroded, are often very wet (even being "hydric" soils), and have thin A horizons overlying very clayey B horizons. In other words, the physical environment is highly limiting – even more so than the soil surveys suggest.

Conclusion

Successful switchgrass production is reasonable for the soils and landscapes of the Chariton Valley. Yields show considerable spatial and temporal variability, both within and between fields and across years. This variability will remain even with best management practices. Soil-landscape controls result in the highest yields occurring on footslopes and summits with lowest yields occurring on backslopes. Effective nitrogen fertilization is essential to successful switchgrass yields with preliminary results indicating an increase of 0.01 Mg/ha biomass yield per kg of N fertilizer. Additional research is essential to evaluate the value and need of a complete fertility program for maximizing switchgrass yields.

There are environmental costs to switchgrass production in the Chariton Valley. Gullying was found in more than ½ of the fields examined. Evidence of rill and sheet erosion was more common although its impact was not documented due to shrink-swell. On the plus side, switchgrass production results in high amounts of stable aggregates in A horizons. This should inhibit future rill and sheet erosion.

Table II.9. Summary information on fields used to evaluate gullying in switchgrass fields, Chariton River Watershed.

Field no.	Approx. Size	Section and county location	Stand quality	Gullies noted	Transect no.
	(ha)			(number)	
1	15	Sec. 14, T73N, R23W, Lucas Co.	good	0	
2	35	Sec. 19, T73N, R22W, Lucas Co.	good	2	1, 2
3	14	Sec. 23, T73N, R23W, Lucas Co.	excellent	1	3
4	10	Sec. 27, T72N, R23W, Lucas Co.	variable	3	4
5	na	Sec. 4, T70N, R18W, Appanoose Co.	good	0 (has rills)	
6	na	Sec. 9&10, T70N,R18W, Appanoose Co.	good	0	
7	24	Sec. 32, T72N, R22W, Lucas Co.	excellent	2	9, 10
8[1]	20	Sec. 27, T70N, R21W, Wayne Co.	ok/good	0 (has rills)	
9	4	Sec. 2, T68N, R22W, Wayne Co.	ok/poor	0	
10	32	Sec. 30, T71N, R22W, Lucas Co.	v. good	3	5, 6
11	32	Sec. 19, T71N, R22W, Lucas Co.	v. good	2	7, 8
12[2]	14	Sec. 22, T72N, R22W, Lucas Co	v. good	1	11
13[3]	4	Sec. 21, T72N, R22W, Lucas Co.	good	1	12
Total	204			15	12

1 = Please note, gully field 8 is the same as N fertility trial field 4.
2 = Please note, gully field 12 is the same as N fertility trial field 2.
3 = Please note, gully field 13 is the same as N fertility trial field 1.

Table II.10. Summary of aggregate stability results for A horizons of established switchgrass fields. (Field numbers refer to the fields used in the nitrogen trials; a total of 180 A horizon samples were analyzed).

Field No.	Aggregate stability (%)	Landscape Position	Aggregate stability (%)	Nitrogen fertilizer (kg/ha)	Aggregate stability (%)
1	78	Shoulder	70	0	76
2	73	Backslope	75	56	75
3	74	Footslope	74	112	72
4	67			224	70

Row crop fields generally have about 30 to 40% aggregate stability (Patton, 1999).

Table II.11. Taxonomic classification of the 93 pedons (“deep cores”) collected from in or near the four fields used in the nitrogen fertility trials.

50 Mollisols	31 Alfisols	12 Inceptisols
32 Vertic Argiaquolls	19 Vertic Endoaqualfs	8 Vertic Endoaquepts
13 Aquertic Argiudolls	8 Vertic Hapludalfs	3 Vertic Eutrodepts
4 Aquertic Hapludolls	4 Chromic Vertic Endoaqualfs	1 Aquertic Hapludalfs
1 Vertic Endoaquoll		

III. Biofuel Crop Germplasm Evaluation

III.1. Switchgrass Germplasm Yield and Quality

To determine the biofuel potential of a diverse set of switchgrass cultivars and germplasm in the Chariton Valley.

Methods:

Plant materials:	20 entries, incl. released cultivars and experimental germplasms (from IA, NE, and OK)
Planting date/location:	13 May 1997, McNay Research Farm in Lucas County
Experimental design:	Four replications of a randomized complete block design
Plot size:	10’ x 15’, with a 5’ alley between plots
Fertilization:	78 kg N ha^{-1} in May 1998, April 1999, and April 2000
Harvest treatments:	November 1998, October 1999

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. The experiment was originally an 8 replicate lattice design, but four reps were eliminated due to the weed pressure. Stands were uneven in 1998, but by 1999, all stands in the four reps evaluated had thickened acceptably. The study is continuing in 2000, with excellent growth of all plots.

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, but some other entries also perfomed well, including HDMDC3, a Nebraska experimental selected for high digestibility, and NU94-2CH, an upland selection from Oklahoma. The performance of HDMDC3 was unexpected (K. Vogel, pers. comm.) and may have resulted from a seed mix-up. Cave-In-Rock, the most widely recommended cultivar for Iowa, may not be the best for use as a biofuel crop. Since neither winter experienced by the plants was particularly adverse, the true persistence of the high yielding germplasm is unclear. Nevertheless, the yield potentials seen in our small plot trials are considerably higher than our field scale trials, suggesting that higher yields at the field are possible. Further experimentation with the lowland ecotypes is warranted in southern Iowa.

Germplasm differed for most other traits measured as well. Total ash content varied from 53 g/kg for Alamo to 71g/kg for 'Shelter' (Table III.2). Variation for cell-wall content and composition is clearly evident (Table III.2). Selection for altered fiber composition appears possible as well, since different combinations of hemicellulose, cellulose, and lignin are obvious among the entries. Chemical constituents also differed, suggesting some germplasm may be more suited to co-firing than others, although 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 needs to be assessed. Selecting for high yield and good biofuel quality appears possible.

Table III.1. Switchgrass variety yields and plant traits in 1998 and 1999.

Cultivar	Eco-type[†]	Yield 1998	Yield 1999	Yield Mean	Canopy Height July	Canopy Height August	Stand[‡] 1998	Stand[‡] 1999	Leaf: Stem[#]
		-------------Mg ha^{-1}-------------			-----------cm------------		---------score--------		Ratio
Alamo	LL	6.3	17.5	11.9	87	126	2.4	3	0.53
Blackwell	UL	7	9.9	8.4	77	96	2.2	3	0.39
Caddo	UL	5.1	11.4	8.3	71	97	2	2.4	0.63
Carthage	UL	6.8	14.2	10.5	72	103	2.8	3	0.74
CIR	I	6.3	12.5	9.4	88	119	2.8	3	0.51
Forestburg	LL	4.9	8.8	6.8	64	79	1.1	2.2	0.49
HDMDC3	UL	7.6	13.5	10.5	71	92	2.1	2.5	0.58
HYLD-C3	UL	5.7	11.4	8.6	69	95	2.5	2.9	0.49
IA-GT	UL	6.6	10.5	8.5	80	110	3	3	0.48
IA-LM	UL	7.1	11	9.1	88	112	3	2.9	0.45
Kanlow	LL	8.4	16.3	12.4	97	129	2.8	3	0.46
NL93-2CH	LL	5.5	11.5	8.5	75	114	2	2.8	0.79
NU94-2CH	UL	7.2	15	11.1	93	120	2.4	2.8	0.46
Pathfinder	UL	5.5	9.4	7.5	59	86	1.1	2.2	0.66
Shawnee	UP	5.8	13.1	9.5	76	104	2.6	2.6	0.52
Shelter	LL	7.3	10.2	8.7	76	99	2	2.5	0.63
SU92-ISO	LL	7.2	11.2	9.2	77	104	1.4	2.5	0.42
SU94-2CH	LL	6.8	10.7	8.7	76	100	2.6	2.9	0.58
Sunburst	UL	5.3	8.2	6.7	64	88	1.8	2.8	0.44
Trailblazer	UL	5.5	10.5	8	68	89	1.9	2.8	0.47
Mean		6.4	11.8	9.1	76	103	2.2	2.8	0.54
LSD (5%)		2.1	4.3	2.7	11	14	0.6	0.5	0.17

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

[‡] Stand: 0=None, 1=Poor (1-33%), 2=Fair (34-66%), and 3=Good (67-100%).

[#] Leaf:Stem ratio based on mass of samples collected at the November 98 harvest.

Table III.2. Mean cell wall components and mineral composition of 20 switchgrass populations averaged over thee harvests in 1998 and 1999 in southern Iowa.

Cultivar	Fibers: NDF	ADF	ADL	Hemi.	Cell.	Total N†	Ash	Minerals: Cl	P	S
	g kg^{-1}							mg kg^{-1}		
Alamo	739	402	54	336	349	4.9	57	1873	671	156
Blackwell	764	441	72	322	369	4.7	61	1553	725	122
Caddo	741	423	67	318	356	5.3	65	1273	601	120
Carthage	729	407	62	323	345	5.1	69	1796	532	106
CIR	753	427	68	326	359	4.9	62	1826	624	103
Forestburg	738	411	64	327	348	5.8	70	1345	695	155
HDMDC3	737	414	65	323	349	5.4	74	1546	705	142
HYLD-C3	742	423	69	319	354	5.3	65	1565	711	128
IA-GT	744	430	73	314	357	4.7	65	1428	565	138
IA-LM	746	433	71	314	362	4.3	62	1431	634	97
Kanlow	763	431	63	332	369	4.6	55	1753	678	171
NL93-2CH	738	402	53	337	349	5	64	1621	535	104
NU94-2CH	747	412	56	336	353	4.9	60	2009	635	109
Pathfinder	740	413	62	327	352	5.1	67	1521	724	129
Shawnee	743	427	69	317	358	5.3	64	1541	735	147
Shelter	737	418	63	319	355	4.6	70	1541	577	99
SU92-ISO	760	440	71	321	369	4.9	66	1500	696	149
SU94-2CH	749	425	70	324	355	5.6	61	1827	749	142
Sunburst	759	432	68	327	364	5.1	65	1500	871	153
Trailblazer	743	419	67	324	352	5.6	66	1532	799	169
Mean	746	421	65	324	356	5	64	1601	674	132
LSD (5%)	21	19	6	12	14	0.5	2	620	197	79

† Nitrogen determined by the Kjeldahl procedure.

Table III.3. Comparison of biomass minerals (determined by ion chromatography) in November 1998 and in March 1999, and between leaves and stems in November 1998 for 20 germplasms.

	Cl		P		S		Cl		P		S	
	Total plant		Total plant		Total Plant		Leaf	Stem	Leaf	Stem	Leaf	Stem
Entry	11/98	3/99	11/98	3/99	11/98	3/99	11/98	11/98	11/98	11/98	11/98	11/98
	------------------------mg kg^{-1} ------------------------						------------------------mg kg^{-1} ------------------------					
Alamo	1788	401	773	224	48	174	489	2481	186	1084	32	253
Blackwell	1352	337	739	460	80	125	375	1726	203	946	18	166
CIR	1553	524	771	281	46	95	366	2159	196	1066	14	137
Caddo	1120	349	681	287	63	150	403	1563	228	941	13	232
Carthage	1250	347	554	274	59	112	524	1781	248	796	14	185
Forestburg	1483	331	670	394	66	144	426	1986	266	871	61	184
HDMDC3	1524	359	799	389	71	179	464	2143	251	1122	52	248
HYLD-C3	1552	305	900	357	58	189	489	2073	261	1214	56	251
IA-GT	1594	313	725	244	54	135	518	2104	160	979	35	178
IA-LM	1511	363	726	307	54	83	377	2015	189	961	34	103
Kanlow	1804	471	806	319	71	193	500	2336	209	1055	42	256
NL93-2CH	1588	334	630	222	39	113	529	2384	196	965	36	172
NU94-2CH	2129	379	850	269	59	130	459	2856	206	1145	29	178
Pathfinder	1305	295	836	446	75	166	408	1899	239	1227	32	254
SU92-ISO	1369	366	886	354	75	147	424	1756	257	1146	29	198
SU94-2CH	1702	383	976	413	61	181	461	2416	266	1389	49	264
Shawnee	1453	369	805	313	72	182	398	1993	248	1091	31	259
Shelter	1241	274	564	274	42	95	341	1805	184	804	18	139
Sunburst	1208	377	1019	483	83	214	372	1565	240	1359	38	289
Trailblazer	1408	345	1006	373	94	248	403	1876	266	1352	45	344
Mean	1497	361	786	334	64	153	436	2046	225	1076	34	215
LSD (5%)	368	ns	204	123	ns	81	ns	457	ns	313	ns	122

Table III.4. Mean values for various biomass quality characters in leaves and stems at the November 1998 harvest averaged over 20 germplasms grown in southern Iowa.

	November 98 harvest		Contrast
Trait	Leaves	Stems	Leaf vs Stem Stems
Dry Weight	35%	75%	
Fiber	----------g kg^{-1}----------		
NDF	692	803	*
ADF	362	468	*
ADL	53	80	*
Hemicellulose	330	335	*
Cellulose	309	389	*
Total N	7	2.4	*
Ash	90	49	*
Minerals	--------- mg kg^{-1}---------		
Cl	436	1984	*
P	224	1080	*
S	34	195	ns

* Contrast between leaves and stems significant at P<0.05. ns = not significant.

III.2. Reed Canarygrass Breeding and Evaluation

(Dr. Michael Casler, Univ. of WI, 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 focussed 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

To determine differences among currently available germplasm for biomass yield and quality under three harvest managements.

Methods

Plant materials:	Seven cultivars plus a mix of all seven (all low alkaloid except Common)
Harvest treatments:	Spring + Fall, Fall only, and Late Winter only (in Arlington, add Spring + Winter and Hay)
Planting date/location:	22 August 1997 at the Agronomy Farm, Ames, IA; May 1998 at Arlington, WI
Experimental design:	Randomized complete block design, four replications
Plot size:	3' x 20', 3' border surrounding each plot
Harvest dates:	6/24/98; 11/17/98; 3/16/99; 6/25/99; 10/15/99; 3/15/00 at Ames; Arlington dates similar.
Fertility:	112 kg N ha^{-1} in early April (changing to split application in 2000–see below)

Additional tests were planted in southern Iowa at the McNay Farm in Lucas and in Lexington, KY (Dr. Tim Phillips cooperating) in 1999. The McNay test established well, and was mowed several times to control weeds in 1999. Data collection was begun in June 2000. The Kentucky site also established acceptably despite the long drought in that area in 1999. No data were taken at either site in 1999.

Results

The two harvest system is superior to a fall-only management (Table III.5). In 1999, the second (fall) harvest did not yield well, primarily due to a lack of N (plants were yellow at both locations). In 1998 and 1999, we applied all N at one time in the spring. In 2000, we plan to split the application, with ½ in April and the other ½ after the spring harvest (for the treatments without a spring harvest, all 112 kg will be applied in April). The over-wintered material yielded considerably less than fall harvest, partially because the plots were nearly completely lodged. Data are not available on the winter 2000 harvest from Arlington, although it was taken. This management is probably not acceptable. Yields were higher at Ames than Arlington in 1999 under both harvest treatments in common between the locations (Table III.6). The hay harvest treatment at Arlington, which should have included a summer harvest, followed the same schedule as Spring + Fall, due to the slow regrowth after the first harvest. Paradoxically, Arlington had taller plants under the spring+fall treatment. Whether this suggests that future yields may be higher as the stands thicken over time remains to be seen. Few differences were noted among varieties under either system (Table III.7). The one superior entry, PSC1142, showed much higher yields than all others at Arlington, but was similar to all at Ames (see Appendix III for more complete data tables).

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% for the PI evaluation (Appendix table III.2)).

Proximate analysis of the 1999 biomass produced at Ames shows fairly high ash contents (Table III.8). 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. Comparative values with switchgrass will be possible in a new test seeded in June 2000 at the McNay Research Farm that has reed canarygrass and switchgrass side-by-side. The BTU content of biomass was slightly higher when harvested in the spring in 1999, but not in 1998. 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). The spring harvest had low SiO_2 content. K_2O and P_2O_5 declined sharply after spring. Most other elements differed between the harvest managements. Chloride concentration was also high, but the single fall harvest was substantially lower (about ½) that of spring.

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. However, environmental effects, including different soil types, may influence these traits. As data from the other locations becomes available, we will be able to make stronger statements about the suitability of reed canarygrass biomass as a biofuel.

Table III.5. Reed canarygrass biomass yields under several harvest treatments at Ames, IA and Arlington, WI. No data was collected in 1998 at Arlington.

		Yield								Height (cm)	
Location	Harvest	Spr 98	Fall 98	Wint 98	Total	Spr 99	Fall 99	Wint 00	Total	Spr 99	Fall 99
		----------------------------- tons dry matter acre^{-1}-----------------------------								------- cm-------	
Overall	Fall	-	-	-	-	-	3.43	-	3.43	-	116
	Spr+Fall	-	-	-	-	3.19	0.96	-	4.16	134	49
	Winter	-	-	-	-	-	-	-	-	-	-
	Contrast						*		*		*
Ames	Fall	-	3.76	-	3.76	-	3.92	-	3.92	-	119
	Spr+Fall	2.92	2.69	-	5.62	3.92	0.99	-	4.92	119	45
	Winter	-	-	2.10	2.10	-	-	2.44	2.44	-	-
	LSD (5%)/contrast		*		0.20		*		0.24		
Arlington	Fall	-	-	-	-	-	2.92	-	2.91	-	113
	Hay*	-	-	-	-	2.43	0.95	-	3.38	148	54
	Spr+Fall	-	-	-	-	2.44	0.94	-	3.39	148	54
	Spr+Win	-	-	-	-	2.28	-	**	2.28	148	-
	Winter	-	-	-	-	-	-	**	-	-	-
	LSD (5%)					0.07	0.12		0.12	ns	1.8

*No summer cut taken due to limited regrowth; thus, hay management was equal to a spring + fall management.
** Data not yet available.

Table III.6. Reed canarygrass yields at two midwestern locations, Ames, IA and Arlington, WI, under two harvest management treatments in 1999.

	Single harvest, fall		**Two harvests, spring and fall**				
	Yield	Height	Yield			Height (cm)	
Location	Fall 99	Fall 99	Spr 99	Fall 99	Total 99	Spr 99	Fall 99
	T DM/Acre	cm	----- tons dry matter acre^{-1}------			------- cm-------	
Ames	3.94	119	3.94	0.99	4.94	119	45
Arlington	2.92	113	2.44	0.94	3.39	148	53
Contrast	*	*	*	ns	*	*	*

Table III.7. Reed canarygrass variety yields averaged across two midwestern locations, Ames, IA and Arlington, WI, under two harvest management treatments in 1999.

	Single harvest, fall		**Two harvests, spring and fall**				
	Yield	Height	Yield			Height	
Cultivar	Fall 99	Fall 99	Spr 99	Fall 99	Total 99	Spr 99	Fall 99
	T/A	cm	--------------T/A--------------			----------cm----------	
Bellevue	3.43	115	3.21	0.91	4.13	135	49
Common	3.41	115	3.08	0.93	4.01	135	49
PSC1142	3.71	120	3.45	1.15	4.63	135	49
Palaton	3.30	113	3.12	0.98	4.10	131	51
Rival	3.12	116	2.84	0.83	3.66	134	46
Vantage	3.58	117	3.23	0.96	4.20	136	48
Venture	3.45	118	3.41	0.99	4.41	130	51
Mean	3.43	116	3.19	0.96	4.16	134	49
LSD (5%)	ns	ns	0.28	0.15	0.36	ns	ns

Table III.8. Proximate analysis of reed canarygrass biomass from the Ames, IA variety trial in 1998 and 1999 for three harvest managements. Samples were bulked across all varieties.

	Ash		Fixed Carbon		Volatile Matter		BTU	
Harvest	1998	1999	1998	1999	1998	1999	1998	1999
	---------------------------------% dry wt.----------------------------------						------Btu/lb------	
2 harvest: Spring	9.9	7.9	18.1	19.2	72.0	72.9	7588	7700
2 harvest: Fall	10.8	12.8	16.7	17.2	72.5	70.0	7542	7300
1 harvest: Fall	11.3	9.3	16.3	17.4	72.5	73.4	7501	7493
1 harvest: Winter	11.6	†	14.2	†	74.2	†	7482	†
Mean	10.9	10.0	16.3	17.9	72.8	72.1	7528	7498
LSD (5%)	1.2	1.1	0.3	0.4	0.6	1.1	ns	67

† Samples from winter 2000 have not been analyzed.

Table III.9. Ultimate analysis of reed canarygrass biomass from the Ames, IA variety trial in 1998 and 1999 for three harvest managements. Samples were bulked across all varieties.

	C		H		N		O		S	
Harvest	1998	1999	1998	1999	1998	1999	1998	1999	1998	1999
	--% dry wt.---									
2 harvest: Spring	44.7	44.3	5.28	5.47	1.62	1.51	38.4	40.8	0.11	0.07
2 harvest: Fall	43.9	42.5	5.18	5.27	0.89	0.88	39.1	38.5	0.09	0.12
1 harvest: Fall	42.6	43.6	4.96	5.40	0.92	0.64	40.2	41.0	0.08	0.10
1 harvest: Winter	43.3	†	5.09	†	0.83	†	39.2	†	0.07	†
Mean	43.6	43.5	5.13	5.38	1.06	1.01	39.2	40.1	0.09	0.10
LSD (5%)	1.3	1.1	ns	0.07	0.32	0.28	0.9	0.6	ns	ns

† Samples from winter 2000 have not been analyzed.

Table III.10. Elemental analysis of reed canarygrass biomass collected in 1999 at Ames, IA. Samples bulked across all varieties. (Other elements showed no variation and exceedingly small concentrations.)

		Management System				
Element or		Two Harvest		One Harvest		
Mineral	Units	Spring 1999	Fall 1999	Fall 1999	Mean	LSD (5%)
Constituents determined using INAA[†] on dry vegetation						
AU	ppb	5.50	1.13	2.07	2.90	2.6
BA	ppm	14.33	27.67	15.67	19.22	0.76
BR	ppm	8.07	7.13	3.50	6.23	1.28
CA	%	0.25	0.46	0.21	0.31	0.04
K	%	2.00	1.20	0.85	1.35	0.13
MO	ppm	0.75	2.73	0.96	1.48	1.07
NA	ppm	45.53	44.93	54.70	48.39	ns
RB	ppm	12.33	8.00	5.00	8.44	2.20
ZN	ppm	20.00	27.00	26.00	24.33	ns
Constituents determined using INAA on ashed vegetation (ashed at 480°C)						
Ash	% dry wt.	7.10	9.02	7.59	7.90	0.67
AU	ppb	46.67	10.67	18.67	25.33	20.00
BA	ppm	140.00	150.00	143.33	144.44	ns
BR	ppm	126.33	56.33	57.00	79.89	65.00
CA	%	2.57	4.23	2.50	3.10	0.52
K	%	26.10	10.27	10.68	15.68	2.12
MO	ppm	6.67	20.00	9.00	11.89	9.70
NA	ppm	0.04	0.06	0.06	0.05	ns
RB	ppm	115.00	51.33	48.00	71.44	28.90
ZN	ppm	246.67	253.33	303.33	267.78	50.40
Constituents determined using ICP on fused and acid-digested vegetation						
SiO_2	%	48.41	71.99	74.00	64.80	2.34
Al_2O_3	%	0.23	0.23	0.41	0.29	0.15
Fe_2O_3	%	0.19	0.16	0.24	0.20	ns
MnO	%	0.07	0.10	0.11	0.09	ns
MgO	%	3.07	2.35	1.70	2.37	0.35
CaO	%	3.53	5.04	3.05	3.87	0.37
Na_2O	%	0.69	0.37	0.06	0.37	ns
K_2O	%	26.63	9.30	11.04	15.66	2.24
P_2O_5	%	5.59	4.84	4.11	4.84	0.72
LOI[‡]	%	11.45	5.88	5.65	7.66	0.72
Ba	ppm	19.00	27.33	18.33	21.56	3.98
Constituents determined using ICP on aqua-regia digested vegetation						
Mg	ppm	0.17	0.19	0.09	0.15	0.02
P	ppm	1795	2376	1445	1872	326
S	ppm	443	707	522	558	84
Cl	ppm	9988	7399	5776	7721	1192

[†]INAA=Instrumental neutron activation analysis; ICP=Inductively coupled plasma emission spectrometry.[‡]

[‡]LOI=Loss on Ignition

III.2.2. Reed canarygrass germplasm evaluation

To determine the biofuel potential of a diverse set of reed canarygrass germplasms 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

Plant material:	121 (100 at Arlington) germplasm sources (accessions) from Europe and North America. (For a complete list of accessions and their origin, see Appendix III.)
Planting date/location:	Transplanted mid-July 1998, Agronomy Farm, Ames, IA and Arlington, WI
Plot Design:	Twenty plants per accession per location in each of two replications
Fertility:	100 lb N/A in April 1999
Harvests:	Late May 1999; October 1999

Results and Discussion

An impressive range of variation is present among the accessions tested for virtually all traits related to biomass crops, including yield (Tables III.11, III.13 and Appendix III). The top 25 entries at each location show many differences, though several are common to both. Most importantly, numerous accessions show yields as high as, or higher than, the elite cultivars, such as 'Palaton." This suggests 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, but a more thorough job is needed) 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 (Appendix III), but in general, reed canarygrass is well adapted to severe winter weather.

Biomass quality, as measured by cell-wall constituents, varied widely among the accessions, with neutral detergent fiber (i.e., the sum of hemicellulose, cellulose, and lignin) ranging 18% in May and 14% in October at Ames (Table III.12; complete data in the Appendix). Generally, the cultivars with the highest cell wall content were not the highest yielding, but the high yielding cultivars usually had intermediate, or at least not the lowest values. The variation among accessions suggests that high performing biomass cultivars can be developed.

Phenotypic correlations of yield with various cell wall traits show differences between spring and fall harvests (Table III.13). In the May harvest, as expected, yield was positively correlated to increasing cell-wall components and negatively correlated with digestibility and crude protein. However, for the fall harvest, the correlations were reversed, and much lower. This suggests that selecting for improved biomass quality and yield can be done concurrently, but that some attention to the relationship between traits in the fall is needed.

A second year of data is being collected in 2000, after which complete elemental analyses will be conducted on all samples. Results from the two years will provide better information on which to base a selection program for improved biofuel quality.

Table III.11. Several plant traits and biomass yield for the top 25 ranking reed canarygrass accessions for biomass yield at Ames, IA and Arlington, WI in 1999. (Complete data in Appendix III).

Ames						Arlington					
	Spring	Plant	Yield (1999)				Spring	Plant	Yield (1999)		
Entry	Vigor	Height	Spring	Fall	Total	Entry	Vigor	Height	Spring	Fall	Total
	score	cm	--------g plant^{-1}--------				score	cm	--------g plant^{-1}--------		
253316	7.0	111	129	368	497	251531	8.0	131	103	247	344
High_SLW	6.9	108	114	323	439	235482	4.0	98	49	241	290
235482	4.8	105	106	307	415	253317	8.5	137	113	177	288
253315	7.0	126	112	300	414	578797	7.0	155	108	173	281
372558	6.5	109	128	287	414	251841	7.0	140	103	158	264
578791	6.8	111	102	309	411	234790	4.4	143	111	144	257
251842	6.4	114	95	316	408	272123	5.5	149	95	154	254
234696	5.1	100	97	306	406	235485	7.5	142	111	144	253
RC-6	6.0	115	107	296	403	Palaton	7.0	132	108	142	253
422030	5.3	115	96	307	399	272122	6.0	133	103	152	252
235547	6.4	96	96	289	392	578793	7.0	148	102	144	248
380965	4.5	111	96	298	388	433725	5.5	122	97	150	248
269728	5.0	106	93	287	386	PSC_1142	7.9	162	100	147	248
539030	7.1	115	107	280	385	255887	6.4	148	103	144	247
344557	5.9	103	94	287	379	505893	7.0	146	118	128	246
251426	6.0	111	97	276	378	435301	8.0	156	120	123	246
Rival	5.9	103	118	255	378	209979	8.0	145	114	135	245
PSC_1142	6.5	118	102	270	377	235546	7.0	131	112	129	244
Lo_SLW	6.1	105	103	266	376	269728	5.0	108	95	148	243
278706	5.9	108	97	275	375	372558	4.6	131	98	146	241
251531	5.9	112	108	270	372	435300	7.6	143	104	140	239
435312	6.8	105	110	268	370	227670	6.0	118	67	173	239
RC-11	5.6	101	98	264	368	315486	7.4	151	97	133	237
505893	5.5	106	98	267	368	234780	7.0	122	103	129	236
Fraser	6.3	111	108	257	366	578791	6.0	145	94	140	234
Mean of all	6	109	104	289	395		6.0	109	104	289	395

Table III.12. Biomass quality trait means, maximum and minimum values, ranges, and standard deviations for all accessions in May and October, 1999 at Ames, IA. (Complete data in Appendix III.)

	5/27/99					10/15/99				
Statistic	IVDMD†	NDF	ADF	ADL	CP	IVDMD	NDF	ADF	ADL	CP
	------------------------------%------------------------------					------------------------------%------------------------------				
Mean	72.5	52.5	29.0	2.2	21.0	49.9	56.5	30.1	4.1	6.9
Maximum	80.3	59.0	33.9	3.0	27.9	57.4	63.5	34.9	5.22	11.65
Minimum	66.4	41.1	19.7	1.1	15.4	41.7	49.5	26.0	3.28	4.2
Range	13.9	17.9	14.2	1.9	12.5	15.7	14.0	8.9	1.94	7.45
Std. Dev.	2.49	3.00	2.27	0.34	2.25	3.02	2.59	1.87	0.37	1.37

†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.

Table III.13. Phenotypic correlations of dry matter yield with biomass quality traits at two harvests in 1999 (Ames, IA data only).

Quality trait	Correlation	Quality trait	Correlation
May	Yield (May)	October	Yield (October)
IVDMD	-0.64****	IVDMD	0.26***
NDF	0.62****	NDF	-0.32****
ADF	0.64****	ADF	-0.22***
ADL	0.63****	ADL	-0.18**
CP	-0.65****	CP	0.02NS

, *, **** Correlation significant at $P<0.01$, 0.001, and 0.0001, respectively. NS = not significant.

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Appendices

Appendix I.1. Detailed establishment year cost estimates for seven production scenarios described in section I.1, and expected costs of reseeding under alternative seeding timings.

Scenario 1. Frost Seeding: Switchgrass following Crops
Establishment Year

Preharvest Machinery Operations	Cost Per Acre*
Disc	$8.00
Harrow	3.75
Airflow spreader (seed and fertilizers)	5.00
Spraying chemicals	4.25
Total machinery cost	**$21.00**

Operating Expenses	Unit	Price/Unit	Amount	Cost Per Acre
Seed	lb of PLS	$4.00	6.00	$24.00
Fertilizer	(0-30-40)**			14.30
Lime (including its application)	ton	11.50	3.00	34.50
Herbicide				
- Atrazine	qt.	2.93	1.50	4.40
- 2,4 D	pt.	1.69	1.50	2.54
Total operating cost	**$/acre**			**$79.73**
Land Charge (cash rent equivalent)	$/acre			$75.00
Total Establishment Costs				$175.73
Prorated Establishment Costs (11 yrs. @ 8%)				$24.62

*** Source: 1999 Iowa Farm Custom Rate Survey, FM-1698, March 1999.**
**** Phosphorus Price = $.29/lb; Potassium Price = $.14/lb**

Scenario 2. Frost Seeding: Switchgrass Conversion from Grassland
Establishment Year

Preharvest Machinery Operations	Cost Per Acre*
Mow	$6.60
Airflow spreader (seed and fertilizers)	5.00
Spraying Roundup	4.25
Spraying Atrazine and 2,4 D	4.25
Total machinery cost	**$20.10**

Operating Expenses	Unit	Price/Unit	Amount	Cost Per Acre
Seed	lb of PLS	$4.00	6.00	$24.00
Fertilizer	(0-30-40)**			14.30
Lime (including its application)	ton	11.50	3.00	34.50
Herbicide				
- Atrazine	qt.	2.93	1.50	4.40
- 2,4 D	pt.	1.69	1.50	2.54
- Roundup	qt.	8.39	2.00	16.79
Total operating cost	**$/acre**			**$96.52**
Land Charge (cash rent equivalent)	$/acre			$50.00
Total Establishment Costs				$166.62
Prorated Establishment Costs (11 yrs. @ 8%)				$23.34

*** Source: 1999 Iowa Farm Custom Rate Survey, FM-1698, March 1999.**
**** Phosphorus Price = $.29/lb; Potassium Price = $.14/lb**

Scenario 3. Spring Seeding: Switchgrass following Crops with Airflow Planter
Establishment Year

Preharvest Machinery Operations	Cost Per Acre*
Disc	$8.00
Harrow	3.75
Roll	4.00
Airflow spreader (seed and fertilizers)	5.00
Spraying chemicals	4.25
Total machinery cost	**$25.00**

Operating Expenses	Unit	Price/Unit	Amount	Cost Per Acre
Seed	lb of PLS	$4.00	5.00	$20.00
Fertilizer	(0-30-40)**			14.30
Lime (including its application)	ton	11.50	3.00	34.50
Herbicide				
- Atrazine	qt.	2.93	1.50	4.40
- 2,4 D	pt.	1.69	1.50	2.54
Total operating cost	**$/acre**			**$75.73**

Land Charge (cash rent equivalent)	$/acre	$75.00
Total Establishment Costs		$175.73
Prorated Establishment Costs (11 yrs. @ 8%)		$24.62

*** Source: 1999 Iowa Farm Custom Rate Survey, FM-1698, March 1999.**
**** Phosphorus Price = $.29/lb; Potassium Price = $.14/lb**

Scenario 4. **Spring Seeding: Switchgrass following Crops with a Drill Establishment Year**

Preharvest Machinery Operations	Cost Per Acre*
Disc	$8.00
Harrow	3.75
Drill Seed	8.60
Spread fertilizers	3.15
Spraying chemicals	4.25
Total machinery cost	**$27.75**

Operating Expenses	Unit	Price/Unit	Amount	Cost Per Acre
Seed	lb of PLS	$4.00	5.00	$20.00
Fertilizer	(0-30-40)**			14.30
Lime (including its application)	ton	11.50	3.00	34.50
Herbicide				
- Atrazine	qt.	2.93	1.50	4.40
- 2,4 D	pt.	1.69	1.50	2.54
Total operating cost	**$/acre**			**$75.73**

Land Charge (cash rent equivalent)	$/acre	$75.00
Total Establishment Costs		$178.48
Prorated Establishment Costs (11 yrs. @ 8%)		$25.00

*** Source: 1999 Iowa Farm Custom Rate Survey, FM-1698, March 1999.**
**** Phosphorus Price = $.29/lb; Potassium Price = $.14/lb**

Scenario 5. Spring Seeding: Switchgrass following Crops with a No-till Drill
Establishment Year

Preharvest Machinery Operations	**Cost Per Acre***
No till drill	$10.00
Spread fertilizers	3.15
Spraying chemicals	4.25
Total machinery cost	**$17.40**

Operating Expenses	**Unit**	**Price/Unit**	**Amount**	**Cost Per Acre**
Seed	lb of PLS	$4.00	5.00	$20.00
Fertilizer	(0-30-40)**			14.30
Lime (including its application)	ton	11.50	3.00	34.50
Herbicide				
- Atrazine	qt.	2.93	1.50	4.40
- 2,4 D	pt.	1.69	1.50	2.54
Total operating cost	**$/acre**			**$75.73**

Land Charge (cash rent equivalent)	$/acre	$75.00
Total Establishment Costs		$168.13
Prorated Establishment Costs (11 yrs. @ 8%)		$23.55

*** Source: 1999 Iowa Farm Custom Rate Survey, FM-1698, March 1999.**
**** Phosphorus Price = $.29/lb; Potassium Price = $.14/lb**

Scenario 6. Spring Seeding: Switchgrass Conversion from Grassland with a Drill Establishment Year

Preharvest Machinery Operations	Cost Per Acre*
Mow	$6.60
Drill seed	8.60
Spread fertilizers	3.15
Spraying Roundup	4.25
Spraying Atrazine and 2,4 D	4.25
Total machinery cost	**$26.85**

Operating Expenses	Unit	Price/Unit	Amount	Cost Per Acre
Seed	lb of PLS	$4.00	5.00	$20.00
Fertilizer	(0-30-40)**			14.30
Lime (including its application)	ton	11.50	3.00	34.50
Herbicide				
- Atrazine	qt.	2.93	1.50	4.40
- 2,4 D	pt.	1.69	1.50	2.54
- Roundup	qt.	8.39	2.00	16.79
Total operating cost	**$/acre**			**$92.52**
Land Charge (cash rent equivalent)	$/acre			$50.00
Total Establishment Costs				$169.37
Prorated Establishment Costs (11 yrs. @ 8%)				$23.73

*** Source: 1999 Iowa Farm Custom Rate Survey, FM-1698, March 1999.**
**** Phosphorus Price = $.29/lb; Potassium Price = $.14/lb**

Scenario 7. Spring Seeding: Switchgrass Conversion from Grassland with a No-till Drill Establishment Year

Preharvest Machinery Operations	Cost Per Acre*
Mow	$6.60
No till drill	10.00
Spread fertilizers	3.15
Spraying Roundup	4.25
Spraying Atrazine and 2,4 D	4.25
Total machinery cost	**$28.25**

Operating Expenses	Unit	Price/Unit	Amount	Cost Per Acre
Seed	lb of PLS	$4.00	5.00	$20.00
Fertilizer	(0-30-40)**			14.30
Lime (including its application)	ton	11.50	3.00	34.50
Herbicide				
- Atrazine	qt.	2.93	1.50	4.40
- 2,4 D	pt.	1.69	1.50	2.54
- Roundup	qt.	8.39	2.00	16.79
Total operating cost	**$/acre**			**$92.52**
Land Charge (cash rent equivalent)	$/acre			$50.00
Total Establishment Costs				$170.77
Prorated Establishment Costs (11 yrs. @ 8%)				$23.92

*** Source: 1999 Iowa Farm Custom Rate Survey, FM-1698, March 1999.**
**** Phosphorus Price = $.29/lb; Potassium Price = $.14/lb**

Re-Seeding Costs Under Frost Seeding (Approximately 25% of the Time)

Frost Seeding: Re-Seeding Costs (**Switchgrass following Crops**)

Preharvest Machinery Operations	Cost Per Acre*
Airflow spreader (seed and fertilizers)	$5.00
Spraying chemicals	4.25
Total machinery cost	**$9.25**

Operating Expenses	Unit	Price/Unit	Amount	Cost Per Acre
Seed	lb of PLS	$4.00	4.00	$16.00
Fertilizer	(0-30-40)**			14.30
Herbicide				
- Atrazine	qt.	2.93	1.50	4.40
- 2,4 D	pt.	1.69	1.50	2.54
Total operating cost	**$/acre**			**$37.23**

Land Charge (cash rent equivalent)	$/acre	$75.00
Total Re-Seeding Cost	$/acre	$121.48
Expected Re-Seeding Costs		$30.37
Prorated Re-Seeding Cost (10 yrs. @ 8%)		$4.53

*** Source: 1999 Iowa Farm Custom Rate Survey, FM-1698, March 1999**.
**** Phosphorus Price = $.29/lb; Potassium Price = $.14/lb**

Frost Seeding Costs: Re-Seeding Costs (**Switchgrass Conversion from Grassland**)

Preharvest Machinery Operations	**Cost Per Acre***
Airflow spreader (seed and fertilizers)	$5.00
Spraying chemicals	4.25
Total machinery cost	**$9.25**

Operating Expenses	**Unit**	**Price/Unit**	**Amount**	**Cost Per Acre**
Seed	lb of PLS	$4.00	4.00	$16.00
Fertilizer	(0-30-40)**			14.30
Herbicide				
- Atrazine	qt.	2.93	1.50	4.40
- 2,4 D	pt.	1.69	1.50	2.54
Total operating cost	**$/acre**			**$37.23**

Land Charge (cash rent equivalent)	$/acre	$50.00
Total Re-Seeding Cost	$/acre	$96.48
Expected Re-Seeding Costs		$24.12
Prorated Re-Seeding Cost (10 yrs. @ 8%)		$3.59

*** Source: 1999 Iowa Farm Custom Rate Survey, FM-1698, March 1999.**

**** Phosphorus Price = $.29/lb; Potassium Price = $.14/lb**

Re-Seeding Costs Under Spring Seeding (Approximately 50% of the Time)

Spring Seeding: Re-Seeding (**Switchgrass following Crops, All Scenarios**)

Preharvest Machinery Operations	**Cost Per Acre***
Airflow spreader (seed and fertilizers)	$5.00
Spraying chemicals	4.25
Total machinery cost	**$9.25**

Operating Expenses	**Unit**	**Price/Unit**	**Amount**	**Cost Per Acre**
Seed	lb of PLS	$4.00	4.00	$16.00
Fertilizer	(0-30-40)**			14.30
Herbicide				
- Atrazine	qt.	2.93	1.50	4.40
- 2,4 D	pt.	1.69	1.50	2.54
Total operating cost	**$/acre**			**$37.23**

Land Charge (cash rent equivalent)	$/acre	$75.00
Total Re-Seeding Cost	$/acre	$121.48
Expected Re-Seeding Costs		$60.74
Prorated Re-Seeding Cost (10 yrs. @ 8%)		$9.05

*** Source: 1999 Iowa Farm Custom Rate Survey, FM-1698, March 1999.**
**** Phosphorus Price = $.29/lb; Potassium Price = $.14/lb**

Spring Seeding: Re-Seeding Costs (**Switchgrass Conversion from Grassland**)

Preharvest Machinery Operations	**Cost Per Acre***
Airflow spreader (seed and fertilizers)	$5.00
Spraying chemicals	4.25
Total machinery cost	**$9.25**

Operating Expenses	**Unit**	**Price/Unit**	**Amount**	**Cost Per Acre**
Seed	lb of PLS	$4.00	4.00	$16.00
Fertilizer	(0-30-40)**			14.30
Herbicide				
- Atrazine	qt.	2.93	1.50	4.40
- 2,4 D	pt.	1.69	1.50	2.54
Total operating cost	**$/acre**			**$37.23**

Land Charge (cash rent equivalent)	$/acre	$50.00
Total Re-Seeding Cost	$/acre	$96.48
Expected Re-Seeding Costs		$48.24
Prorated Re-Seeding Cost (10 yrs. @ 8%)		$7.19

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*** Source: 1999 Iowa Farm Custom Rate Survey, FM-1698, March 1999.**

**** Phosphorus Price = $.29/lb; Potassium Price = $.14/lb**

Appendix I.2. Detailed yearly production cost estimates for seven production scenarios described in section I.1, for four potential switchgrass yield levels.

Scenario 1. Frost Seeding: Switchgrass Following Crops

Expected Yield: 1.5 tons/acre
Approximately 3.5 large square bales: 875 lbs./bale

Preharvest Machinery Operations	**Cost Per Acre***
Spread liquid nitrogen	$4.05
Application P&K	3.15
Spraying chemicals	4.25
Total machinery cost	**$11.45**

Operating Expenses	**Unit**	**Price/Unit**	**Amount**	**Cost Per Acre**
Nitrogen	lb.	$.16	100.00	$16.00
P	lb.	.29	8.17	2.37
K	lb.	.14	34.20	4.79
Herbicide				
- Atrazine	qt.	2.93	1.50	4.40
- 2,4 D	pt.	1.69	1.50	2.54
Total operating cost	**$/acre**			**$30.09**
Interest on operating expenses (9%)	**$/acre**			**$1.35**

Harvesting and Storing Expenses	**Cost/Ton**	**Cost Per Acre**
Mowing/conditioning	$5.63	$8.45
Raking	2.73	4.10
Baling (large square bales)	16.57	24.86
Staging and loading	6.51	9.77
Total harvesting cost	**$31.45**	**$47.18**

Land Charge (cash rent equivalent)	$75.00
Prorated Establishment Costs (11 yrs. @ 8%)	$24.62
Prorated Re-Seeding Costs (10 yrs. @ 8%)	$4.53
Total Production Costs Per Acre	$194.22
Total Costs Per Bale	$55.49
Total Costs Per Ton	$129.48

*** Source: 1999 Iowa Farm Custom Rate Survey, FM-1698, March 1999.**

Scenario 2. Frost Seeding: Switchgrass Conversion From Grasslands

Expected Yield: 1.5 tons/acre
Approximately 3.5 large square bales: 875 lbs./bale

Preharvest Machinery Operations	**Cost Per Acre***
Spread liquid nitrogen	$4.05
Application P&K	3.15
Spraying chemicals	4.25
Total machinery cost	**$11.45**

Operating Expenses	**Unit**	**Price/Unit**	**Amount**	**Cost Per Acre**
Nitrogen	lb.	$.16	100.00	$16.00
P	lb.	.29	8.17	2.37
K	lb.	.14	34.20	4.79
Herbicide				
- Atrazine	qt.	2.93	1.50	4.40
- 2,4 D	pt.	1.69	1.50	2.54
Total operating cost	**$/acre**			**$30.09**
Interest on operating expenses (9%)	**$/acre**			**$1.35**

Harvesting and Storing Expenses	**Cost/Ton**	**Cost Per Acre**
Mowing/conditioning	$5.63	$8.45
Raking	2.73	4.10
Baling (large square bales)	16.57	24.86
Staging and loading	6.51	9.77
Total harvesting cost	**$31.45**	**$47.18**

Land Charge (cash rent equivalent)	$50.00
Prorated Establishment Costs (11 yrs. @ 8%)	$23.34
Prorated Re-Seeding Costs (10 yrs. @ 8%)	$3.59
Total Production Costs Per Acre	$167.01
Total Costs Per Bale	$47.72
Total Costs Per Ton	$111.34

*** Source: 1999 Iowa Farm Custom Rate Survey, FM-1698, March 1999.**

Scenario 3. Spring Seeding: Switchgrass Following Crops with Airflow Planter

Expected Yield: 1.5 tons/acre
Approximately 3.5 large square bales: 875 lbs./bale

Preharvest Machinery Operations	**Cost Per Acre***
Spread liquid nitrogen	$4.05
Application P&K	3.15
Spraying chemicals	4.25
Total machinery cost	**$11.45**

Operating Expenses	**Unit**	**Price/Unit**	**Amount**	**Cost Per Acre**
Nitrogen	lb.	$.16	100.00	$16.00
P	lb.	.29	8.17	2.37
K	lb.	.14	34.20	4.79
Herbicide				
- Atrazine	qt.	2.93	1.50	4.40
- 2,4 D	pt.	1.69	1.50	2.54
Total operating cost	**$/acre**			**$30.09**
Interest on operating expenses (9%)	**$/acre**			**$1.35**

Harvesting and Storing Expenses	**Cost/Ton**	**Cost Per Acre**
Mowing/conditioning	$5.63	$8.45
Raking	2.73	4.10
Baling (large square bales)	16.57	24.86
Staging and loading	6.51	9.77
Total harvesting cost	**$31.45**	**$47.18**

Land Charge (cash rent equivalent)	$75.00
Prorated Establishment Costs (11 yrs. @ 8%)	$24.62
Prorated Re-Seeding Costs (10 yrs. @ 8%)	$9.05
Total Production Costs Per Acre	$198.74
Total Costs Per Bale	$56.78
Total Costs Per Ton	$132.49

*** Source: 1999 Iowa Farm Custom Rate Survey, FM-1698, March 1999.**

Scenario 4. Spring Seeding: Switchgrass Following Crops with a Drill

Expected Yield: 1.5 tons/acre
Approximately 3.5 large square bales: 875 lbs./bale

Preharvest Machinery Operations	**Cost Per Acre***
Spread liquid nitrogen	$4.05
Application P&K	3.15
Spraying chemicals	4.25
Total machinery cost	**$11.45**

Operating Expenses	**Unit**	**Price/Unit**	**Amount**	**Cost Per Acre**
Nitrogen	lb.	$.16	100.00	$16.00
P	lb.	.29	8.17	2.37
K	lb.	.14	34.20	4.79
Herbicide				
- Atrazine	qt.	2.93	1.50	4.40
- 2,4 D	pt.	1.69	1.50	2.54
Total operating cost	**$/acre**			**$30.09**
Interest on operating expenses (9%)	**$/acre**			**$1.35**

Harvesting and Storing Expenses	**Cost/Ton**	**Cost Per Acre**
Mowing/conditioning	$5.63	$8.45
Raking	2.73	4.10
Baling (large square bales)	16.57	24.86
Staging and loading	6.51	9.77
Total harvesting cost	**$31.45**	**$47.18**

Land Charge (cash rent equivalent)	$75.00
Prorated Establishment Costs (11 yrs. @ 8%)	$25.00
Prorated Re-Seeding Costs (10 yrs. @ 8%)	$9.05
Total Production Costs Per Acre	$199.13
Total Costs Per Bale	$56.89
Total Costs Per Ton	$132.75

*** Source: 1999 Iowa Farm Custom Rate Survey, FM-1698, March 1999.**

Scenario 5. Spring Seeding: Switchgrass Following Crops with No-till Drill

Expected Yield: 1.5 tons/acre
Approximately 3.5 large square bales: 875 lbs./bale

Preharvest Machinery Operations	**Cost Per Acre***
Spread liquid nitrogen	$4.05
Application P&K	3.15
Spraying chemicals	4.25
Total machinery cost	**$11.45**

Operating Expenses	**Unit**	**Price/Unit**	**Amount**	**Cost Per Acre**
Nitrogen	lb.	$.16	100.00	$16.00
P	lb.	.29	8.17	2.37
K	lb.	.14	34.20	4.79
Herbicide				
- Atrazine	qt.	2.93	1.50	4.40
- 2,4 D	pt.	1.69	1.50	2.54
Total operating cost	**$/acre**			**$30.09**
Interest on operating expenses (9%)	**$/acre**			**$1.35**

Harvesting and Storing Expenses	**Cost/Ton**	**Cost Per Acre**
Mowing/conditioning	$5.63	$8.45
Raking	2.73	4.10
Baling (large square bales)	16.57	24.86
Staging and loading	6.51	9.77
Total harvesting cost	**$31.45**	**$47.18**

Land Charge (cash rent equivalent)	$75.00
Prorated Establishment Costs (11 yrs. @ 8%)	$23.55
Prorated Re-Seeding Costs (10 yrs. @ 8%)	$9.05
Total Production Costs Per Acre	$197.68
Total Costs Per Bale	$56.48
Total Costs Per Ton	$131.79

*** Source: 1999 Iowa Farm Custom Rate Survey, FM-1698, March 1999.**

Scenario 6. Spring Seeding: Switchgrass Conversion From Grasslands with a Drill

Expected Yield: 1.5 tons/acre
Approximately 3.5 large square bales: 875 lbs./bale

Preharvest Machinery Operations	**Cost Per Acre***
Spread liquid nitrogen	$4.05
Application P&K	3.15
Spraying chemicals	4.25
Total machinery cost	**$11.45**

Operating Expenses	**Unit**	**Price/Unit**	**Amount**	**Cost Per Acre**
Nitrogen	lb.	$.16	100.00	$16.00
P	lb.	.29	8.17	2.37
K	lb.	.14	34.20	4.79
Herbicide				
- Atrazine	qt.	2.93	1.50	4.40
- 2,4 D	pt.	1.69	1.50	2.54
Total operating cost	**$/acre**			**$30.09**
Interest on operating expenses (9%)	**$/acre**			**$1.35**

Harvesting and Storing Expenses	**Cost/Ton**	**Cost Per Acre**
Mowing/conditioning	$5.63	$8.45
Raking	2.73	4.10
Baling (large square bales)	16.57	24.86
Staging and loading	6.51	9.77
Total harvesting cost	**$31.45**	**$47.18**

Land Charge (cash rent equivalent)	$50.00
Prorated Establishment Costs (11 yrs. @ 8%)	$23.73
Prorated Re-Seeding Costs (10 yrs. @ 8%)	$7.19
Total Production Costs Per Acre	$170.99
Total Costs Per Bale	$48.86
Total Costs Per Ton	$114.00

*** Source: 1999 Iowa Farm Custom Rate Survey, FM-1698, March 1999.**

Scenario 7. Spring Seeding: Switchgrass Conversion From Grasslands with No-till Drill

Expected Yield: 1.5 tons/acre
Approximately 3.5 large square bales: 875 lbs./bale

Preharvest Machinery Operations	**Cost Per Acre***
Spread liquid nitrogen	$4.05
Application P&K	3.15
Spraying chemicals	4.25
Total machinery cost	**$11.45**

Operating Expenses	**Unit**	**Price/Unit**	**Amount**	**Cost Per Acre**
Nitrogen	lb.	$.16	100.00	$16.00
P	lb.	.29	8.17	2.37
K	lb.	.14	34.20	4.79
Herbicide				
- Atrazine	qt.	2.93	1.50	4.40
- 2,4 D	pt.	1.69	1.50	2.54
Total operating cost	**$/acre**			**$30.09**
Interest on operating expenses (9%)	**$/acre**			**$1.35**

Harvesting and Storing Expenses	**Cost/Ton**	**Cost Per Acre**
Mowing/conditioning	$5.63	$8.45
Raking	2.73	4.10
Baling (large square bales)	16.57	24.86
Staging and loading	6.51	9.77
Total harvesting cost	**$31.45**	**$47.18**

Land Charge (cash rent equivalent)	$50.00
Prorated Establishment Costs (11 yrs. @ 8%)	$23.92
Prorated Re-Seeding Costs (10 yrs. @ 8%)	$7.19
Total Production Costs Per Acre	$171.18
Total Costs Per Bale	$48.91
Total Costs Per Ton	$114.12

*** Source: 1999 Iowa Farm Custom Rate Survey, FM-1698, March 1999.**

Scenario 1. Frost Seeding: Switchgrass Following Crops

Expected Yield: 3 tons/acre
Approximately 7 large square bales: 875 lbs./bale

Preharvest Machinery Operations	**Cost Per Acre***
Spread liquid nitrogen	$4.05
Application P&K	3.15
Spraying chemicals	4.25
Total machinery cost	**$11.45**

Operating Expenses	**Unit**	**Price/Unit**	**Amount**	**Cost Per Acre**
Nitrogen	lb.	$.16	100.00	$16.00
P	lb.	.29	16.34	4.74
K	lb.	.14	68.40	9.58
Herbicide				
- Atrazine	qt.	2.93	1.50	4.40
- 2,4 D	pt.	1.69	1.50	2.54
Total operating cost	**$/acre**			**$37.25**
Interest on operating expenses (9%)	**$/acre**			**$1.68**

Harvesting and Storing Expenses	**Cost/Ton**	**Cost Per Acre**
Mowing/conditioning	$2.82	$8.45
Raking	1.37	4.10
Baling (large square bales)	16.57	49.71
Staging and loading	18.86	19.54
Total harvesting cost	**$39.62**	**$81.81**

Land Charge (cash rent equivalent)	$75.00
Prorated Establishment Costs (11 yrs. @ 8%)	$24.62
Prorated Re-Seeding Costs (10 yrs. @ 8%)	$4.53
Total Production Costs Per Acre	$236.32
Total Costs Per Bale	$33.76
Total Costs Per Ton	$78.77

*** Source: 1999 Iowa Farm Custom Rate Survey, FM-1698, March 1999.**

Scenario 2. Frost Seeding: Switchgrass Conversion From Grasslands

Expected Yield: 3 tons/acre
Approximately 7 large square bales: 875 lbs./bale

Preharvest Machinery Operations	**Cost Per Acre***
Spread liquid nitrogen	$4.05
Application P&K	3.15
Spraying chemicals	4.25
Total machinery cost	**$11.45**

Operating Expenses	**Unit**	**Price/Unit**	**Amount**	**Cost Per Acre**
Nitrogen	lb.	$.16	100.00	$16.00
P	lb.	.29	16.34	4.74
K	lb.	.14	68.40	9.58
Herbicide				
- Atrazine	qt.	2.93	1.50	4.40
- 2,4 D	pt.	1.69	1.50	2.54
Total operating cost	**$/acre**			**$37.25**
Interest on operating expenses (9%)	**$/acre**			**$1.68**

Harvesting and Storing Expenses	**Cost/Ton**	**Cost Per Acre**
Mowing/conditioning	$6.00	$8.45
Raking	3.00	4.10
Baling (large square bales)	16.57	49.71
Staging and loading	7.00	19.54
Total harvesting cost	**$32.57**	**$81.81**

Land Charge (cash rent equivalent)	$50.00
Prorated Establishment Costs (11 yrs. @ 8%)	$23.34
Prorated Re-Seeding Costs (10 yrs. @ 8%)	$3.59
Total Production Costs Per Acre	$209.12
Total Costs Per Bale	$29.87
Total Costs Per Ton	$69.71

*** Source: 1999 Iowa Farm Custom Rate Survey, FM-1698, March 1999.**

Scenario 3. Spring Seeding: Switchgrass Following Crops with Airflow Planter

Expected Yield: 3 tons/acre
Approximately 7 large square bales: 875 lbs./bale

Preharvest Machinery Operations	**Cost Per Acre***
Spread liquid nitrogen	$4.05
Application P&K	3.15
Spraying chemicals	4.25
Total machinery cost	**$11.45**

Operating Expenses	**Unit**	**Price/Unit**	**Amount**	**Cost Per Acre**
Nitrogen	lb.	$.16	100.00	$16.00
P	lb.	.29	16.34	4.74
K	lb.	.14	68.40	9.58
Herbicide				
- Atrazine	qt.	2.93	1.50	4.40
- 2,4 D	pt.	1.69	1.50	2.54
Total operating cost	**$/acre**			**$37.25**
Interest on operating expenses (9%)	**$/acre**			**$1.68**

Harvesting and Storing Expenses	**Cost/Ton**	**Cost Per Acre**
Mowing/conditioning	$2.82	$8.45
Raking	1.37	4.10
Baling (large square bales)	16.57	49.71
Staging and loading	6.51	19.54
Total harvesting cost	**$27.27**	**$81.81**

Land Charge (cash rent equivalent)	$75.00
Prorated Establishment Costs (11 yrs. @ 8%)	$24.62
Prorated Re-Seeding Costs (10 yrs. @ 8%)	$9.05
Total Production Costs Per Acre	$240.85
Total Costs Per Bale	$34.41
Total Costs Per Ton	$80.28

*** Source: 1999 Iowa Farm Custom Rate Survey, FM-1698, March 1999.**

Scenario 4. Spring Seeding: Switchgrass Following Crops with a Drill

Expected Yield: 3 tons/acre
Approximately 7 large square bales: 875 lbs./bale

Preharvest Machinery Operations	**Cost Per Acre***
Spread liquid nitrogen	$4.05
Application P&K	3.15
Spraying chemicals	4.25
Total machinery cost	**$11.45**

Operating Expenses	**Unit**	**Price/Unit**	**Amount**	**Cost Per Acre**
Nitrogen	lb.	$.16	100.00	$16.00
P	lb.	.29	16.34	4.74
K	lb.	.14	68.40	9.58
Herbicide				
- Atrazine	qt.	2.93	1.50	4.40
- 2,4 D	pt.	1.69	1.50	2.54
Total operating cost	**$/acre**			**$37.25**
Interest on operating expenses (9%)	**$/acre**			**$1.68**

Harvesting and Storing Expenses	**Cost/Ton**	**Cost Per Acre**
Mowing/conditioning	$2.82	$8.45
Raking	1.37	4.10
Baling (large square bales)	16.57	49.71
Staging and loading	6.51	19.54
Total harvesting cost	**$27.27**	**$81.81**

Land Charge (cash rent equivalent)	$75.00
Prorated Establishment Costs (11 yrs. @ 8%)	$25.00
Prorated Re-Seeding Costs (10 yrs. @ 8%)	$9.05
Total Production Costs Per Acre	$241.23
Total Costs Per Bale	$34.46
Total Costs Per Ton	$80.41

*** Source: 1999 Iowa Farm Custom Rate Survey, FM-1698, March 1999.**

Scenario 5. Spring Seeding: Switchgrass Following Crops with No-till Drill

Expected Yield: 3 tons/acre
Approximately 7 large square bales: 875 lbs./bale

Preharvest Machinery Operations	**Cost Per Acre***
Spread liquid nitrogen	$4.05
Application P&K	3.15
Spraying chemicals	4.25
Total machinery cost	**$11.45**

Operating Expenses	**Unit**	**Price/Unit**	**Amount**	**Cost Per Acre**
Nitrogen	lb.	$.16	100.00	$16.00
P	lb.	.29	16.34	4.74
K	lb.	.14	68.40	9.58
Herbicide				
- Atrazine	qt.	2.93	1.50	4.40
- 2,4 D	pt.	1.69	1.50	2.54
Total operating cost	**$/acre**			**$37.25**
Interest on operating expenses (9%)	**$/acre**			**$1.68**

Harvesting and Storing Expenses	**Cost/Ton**	**Cost Per Acre**
Mowing/conditioning	$2.82	$8.45
Raking	1.37	4.10
Baling (large square bales)	16.57	49.71
Staging and loading	6.51	19.45
Total harvesting cost	**$27.27**	**$81.81**

Land Charge (cash rent equivalent)	$75.00
Prorated Establishment Costs (11 yrs. @ 8%)	$23.55
Prorated Re-Seeding Costs (10 yrs. @ 8%)	$9.05
Total Production Costs Per Acre	$239.79
Total Costs Per Bale	$34.26
Total Costs Per Ton	$79.93

*** Source: 1999 Iowa Farm Custom Rate Survey, FM-1698, March 1999.**

Scenario 6. Spring Seeding: Switchgrass Conversion From Grasslands with a Drill

Expected Yield: 3 tons/acre
Approximately 7 large square bales: 875 lbs./bale

Preharvest Machinery Operations	**Cost Per Acre***
Spread liquid nitrogen	$4.05
Application P&K	3.15
Spraying chemicals	4.25
Total machinery cost	**$11.45**

Operating Expenses	**Unit**	**Price/Unit**	**Amount**	**Cost Per Acre**
Nitrogen	lb.	$.16	100.00	$16.00
P	lb.	.29	16.34	4.74
K	lb.	.14	68.40	9.58
Herbicide				
- Atrazine	qt.	2.93	1.50	4.40
- 2,4 D	pt.	1.69	1.50	2.54
Total operating cost	**$/acre**			**$37.25**
Interest on operating expenses (9%)	**$/acre**			**$1.68**

Harvesting and Storing Expenses	**Cost/Ton**	**Cost Per Acre**
Mowing/conditioning	$2.82	$8.45
Raking	1.37	4.10
Baling (large square bales)	16.57	49.71
Staging and loading	6.51	19.54
Total harvesting cost	**$27.27**	**$81.81**

Land Charge (cash rent equivalent)	$50.00
Prorated Establishment Costs (11 yrs. @ 8%)	$23.73
Prorated Re-Seeding Costs (10 yrs. @ 8%)	$7.19
Total Production Costs Per Acre	$213.10
Total Costs Per Bale	$30.44
Total Costs Per Ton	$71.03

*** Source: 1999 Iowa Farm Custom Rate Survey, FM-1698, March 1999.**

Scenario 7. Spring Seeding: Switchgrass Conversion From Grasslands with No-till Drill

Expected Yield: 3 tons/acre
Approximately 7 large square bales: 875 lbs./bale

Preharvest Machinery Operations	**Cost Per Acre***
Spread liquid nitrogen	$4.05
Application P&K	3.15
Spraying chemicals	4.25
Total machinery cost	**$11.45**

Operating Expenses	**Unit**	**Price/Unit**	**Amount**	**Cost Per Acre**
Nitrogen	lb.	$.16	100.00	$16.00
P	lb.	.29	16.34	4.74
K	lb.	.14	68.40	9.58
Herbicide				
- Atrazine	qt.	2.93	1.50	4.40
- 2,4 D	pt.	1.69	1.50	2.54
Total operating cost	**$/acre**			**$37.25**
Interest on operating expenses (9%)	**$/acre**			**$1.68**

Harvesting and Storing Expenses	**Cost/Ton**	**Cost Per Acre**
Mowing/conditioning	$2.82	$8.45
Raking	1.37	4.10
Baling (large square bales)	16.57	49.71
Staging and loading	6.51	19.54
Total harvesting cost	**$27.27**	**$81.81**

Land Charge (cash rent equivalent)	$50.00
Prorated Establishment Costs (11 yrs. @ 8%)	$23.92
Prorated Re-Seeding Costs (10 yrs. @ 8%)	$7.19
Total Production Costs Per Acre	$213.29
Total Costs Per Bale	$30.47
Total Costs Per Ton	$71.10

*** Source: 1999 Iowa Farm Custom Rate Survey, FM-1698, March 1999.**

Scenario 1. Frost Seeding: Switchgrass Following Crops

Expected Yield: 4 tons/acre
Approximately 9 large square bales: 875 lbs./bale

Preharvest Machinery Operations	**Cost Per Acre***
Spread liquid nitrogen	$4.05
Application P&K	3.15
Spraying chemicals	4.25
Total machinery cost	**$11.45**

Operating Expenses	**Unit**	**Price/Unit**	**Amount**	**Cost Per Acre**
Nitrogen	lb.	$.16	100.00	$16.00
P	lb.	.29	21.79	6.32
K	lb.	.14	91.20	12.77
Herbicide				
- Atrazine	qt.	2.93	1.50	4.40
- 2,4 D	pt.	1.69	1.50	2.54
Total operating cost	**$/acre**			**$42.02**
Interest on operating expenses (9%)	**$/acre**			**$1.89**

Harvesting and Storing Expenses	**Cost/Ton**	**Cost Per Acre**
Mowing/conditioning	2.11	$8.45
Raking	1.03	4.10
Baling (large square bales)	16.57	66.29
Staging and loading	6.51	26.06
Total harvesting cost	**$26.22**	**$104.89**

Land Charge (cash rent equivalent)	$75.00
Prorated Establishment Costs (11 yrs. @ 8%)	$24.62
Prorated Re-Seeding Costs (10 yrs. @ 8%)	$4.53
Total Production Costs Per Acre	$264.40
Total Costs Per Bale	$28.34
Total Costs Per Ton	$66.10

*** Source: 1999 Iowa Farm Custom Rate Survey, FM-1698, March 1999.**

Scenario 2. Frost Seeding: Switchgrass Conversion From Grasslands

Expected Yield: 4 tons/acre
Approximately 9 large square bales: 875 lbs./bale

Preharvest Machinery Operations	**Cost Per Acre***
Spread liquid nitrogen	$4.05
Application P&K	3.15
Spraying chemicals	4.25
Total machinery cost	**$11.45**

Operating Expenses	**Unit**	**Price/Unit**	**Amount**	**Cost Per Acre**
Nitrogen	lb.	$.16	100.00	$16.00
P	lb.	.29	21.79	6.32
K	lb.	.14	91.20	12.77
Herbicide				
- Atrazine	qt.	2.93	1.50	4.40
- 2,4 D	pt.	1.69	1.50	2.54
Total operating cost	**$/acre**			**$42.02**
Interest on operating expenses (9%)	**$/acre**			**$1.89**

Harvesting and Storing Expenses	**Cost/Ton**	**Cost Per Acre**
Mowing/conditioning	$2.11	$8.45
Raking	1.03	4.10
Baling (large square bales)	16.57	66.29
Staging and loading	6.51	26.06
Total harvesting cost	**$26.22**	**$104.89**

Land Charge (cash rent equivalent)	$50.00
Prorated Establishment Costs (11 yrs. @ 8%)	$23.34
Prorated Re-Seeding Costs (10 yrs. @ 8%)	$3.59
Total Production Costs Per Acre	$237.19
Total Costs Per Bale	$25.42
Total Costs Per Ton	$59.30

*** Source: 1999 Iowa Farm Custom Rate Survey, FM-1698, March 1999.**

Scenario 3. Spring Seeding: Switchgrass Following Crops with Airflow Planter

Expected Yield: 4 tons/acre
Approximately 9 large square bales: 875 lbs./bale

Preharvest Machinery Operations	**Cost Per Acre***
Spread liquid nitrogen	$4.05
Application P&K	3.15
Spraying chemicals	4.25
Total machinery cost	**$11.45**

Operating Expenses	**Unit**	**Price/Unit**	**Amount**	**Cost Per Acre**
Nitrogen	lb.	$.16	100.00	$16.00
P	lb.	.29	21.79	6.32
K	lb.	.14	91.20	12.77
Herbicide				
- Atrazine	qt.	2.93	1.50	4.40
- 2,4 D	pt.	1.69	1.50	2.54
Total operating cost	**$/acre**			**$42.02**
Interest on operating expenses (9%)	**$/acre**			**$1.89**

Harvesting and Storing Expenses	**Cost/Ton**	**Cost Per Acre**
Mowing/conditioning	$2.11	$8.45
Raking	1.03	4.10
Baling (large square bales)	16.57	66.29
Staging and loading	6.51	26.06
Total harvesting cost	**$26.22**	**$104.89**

Land Charge (cash rent equivalent)	$75.00
Prorated Establishment Costs (11 yrs. @ 8%)	$24.62
Prorated Re-Seeding Costs (10 yrs. @ 8%)	$9.05
Total Production Costs Per Acre	$268.92
Total Costs Per Bale	$28.82
Total Costs Per Ton	$67.23

*** Source: 1999 Iowa Farm Custom Rate Survey, FM-1698, March 1999.**

Scenario 4. Spring Seeding: Switchgrass Following Crops with a Drill

Expected Yield: 4 tons/acre
Approximately 9 large square bales: 875 lbs./bale

Preharvest Machinery Operations	**Cost Per Acre***
Spread liquid nitrogen	$4.05
Application P&K	3.15
Spraying chemicals	4.25
Total machinery cost	**$11.45**

Operating Expenses	**Unit**	**Price/Unit**	**Amount**	**Cost Per Acre**
Nitrogen	lb.	$.16	100.00	$16.00
P	lb.	.29	21.79	6.32
K	lb.	.14	91.20	12.77
Herbicide				
- Atrazine	qt.	2.93	1.50	4.40
- 2,4 D	pt.	1.69	1.50	2.54
Total operating cost	**$/acre**			**$42.02**
Interest on operating expenses (9%)	**$/acre**			**$1.89**

Harvesting and Storing Expenses	**Cost/Ton**	**Cost Per Acre**
Mowing/conditioning	$2.11	$8.45
Raking	1.03	4.10
Baling (large square bales)	16.57	66.29
Staging and loading	6.51	26.06
Total harvesting cost	**$26.22**	**$104.89**

Land Charge (cash rent equivalent)	$75.00
Prorated Establishment Costs (11 yrs. @ 8%)	$25.00
Prorated Re-Seeding Costs (10 yrs. @ 8%)	$9.05
Total Production Costs Per Acre	$269.31
Total Costs Per Bale	$28.86
Total Costs Per Ton	$67.33

*** Source: 1999 Iowa Farm Custom Rate Survey, FM-1698, March 1999.**

Scenario 5. Spring Seeding: Switchgrass Following Crops with a No-till Drill

Expected Yield: 4 tons/acre
Approximately 9 large square bales: 875 lbs./bale

Preharvest Machinery Operations	**Cost Per Acre***
Spread liquid nitrogen	$4.05
Application P&K	3.15
Spraying chemicals	4.25
Total machinery cost	**$11.45**

Operating Expenses	**Unit**	**Price/Unit**	**Amount**	**Cost Per Acre**
Nitrogen	lb.	$.16	100.00	$16.00
P	lb.	.29	21.79	6.32
K	lb.	.14	91.20	12.77
Herbicide				
- Atrazine	qt.	2.93	1.50	4.40
- 2,4 D	pt.	1.69	1.50	2.54
Total operating cost	**$/acre**			**$42.02**
Interest on operating expenses (9%)	**$/acre**			**$1.89**

Harvesting and Storing Expenses	**Cost/Ton**	**Cost Per Acre**
Mowing/conditioning	$6.00	$8.45
Raking	3.00	4.10
Baling (large square bales)	16.57	66.29
Staging and loading	7.00	26.06
Total harvesting cost	**$32.57**	**$104.89**

Land Charge (cash rent equivalent)	$75.00
Prorated Establishment Costs (11 yrs. @ 8%)	$26.06
Prorated Re-Seeding Costs (10 yrs. @ 8%)	$9.05
Total Production Costs Per Acre	$267.86
Total Costs Per Bale	$28.71
Total Costs Per Ton	$66.96

*** Source: 1999 Iowa Farm Custom Rate Survey, FM-1698, March 1999.**

Scenario 6: Spring Seeding: Switchgrass Conversion From Grasslands with a Drill

Expected Yield: 4 tons/acre
Approximately 9 large square bales: 875 lbs./bale

Preharvest Machinery Operations	**Cost Per Acre***
Spread liquid nitrogen	$4.05
Application P&K	3.15
Spraying chemicals	4.25
Total machinery cost	**$11.45**

Operating Expenses	**Unit**	**Price/Unit**	**Amount**	**Cost Per Acre**
Nitrogen	lb.	$.16	100.00	$16.00
P	lb.	.29	21.79	6.32
K	lb.	.14	91.20	12.77
Herbicide				
- Atrazine	qt.	2.93	1.50	4.40
- 2,4 D	pt.	1.69	1.50	2.54
Total operating cost	**$/acre**			**$42.02**
Interest on operating expenses (9%)	**$/acre**			**$1.89**

Harvesting and Storing Expenses	**Cost/Ton**	**Cost Per Acre**
Mowing/conditioning	$2.11	$8.45
Raking	1.03	4.10
Baling (large square bales)	16.57	66.29
Staging and loading	6.51	26.06
Total harvesting cost	**$26.22**	**$104.89**

Land Charge (cash rent equivalent)	$50.00
Prorated Establishment Costs (11 yrs. @ 8%)	$23.73
Prorated Re-Seeding Costs (10 yrs. @ 8%)	$7.19
Total Production Costs Per Acre	$241.70
Total Costs Per Bale	$25.85
Total Costs Per Ton	$60.29

*** Source: 1999 Iowa Farm Custom Rate Survey, FM-1698, March 1999.**

Scenario 7: Spring Seeding: Switchgrass Conversion From Grasslands with a No-till Drill

Expected Yield: 4 tons/acre
Approximately 9 large square bales: 875 lbs./bale

Preharvest Machinery Operations	Cost Per Acre*
Spread liquid nitrogen	$4.05
Application P&K	3.15
Spraying chemicals	4.25
Total machinery cost	**$11.45**

Operating Expenses	Unit	Price/Unit	Amount	Cost Per Acre
Nitrogen	lb.	$.16	100.00	$16.00
P	lb.	.29	21.79	6.32
K	lb.	.14	91.20	12.77
Herbicide				
- Atrazine	qt.	2.93	1.50	4.40
- 2,4 D	pt.	1.69	1.50	2.54
Total operating cost	**$/acre**			**$42.02**
Interest on operating expenses (9%)	**$/acre**			**$1.89**

Harvesting and Storing Expenses	Cost/Ton	Cost Per Acre
Mowing/conditioning	$2.11	$8.45
Raking	1.03	4.10
Baling (large square bales)	16.57	66.29
Staging and loading	6.51	26.06
Total harvesting cost	**$26.22**	**$104.89**

Land Charge (cash rent equivalent)	$50.00
Prorated Establishment Costs (11 yrs. @ 8%)	$23.92
Prorated Re-Seeding Costs (10 yrs. @ 8%)	$7.19
Total Production Costs Per Acre	$241.37
Total Costs Per Bale	$25.87
Total Costs Per Ton	$60.34

*** Source: 1999 Iowa Farm Custom Rate Survey, FM-1698, March 1999.**

Scenario 1. Frost Seeding: Switchgrass Following Crops

Expected Yield: 6 tons/acre
Approximately 14 large square bales: 875 lbs./bale

Preharvest Machinery Operations	**Cost Per Acre***
Spread liquid nitrogen	$4.05
Application P&K	3.15
Spraying chemicals	4.25
Total machinery cost	**$11.45**

Operating Expenses	**Unit**	**Price/Unit**	**Amount**	**Cost Per Acre**
Nitrogen	lb.	$.16	100.00	$16.00
P	lb.	.29	32.69	9.48
K	lb.	.14	136.80	19.15
Herbicide				
- Atrazine	qt.	2.93	1.50	4.40
- 2,4 D	pt.	1.69	1.50	2.54
Total operating cost	**$/acre**			**$51.56**
Interest on operating expenses (9%)	**$/acre**			**$2.32**

Harvesting and Storing Expenses	**Cost/Ton**	**Cost Per Acre**
Mowing/conditioning	$1.41	$8.45
Raking	.68	4.10
Baling (large square bales)	16.57	99.43
Staging and loading	6.51	39.09
Total harvesting cost	**$25.18**	**$151.06**

Land Charge (cash rent equivalent)	$75.00
Prorated Establishment Costs (11 yrs. @ 8%)	$24.62
Prorated Re-Seeding Costs (10 yrs. @ 8%)	$4.53
Total Production Costs Per Acre	$320.54
Total Costs Per Bale	$22.90
Total Costs Per Ton	$53.42

*** Source: 1999 Iowa Farm Custom Rate Survey, FM-1698, March 1999.**

Scenario 2. Frost Seeding: Switchgrass Conversion From Grasslands

Expected Yield: 6 tons/acre
Approximately 14 large square bales: 875 lbs./bale

Preharvest Machinery Operations	**Cost Per Acre***
Spread liquid nitrogen	$4.05
Application P&K	3.15
Spraying chemicals	4.25
Total machinery cost	**$11.45**

Operating Expenses	**Unit**	**Price/Unit**	**Amount**	**Cost Per Acre**
Nitrogen	lb.	$.16	100.00	$16.00
P	lb.	.29	32.69	9.48
K	lb.	.14	136.80	19.15
Herbicide				
- Atrazine	qt.	2.93	1.50	4.40
- 2,4 D	pt.	1.69	1.50	2.54
Total operating cost	**$/acre**			**$51.56**
Interest on operating expenses (9%)	**$/acre**			**$2.32**

Harvesting and Storing Expenses	**Cost/Ton**	**Cost Per Acre**
Mowing/conditioning	$1.41	$8.45
Raking	.68	4.10
Baling (large square bales)	16.57	99.43
Staging and loading	6.51	39.09
Total harvesting cost	**$25.18**	**$151.06**

Land Charge (cash rent equivalent)	$50.00
Prorated Establishment Costs (11 yrs. @ 8%)	$23.34
Prorated Re-Seeding Costs (10 yrs. @ 8%)	$3.59
Total Production Costs Per Acre	$393.33
Total Costs Per Bale	$20.95
Total Costs Per Ton	$48.89

*** Source: 1999 Iowa Farm Custom Rate Survey, FM-1698, March 1999.**

Scenario 3: Spring Seeding: Switchgrass Following Crops with Airflow Planter

Expected Yield: 6 tons/acre
Approximately 14 large square bales: 875 lbs./bale

Preharvest Machinery Operations	**Cost Per Acre***
Spread liquid nitrogen	$4.05
Application P&K	3.15
Spraying chemicals	4.25
Total machinery cost	**$11.45**

Operating Expenses	**Unit**	**Price/Unit**	**Amount**	**Cost Per Acre**
Nitrogen	lb.	$.16	100.00	$16.00
P	lb.	.29	32.69	9.48
K	lb.	.14	136.80	19.15
Herbicide				
- Atrazine	qt.	2.93	1.50	4.40
- 2,4 D	pt.	1.69	1.50	2.54
Total operating cost	**$/acre**			**$51.56**
Interest on operating expenses (9%)	**$/acre**			**$2.32**

Harvesting and Storing Expenses	**Cost/Ton**	**Cost Per Acre**
Mowing/conditioning	$1.41	$8.45
Raking	.68	4.10
Baling (large square bales)	16.57	99.43
Staging and loading	6.51	39.09
Total harvesting cost	**$25.18**	**$151.06**

Land Charge (cash rent equivalent)	$75.00
Prorated Establishment Costs (11 yrs. @ 8%)	$24.62
Prorated Re-Seeding Costs (10 yrs. @ 8%)	$9.05
Total Production Costs Per Acre	$325.07
Total Costs Per Bale	$23.22
Total Costs Per Ton	$54.18

*** Source: 1999 Iowa Farm Custom Rate Survey, FM-1698, March 1999.**

Scenario 4: Spring Seeding: Switchgrass Following Crops with a Drill

Expected Yield: 6 tons/acre
Approximately 14 large square bales: 875 lbs./bale

Preharvest Machinery Operations	**Cost Per Acre***
Spread liquid nitrogen	$4.05
Application P&K	3.15
Spraying chemicals	4.25
Total machinery cost	**$11.45**

Operating Expenses	**Unit**	**Price/Unit**	**Amount**	**Cost Per Acre**
Nitrogen	lb.	$.16	100.00	$16.00
P	lb.	.29	32.69	9.48
K	lb.	.14	136.80	19.15
Herbicide				
- Atrazine	qt.	2.93	1.50	4.40
- 2,4 D	pt.	1.69	1.50	2.54
Total operating cost	**$/acre**			**$51.56**
Interest on operating expenses (9%)	**$/acre**			**$2.32**

Harvesting and Storing Expenses	**Cost/Ton**	**Cost Per Acre**
Mowing/conditioning	$1.41	$8.45
Raking	.68	4.10
Baling (large square bales)	16.57	99.43
Staging and loading	6.51	39.09
Total harvesting cost	**$25.18**	**$151.06**

Land Charge (cash rent equivalent)	$75.00
Prorated Establishment Costs (11 yrs. @ 8%)	$25.00
Prorated Re-Seeding Costs (10 yrs. @ 8%)	$9.05
Total Production Costs Per Acre	$325.45
Total Costs Per Bale	$23.25
Total Costs Per Ton	$54.24

*** Source: 1999 Iowa Farm Custom Rate Survey, FM-1698, March 1999.**

Scenario 5: Spring Seeding: Switchgrass Following Crops with a No-till Drill

Expected Yield: 6 tons/acre
Approximately 14 large square bales: 875 lbs./bale

Preharvest Machinery Operations	**Cost Per Acre***
Spread liquid nitrogen	$4.05
Application P&K	3.15
Spraying chemicals	4.25
Total machinery cost	**$11.45**

Operating Expenses	**Unit**	**Price/Unit**	**Amount**	**Cost Per Acre**
Nitrogen	lb.	$.16	100.00	$16.00
P	lb.	.29	32.69	9.48
K	lb.	.14	136.80	19.15
Herbicide				
- Atrazine	qt.	2.93	1.50	4.40
- 2,4 D	pt.	1.69	1.50	2.54
Total operating cost	**$/acre**			**$51.56**
Interest on operating expenses (9%)	**$/acre**			**$2.32**

Harvesting and Storing Expenses	**Cost/Ton**	**Cost Per Acre**
Mowing/conditioning	$1.41	$8.45
Raking	.68	4.10
Baling (large square bales)	16.57	99.43
Staging and loading	6.51	39.09
Total harvesting cost	**$25.18**	**$151.06**

Land Charge (cash rent equivalent)	$75.00
Prorated Establishment Costs (11 yrs. @ 8%)	$23.55
Prorated Re-Seeding Costs (10 yrs. @ 8%)	$9.05
Total Production Costs Per Acre	$324.00
Total Costs Per Bale	$23.14
Total Costs Per Ton	$54.00

*** Source: 1999 Iowa Farm Custom Rate Survey, FM-1698, March 1999.**

Scenario 6: Spring Seeding: Switchgrass Conversion From Grasslands with a Drill

Expected Yield: 6 tons/acre
Approximately 14 large square bales: 875 lbs./bale

Preharvest Machinery Operations	**Cost Per Acre***
Spread liquid nitrogen	$4.05
Application P&K	3.15
Spraying chemicals	4.25
Total machinery cost	**$11.45**

Operating Expenses	**Unit**	**Price/Unit**	**Amount**	**Cost Per Acre**
Nitrogen	lb.	$.16	100.00	$16.00
P	lb.	.29	32.69	9.48
K	lb.	.14	136.80	19.15
Herbicide				
- Atrazine	qt.	2.93	1.50	4.40
- 2,4 D	pt.	1.69	1.50	2.54
Total operating cost	**$/acre**			**$51.56**
Interest on operating expenses (9%)	**$/acre**			**$2.32**

Harvesting and Storing Expenses	**Cost/Ton**	**Cost Per Acre**
Mowing/conditioning	$1.41	$8.45
Raking	.68	4.10
Baling (large square bales)	16.57	99.43
Staging and loading	6.51	39.09
Total harvesting cost	**$25.18**	**$151.06**

Land Charge (cash rent equivalent)	$50.00
Prorated Establishment Costs (11 yrs. @ 8%)	$23.73
Prorated Re-Seeding Costs (10 yrs. @ 8%)	$7.19
Total Production Costs Per Acre	$297.32
Total Costs Per Bale	$21.24
Total Costs Per Ton	$49.55

*** Source: 1999 Iowa Farm Custom Rate Survey, FM-1698, March 1999.**

Scenario 7: Spring Seeding: Switchgrass Conversion From Grasslands with a No-till Drill

Expected Yield: 6 tons/acre
Approximately 14 large square bales: 875 lbs./bale

Preharvest Machinery Operations	Cost Per Acre*
Spread liquid nitrogen	$4.05
Application P&K	3.15
Spraying chemicals	4.25
Total machinery cost	**$11.45**

Operating Expenses	Unit	Price/Unit	Amount	Cost Per Acre
Nitrogen	lb.	$.16	100.00	$16.00
P	lb.	.29	32.69	9.48
K	lb.	.14	136.80	19.15
Herbicide				
- Atrazine	qt.	2.93	1.50	4.40
- 2,4 D	pt.	1.69	1.50	2.54
Total operating cost	**$/acre**			**$51.56**
Interest on operating expenses (9%)	**$/acre**			**$2.32**

Harvesting and Storing Expenses	Cost/Ton	Cost Per Acre
Mowing/conditioning	$1.41	$8.45
Raking	.68	4.10
Baling (large square bales)	16.57	99.43
Staging and loading	6.51	39.09
Total harvesting cost	**$25.18**	**$151.06**

Land Charge (cash rent equivalent)	$50.00
Prorated Establishment Costs (11 yrs. @ 8%)	$23.92
Prorated Re-Seeding Costs (10 yrs. @ 8%)	$7.19
Total Production Costs Per Acre	$297.51
Total Costs Per Bale	$21.25
Total Costs Per Ton	$49.59

*** Source: 1999 Iowa Farm Custom Rate Survey, FM-1698, March 1999.**

Appendix III: Reed Canarygrass cultivar and germplasm evaluations

Appendix Table III.1. Reed canarygrass variety yields at Ames, IA and Arlington, WI under several harvest managements.

Ames, single harvest

	Yield (T/A)		Height	Yield (T/A)	
Entry	Fall 98	Fall 99	Fall 99	Wint 99	Wint 00
Bellevue	4.28	4.00	118	1.73	2.30
Common	3.73	4.00	120	2.08	2.50
Mix	3.20	3.80	121	2.33	2.45
PSC1142	3.90	4.08	123	1.90	2.78
Palaton	3.75	3.78	114	2.30	2.73
Rival	4.05	3.73	115	2.13	2.13
Vantage	3.63	3.98	123	2.05	2.38
Venture	3.55	4.03	120	2.28	2.30
Mean	3.76	3.92	119	2.10	2.44
LSD (5%)	0.54	ns	ns	ns	ns

Ames, two harvests, spring and fall

	Yield (T/A)						Height	
Entry	Spr 98	Fall 98	Tot 98	Spr 99	Fall 99	Tot 99	Spr 99	Fall 99
Bellevue	2.95	2.45	5.43	4.15	0.95	5.10	122	46
Common	3.05	2.83	5.88	3.75	0.98	4.73	121	44
Mix	3.23	2.68	5.93	3.75	0.98	4.75	118	46
PSC1142	2.83	2.58	5.38	3.75	1.15	4.93	120	44
Palaton	2.83	2.83	5.68	3.88	1.00	4.88	116	46
Rival	2.78	2.65	5.43	3.55	0.83	4.35	117	39
Vantage	2.98	2.63	5.63	4.05	0.98	5.05	117	46
Venture	2.70	2.88	5.60	4.48	1.08	5.55	120	49
Mean	2.92	2.69	5.62	3.92	0.99	4.92	119	45
LSD (5%)	ns	ns	ns	0.52	ns	0.64	ns	ns

Arlington, single harvest, fall

	Yield	Height	Yield (T/A)			Height (cm)	
Entry	Fall 99	Fall 99	Spr 99	Fall 99	Tot 99	Spr 99	Fall 99
	--t/a--	--cm--	------------------t/a------------------			----------cm----------	
Bellevue	2.86	111	2.28	0.88	3.15	149	53
Common	2.83	109	2.41	0.89	3.30	149	54
PSC1142	3.34	117	3.15	1.16	4.33	150	54
Palaton	2.83	111	2.37	0.95	3.33	145	57
Rival	2.52	117	2.12	0.83	2.98	150	53
Vantage	3.18	112	2.42	0.94	3.35	155	51
Venture	2.87	117	2.35	0.91	3.28	141	53
Mean	2.92	113	2.44	0.94	3.39	148	53
LSD (5%)	0.4	6	0.3	0.19	0.44	ns	ns

Appendix Table III.2. 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
PI 371754	Alaska, United States	PN-609	IA & WI

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	ML 4694 IOREED	IA & WI
PI 578790	Arkansas, United States	ARKANSAS UPLAND	IA & WI
PI 578791	Wisconsin, United States	SYN 4 IOREED	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
Venture	US cultivar		IA & WI
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**	

Appendix III.3. Complete agronomic data on reed canarygrass accessions for 1999 at Ames, IA.

AMES

Accession	Winter kill	Spring vigor	Maturity	Re-growth	Dry Matter Spr 99	Dry Matter Fall 99	Yield Spr 99	Yield Fall 99	Yield Tot 99	Height Spr 99	Height Fall 99
	--%--	------------Score ------------			-------%-------		----------g plant^{-1} ----------			------cm------	
172443	13	6.9	2.5	5.5	19	60	104	177	291	112	32
206463	92	5.0	2.5	5.5	21	51	105	.	.	79	19
209979	0	7.0	2.5	5.6	19	51	94	245	344	114	36
225116	0	6.6	2.8	5.9	19	54	107	246	349	123	36
227670	3	5.6	4.0	3.9	23	56	82	170	252	121	29
234694	3	4.6	1.3	4.9	13	57	81	219	303	81	27
234695	0	5.4	2.5	6.0	15	55	91	243	329	105	35
234696	7	5.1	2.3	6.5	19	54	97	306	406	100	29
234698	3	6.3	2.3	5.5	20	57	106	203	308	108	34
234780	0	6.0	3.0	5.5	18	60	106	242	342	108	37
234790	3	5.3	2.8	4.5	19	40	102	218	317	105	33
235023	3	5.5	2.3	6.0	18	55	97	244	332	103	35
235482	0	4.8	3.0	6.5	19	52	106	307	415	105	27
235484	3	5.6	3.0	6.4	20	52	100	220	318	108	36
235485	0	6.5	2.8	6.4	18	54	102	205	313	118	38
235546	14	7.0	3.0	6.0	19	53	129	226	356	108	38
235547	7	6.4	2.5	6.9	20	58	96	289	392	96	31
235551	6	6.0	3.0	6.0	20	52	104	221	321	108	31
236525	5	0.8	1.0	3.0	13	59	18	233	246	57	21
241064	15	6.5	2.5	7.0	19	51	87	249	345	98	36
241065	53	5.8	3.0	3.9	20	.	84	246	337	105	30
251426	0	6.0	3.3	3.0	19	56	97	276	378	111	30
251531	0	5.9	3.0	6.1	19	53	108	270	372	112	36
251841	0	5.9	3.0	6.5	19	51	92	195	290	108	32
251842	2	6.4	2.8	6.4	21	59	95	316	408	114	36
253315	3	7.0	3.0	6.5	19	58	112	300	414	126	40
253316	3	7.0	3.0	6.1	17	51	129	368	497	111	38
253317	0	7.5	3.3	5.6	19	56	110	208	319	116	38
255887	3	5.9	2.8	6.0	18	52	106	248	352	112	36
269728	0	5.0	2.5	5.5	19	55	93	287	386	106	31
272122	0	6.3	2.8	7.0	19	57	111	228	341	107	36
272123	0	6.0	3.0	7.0	16	55	101	143	246	100	33
278706	0	5.9	2.8	5.9	19	59	97	275	375	108	37
284179	26	1.0	1.0	2.5	17	52	13	227	234	43	25
297362	0	5.1	1.5	5.0	17	53	67	136	198	73	34
314102	0	7.1	3.5	4.5	20	54	95	190	278	129	38
314581	0	5.8	2.5	6.6	31	59	76	190	260	104	31
314726	0	8.0	3.5	5.5	21	57	105	192	299	129	43
314727	0	7.3	3.0	5.0	19	57	93	185	287	116	35
314728	0	7.8	3.3	6.0	24	40	111	237	342	119	30
315486	0	7.0	3.3	5.5	20	54	119	212	332	122	35
315487	3	5.1	2.8	6.0	21	62	78	134	208	97	36

316329	73	0.9	1.0	3.5	17	60	25	.	.	45	.
316330	7	1.0	1.3	3.6	17	71	9	205	223	64	23
319825	0	5.4	2.5	6.0	18	51	95	188	284	91	20
329243	97	0.9	.	.	.	60	.	.	.	30	.
337718	0	7.0	3.8	4.1	21	56	101	214	317	129	37
338666	100	.	.	.	.	.	.	.	.	.	.
344557	6	5.9	3.0	5.0	20	55	94	287	379	103	38
345662	0	7.0	3.3	7.0	20	59	92	190	279	115	36
346015	3	5.3	2.5	4.6	19	57	93	264	351	99	34
357645	0	6.9	2.8	5.9	19	55	113	222	336	114	34
368980	0	5.9	3.5	6.1	22	54	83	220	304	128	37
369290	0	6.4	2.3	6.5	17	59	89	146	232	100	29
369291	3	6.9	2.5	7.5	20	59	100	218	322	109	33
369292	0	6.4	2.5	6.0	21	51	83	162	250	115	34
371754	0	6.5	3.0	6.1	18	52	97	238	338	113	33
372558	0	6.5	3.0	6.0	18	39	128	287	414	109	36
380963	0	5.5	3.3	4.1	20	66	90	164	262	120	28
380965	9	4.5	3.0	4.6	19	59	96	298	388	111	33
383726	0	6.4	2.5	4.9	15	56	83	165	249	102	33
387928	2	5.9	2.5	5.9	19	58	94	156	254	100	32
387929	0	5.4	2.8	5.9	19	58	56	128	186	96	30
392389	0	7.9	3.0	5.5	20	64	102	168	271	114	32
406316	0	7.0	3.0	7.0	21	59	103	210	309	108	30
422030	6	5.3	3.0	7.0	20	56	96	307	399	115	40
422031	15	3.6	2.0	4.9	22	57	61	252	312	89	34
433725	0	7.0	2.8	5.1	18	56	110	234	343	110	35
435294	0	5.8	2.8	6.5	18	57	97	213	310	109	34
435295	12	6.9	1.8	6.9	19	54	97	226	321	103	33
435296	6	5.9	2.0	7.0	20	56	99	266	359	96	32
435297	0	6.3	2.5	6.6	20	57	97	189	278	106	31
435298	7	6.0	2.5	6.1	19	59	94	223	320	104	33
435299	0	5.8	2.0	5.4	20	61	73	185	263	94	26
435300	0	6.6	2.5	6.5	20	60	110	185	294	112	30
435301	0	7.8	3.3	6.0	17	56	112	234	341	119	33
435302	0	8.1	3.0	5.0	19	60	110	188	292	119	28
435303	0	7.6	3.0	5.0	19	57	125	154	272	125	41
435304	0	4.5	2.5	6.4	20	57	80	200	288	102	33
435305	0	7.1	2.5	6.9	18	54	97	184	282	105	34
435307	0	6.0	2.0	6.1	18	57	74	213	284	89	26
435308	0	5.9	2.3	6.0	20	56	77	171	251	97	31
435309	0	6.0	2.3	6.1	15	49	84	184	267	99	20
435311	0	5.8	2.8	6.4	19	54	109	184	296	111	36
435312	0	6.8	2.3	6.5	20	54	110	268	370	105	28
440584	0	7.1	2.5	6.6	19	56	94	160	250	103	29
440585	0	5.8	3.0	7.0	21	64	94	166	258	99	28
505892	0	7.0	2.8	6.6	18	57	98	220	317	108	33
505893	2	5.5	3.3	6.5	18	56	98	267	368	106	33

539029	0	6.1	2.8	5.9	17	61	88	187	272	108	34
539030	0	7.1	3.0	6.5	4	60	107	280	385	115	36
557461	0	4.9	3.0	3.5	19	57	85	181	262	94	34
578789	0	6.3	3.0	6.1	19	51	99	225	322	118	37
578790	15	1.0	1.3	3.1	20	69	9	.	.	53	.
578791	0	6.8	3.0	6.0	19	58	102	309	411	111	37
578792	27	0.9	1.0	0.9	22	.	10	.	.	23	1
578793	0	7.2	2.5	5.9	18	58	124	228	347	122	40
578795	28	1.0	1.0	2.6	18	54	4	.	.	54	34
578796	0	7.2	3.0	7.0	18	55	111	203	315	113	36
578797	0	6.5	4.0	6.0	19	53	105	217	322	122	43
597488	0	5.5	3.0	5.0	18	49	92	151	241	112	38
Bellevue	0	6.3	2.8	5.4	19	52	98	225	319	109	28
Flare	0	5.4	2.8	7.5	15	55	96	253	346	111	36
Fraser	3	6.3	3.0	6.0	26	63	108	257	366	111	36
High_SLW	0	6.9	2.3	7.0	19	55	114	323	439	108	37
Lo_SLW	0	6.1	2.8	6.0	20	60	103	266	376	105	39
Palaton	0	6.5	3.3	6.0	19	61	111	234	350	115	42
PS-3	0	6.6	3.0	5.9	18	54	115	230	341	110	39
PSC_1142	3	6.5	3.5	6.5	19	48	102	270	377	118	37
RC-11	0	5.6	2.8	5.5	19	55	98	264	368	101	33
RC-5	0	6.4	2.8	5.0	19	54	106	235	340	109	34
RC-6	0	6.0	2.8	5.6	18	58	107	296	403	115	38
RC-7	7	6.5	2.8	6.1	19	50	100	217	323	100	36
RH33	4	5.0	1.8	5.5	17	51	77	264	332	82	32
RH47	3	5.0	2.8	5.6	19	55	97	225	324	108	38
RH50	0	4.8	1.5	4.5	14	50	61	125	186	77	15
RH78	3	4.1	1.5	4.1	20	46	32	119	151	50	19
RH85	0	3.1	1.5	3.9	17	49	60	198	253	72	27
Rival	3	5.9	2.8	5.9	17	57	118	255	378	103	41
Vantage	0	6.5	3.0	5.4	19	57	99	172	278	110	38
Venture	0	7.4	3.0	6.4	19	55	116	214	330	114	42
Mean	6	6	3	6	19	56	92	222	317	103	33
Maximum	100	8	4	7	31	71	129	368	497	129	109
Minimum	0	1	1	1	4	39	4	119	151	23	2
Range	100	7	3	7	26	32	125	249	346	106	107
Std. Deviation	17.25	1.58	0.62	1.14	2.53	4.72	25.01	48.29	58.28	19.67	15.16
LSD (5%)	16	1.6	0.7	1.5	5.6	12.1	26	116	124	15	9

Appendix III.4. Complete agronomic data on reed canarygrass accessions for 1999 at Arlington, WI.

ARLINGTON

Accession	Winter kill	Spring vigor	Maturity	Re-growth	Dry Matter Spr 99	Dry Matter Fall 99	Yield Spr 99	Yield Fall 99	Yield Tot 99	Height Spr 99	Height Fall 99
	--%--	------------Score	------------		-------%-------		----------g plant^{-1}	----------		------cm------	
172443	0	6.5	5.0	.	21	72	93	96	186	143.6	68
206463	100	.	.	.	.	.	.	.	.	.	.
209979	0	8.0	4.0	.	21	51	114	135	245	145	72
225116	3	7.0	3.5	.	24	53	104	127	230	144	83
227670	0	6.0	5.0	.	20	79	67	173	239	118	61
234694	0	3.0	2.0	.	19	54	49	107	151	91	62
234695	3	6.0	4.5	.	21	54	84	123	207	147	79
234696	3	4.5	3.0	.	20	56	87	142	231	112	74
234698	5	4.9	4.0	.	20	60	90	128	220	135	82
234780	4	7.0	3.5	.	19	52	103	129	236	122	71
234790	5	4.4	4.0	.	20	53	111	144	257	143	73
235023	0	4.5	5.0	.	20	50	100	128	228	131	70
235482	10	4.0	2.0	.	20	34	49	241	290	98	73
235484	0	6.5	3.5	.	21	50	80	142	222	116	65
235485	5	7.5	4.5	.	19	52	111	144	253	142	78
235546	0	7.0	5.0	.	21	54	112	129	244	131	76
236525	9	2.0	2.0	.	20	43	28	147	177	88	69
251426	3	4.5	4.0	.	17	51	83	133	218	126	87
251531	0	8.0	5.0	.	20	51	103	247	344	131	84
251841	4	7.0	4.5	.	20	52	103	158	264	140	80
251842	0	5.0	4.0	.	20	53	75	109	181	126	76
253317	0	8.5	5.0	.	20	48	113	177	288	137	89
255887	0	6.4	5.0	.	19	51	103	144	247	148	89
269728	3	5.0	2.5	.	18	52	95	148	243	108	76
272122	3	6.0	4.5	.	19	52	103	152	252	133	79
272123	0	5.5	5.5	.	19	51	95	154	254	149	82
284179	15	1.0	1.0	.	18	44	14	181	196	83	51
297362	4	3.0	1.5	.	18	56	58	115	177	88	56
314102	0	8.0	4.5	.	20	58	78	123	204	152	88
314581	0	4.0	2.0	.	20	59	70	108	175	134	73
314726	0	9.0	5.0	.	20	66	95	108	202	155	92
314727	0	7.5	3.0	.	19	52	83	128	206	110	65
314728	0	8.0	4.0	.	19	55	94	113	212	135	78
315486	0	7.4	5.5	.	22	50	97	133	237	151	76
315487	0	5.5	2.5	.	22	55	59	114	173	116	90
316329	67	1.1	1.5	.	20	69	32	198	229	81	61
316330	12	2.0	1.5	.	18	44	51	164	211	97	46
319825	0	5.0	4.0	.	20	54	89	124	212	131	65
329243	95	.	.	.	17	43	11	.	.	.	.
337718	0	9.0	6.0	.	20	50	83	126	205	162	54
338666	100	.	.	.	.	.	.	.	.	.	.
344557	0	6.6	4.0	.	21	47	79	146	220	119	78

345662	0	7.0	5.5	.	22	52	101	117	220	146	83
346015	0	4.1	2.5	.	19	52	73	161	228	123	69
357645	0	6.1	3.0	.	19	54	102	117	216	108	84
368980	3	7.5	5.5	.	23	50	78	136	214	162	75
369290	0	5.0	3.5	.	19	58	84	95	181	118	80
369291	0	6.0	3.0	.	20	53	82	107	184	147	78
369292	0	8.5	4.0	.	21	56	86	116	202	138	91
371754	0	6.0	4.0	.	21	52	96	113	211	129	80
372558	0	4.6	4.0	.	20	53	98	146	241	131	74
380963	0	5.9	2.0	.	15	50	69	98	163	102	65
380965	0	4.5	3.5	.	18	52	58	122	183	118	64
383726	0	6.0	3.0	.	20	71	64	119	186	116	64
387928	0	4.4	3.5	.	19	55	90	135	224	117	73
387929	0	5.5	3.5	.	21	52	75	108	184	128	71
392389	0	8.5	4.5	.	20	51	100	87	191	138	81
406316	0	6.0	3.5	.	24	52	78	114	193	140	77
422030	0	7.0	5.0	.	21	28	94	133	225	144	88
422031	20	1.1	2.0	.	20	59	19	140	155	95	61
433725	0	5.5	4.0	.	20	60	97	150	248	122	68
435294	0	5.5	3.5	.	18	53	93	105	197	144	77
435295	0	5.4	2.5	.	19	31	81	119	199	123	80
435296	1	6.5	3.0	.	20	57	98	109	208	115	73
435297	0	6.5	4.0	.	21	56	86	88	167	131	74
435298	0	5.1	4.5	.	21	54	99	114	212	121	64
435299	0	7.1	2.5	.	20	55	77	107	181	112	66
435300	0	7.6	5.5	.	21	54	104	140	239	143	81
435301	0	8.0	5.0	.	19	38	120	123	246	156	72
435302	0	8.5	4.0	.	19	52	103	89	199	146	75
435303	0	7.9	4.0	.	19	54	110	104	217	136	74
435304	0	5.0	3.0	.	20	53	94	102	195	100	79
435305	0	8.0	4.0	.	21	50	102	123	223	139	84
435307	3	5.6	2.0	.	20	64	81	92	171	98	73
435308	3	5.5	4.0	.	22	54	68	128	195	116	78
435309	1	5.0	3.5	.	21	53	86	109	195	133	75
435311	0	6.5	3.5	.	20	53	97	118	216	133	75
435312	3	7.5	2.5	.	20	52	100	103	206	117	87
440584	0	7.1	4.0	.	21	55	88	103	183	120	73
440585	0	5.4	5.0	.	20	87	74	73	153	128	62
505892	0	5.5	4.0	.	20	52	95	106	205	133	74
505893	0	7.0	5.5	.	20	52	118	128	246	146	81
539029	0	6.5	4.5	.	20	53	97	109	203	145	80
539030	1	6.4	5.5	.	21	55	104	109	217	137	82
557461	0	4.0	4.5	.	19	49	79	96	177	118	70
578789	0	6.0	4.5	.	21	51	104	128	229	138	80
578790	26	0.9	2.0	.	20	48	25	146	170	90	48
578791	0	6.0	4.5	.	22	49	94	140	234	145	79
578792	16	1.0	2.0	.	20	42	15	120	134	76	48
578793	1	7.0	4.5	.	19	52	102	144	248	148	80

578795	22	1.1	1.5	.	19	44	11	120	129	90	62
578796	0	6.5	4.0	.	22	54	98	121	220	147	84
578797	0	7.0	6.0	.	19	47	108	173	281	155	95
597488	0	4.0	5.0	.	21	72	72	124	197	131	86
Bellevue	0	6.0	4.5	.	21	55	93	135	226	132	86
Palaton	3	7.0	5.0	.	21	53	108	142	253	132	93
PSC_1142	0	7.9	7.0	.	23	52	100	147	248	162	84
Rival	0	4.6	5.0	.	17	54	92	120	210	140	77
Vantage	0	6.0	4.0	.	19	55	90	135	225	143	94
Venture	0	6.5	5.5	.	26	49	89	132	220	143	92
Mean	5	6	4	.	20	53	86	144	231	123	69
Maximum	100	9	7	.	26	87	120	296	403	162	108
Minimum	1	1	1	.	14	28	11	73	129	50	39
Range	101	8	6	.	12	60	110	223	274	112	69
Std. Deviation	17.40	1.83	1.26	.	1.64	7.72	24.76	39.80	47.32	22.32	12.20
LSD (5%)	8	1.6	1.6	.	3.5	21	22	45	50	27	15

Appendix Table III.5. Biomass quality for all accessions in May and October, 1999 at Ames, IA.

	5/27/99					10/15/99				
Entry	IVDMD†	NDF	ADF	ADL	CP	IVDMD	NDF	ADF	ADL	CP
	--------------------		%		--------------------	--------------------		%		--------------------
172443	71.2	53.7	30	2.5	18.8	48.1	59.9	*33.7*	*4.65*	7.27
206463	72.4	52	28.8	2.2	20.6	51.2	58	31.7	4.12	6.28
209979	70.1	*55.4*	30.8	2.5	18.6	53	52.7	26.9	3.61	6.79
225116	71.2	52.9	29.8	2.5	19.9	49.7	55.3	30.2	4.36	*4.71*
227670	70.5	53.6	*31.2*	2.5	19.2	*44.1*	59.9	*32.8*	*5.03*	7.93
234694	75.7	47	25.3	1.8	25.1	51.3	55	27.3	3.81	8.24
234695	72.3	53.4	29.3	2.1	21.4	52.6	53	28.5	3.86	7
234696	74.1	51.3	28.7	2	21.6	49.5	53.4	28.2	3.93	8.28
234698	69.6	*56.7*	*32*	*2.4*	18.8	53.8	54.3	28.2	3.8	7.38
234780	72.5	54.8	30.4	2.2	20.7	51.9	53.6	29.1	3.99	*5.1*
234790	72.5	53.1	29.6	2.1	20.7	49.7	55.3	29.5	*4.44*	6.86
235023	74.1	50.3	28	2	22.4	51.4	54	28.8	3.91	7.12
235482	71.4	53.4	28.8	2.2	21.5	50.5	55.9	29.8	4.11	7.12
235484	71.2	53.2	30.4	2.2	21.6	56.3	52.8	27.3	3.43	8.39
235485	71.1	54.1	30	2.4	20.1	53.8	52.1	27.4	3.57	7.74
235546	71	54.1	*31*	2.5	19.2	51.5	54.2	28.6	4.03	6.87
235547	71.4	*55.4*	30.5	2.3	19.6	50.9	56.6	30.4	4.2	7.67
235551	70.9	54.6	30.3	2.3	21	54.4	53.3	28.1	3.64	6.99
236525	78.5	45.9	24.5	1.5	26.8	48.4	59.4	*33.3*	*4.53*	6.89
241064	72.3	52.5	29.1	2.3	20.4	57	53.6	27.9	3.76	7.05
241065	75	49.7	27.1	1.7	22.6	48.6	60.2	*32.7*	*4.49*	6.03
251426	71.2	53.4	30.1	2.4	20.7	53.6	55.1	29.5	3.92	7.82
251531	70.8	54	30.1	2.5	19.8	48.7	57.5	29.8	4.29	5.82
251841	72.4	51.3	28.3	2.3	21	52.5	54.7	28.3	3.75	8.39
251842	71.7	52.7	29.2	2.3	19.5	51.6	57.2	30.2	4.01	7.16
253315	70.4	*56.6*	*31.2*	2.5	18.8	52.4	52.3	27.9	3.77	*5.35*
253316	71.5	53.5	30.3	2.4	20.8	54.2	54	27.6	3.86	6.27
253317	*69.1*	*56.9*	*32*	*2.7*	18.7	52.7	53	27.8	3.55	*5.67*
255887	73	53.2	29.1	2.1	20.3	53.6	54.7	27.6	3.7	6.68
269728	72.3	53.4	30	2.2	21.9	*45.3*	53	30.4	4.28	*4.88*
272122	72.7	52.9	29.3	2.2	20.3	57.4	53.8	27.4	3.38	9.17
272123	73.3	52.7	29.5	2	21.7	53.9	53.6	26.9	3.86	6.98
278706	71.5	54.4	30.6	2.2	19.7	48.2	55.6	29.4	4.12	7.46
284179	80.3	44.7	22.6	1.1	27.4	51	56.6	30.9	4.24	*5.19*
297362	79.2	45.4	23.3	1.2	26.4	48.7	57.1	30.6	4.18	7.53
314102	71.2	53.8	29.5	2.4	20.3	50	56.9	30.8	4.31	5.8
314581	74.2	49.7	26.2	1.9	23.2	47.5	59.7	30.8	*4.51*	8.06
314726	69.9	*55.3*	30.9	2.5	*17*	*45.1*	*61.1*	*32.9*	*4.91*	7.26
314727	72.3	52.9	29.7	2.3	20.8	51.9	56.1	29.8	3.99	6.56
314728	70.3	53.8	30.6	2.5	18.7	47.2	57.8	31.5	*4.46*	7.81
315486	70.6	54.2	30.5	2.4	19.3	50.3	54.6	29	3.96	6.21
315487	73.9	50.1	27.8	2	21.5	*43.6*	60.9	*32.5*	*4.61*	6.18
316329	79.9	42.4	21.8	1.3	27.9	53.6	60.8	*34.3*	4.41	*4.2*
316330	77.3	48.4	26	1.5	25.9	*44.5*	60.4	*33.4*	*4.75*	7.52

319825	73.5	52	28.3	2.1	21.7	53.6	53.4	27.1	3.6	9.2
329243	.	.	.	.	.	.	.	.	.	.
337718	*66.4*	*59*	*33.9*	*3*	*15.4*	50.8	56.6	29.8	4.13	6.78
338666	.	.	.	.	.	.	.	.	.	.
344557	71.3	53.9	29.7	2.3	19.5	51.5	55.7	29.3	4	*5.27*
345662	71.5	53.5	29.7	2.2	20.4	46.9	57.2	30.8	*4.49*	*5.54*
346015	72.6	53.4	29.7	2.1	20.3	51.5	54.2	27.9	4	8.26
357645	71	53	29.3	2.3	20.6	48.5	57.3	30.2	4.39	6.71
368980	*67.3*	*57.7*	*32.8*	*2.9*	*16.5*	49	57.2	30.1	4.05	6.82
369290	74.9	50.4	27.6	2.1	21.8	48.3	59	30.2	4.35	6.35
369291	71.9	53.2	29.2	2.1	21.8	49	57.8	31.6	4.23	6.78
369292	70.6	55.1	*31.3*	2.2	21.5	49.6	58.7	30.7	4.33	7.45
371754	73.4	52.4	28.4	2	21.1	48.8	55.9	29.7	4.13	*4.55*
372558	72.9	53.1	28.9	2.2	21.1	48.8	54.6	30.1	4.07	*5.5*
380963	70.6	55	*31.6*	2.4	18.7	*44.2*	*61.5*	*33.2*	*5.22*	9.61
380965	70.4	53.8	30.2	2.3	20.1	49.5	58.4	31.8	*4.7*	9.53
383726	73.2	52.4	29.4	2.1	20	*46*	*61.7*	31.8	*4.55*	8.49
387928	74.1	51.8	27.4	1.9	21.4	48.1	56.3	31.1	4.07	*5.23*
387929	72.8	53.3	27.7	1.9	20.7	48.3	58.7	30.6	4.03	6.56
392389	73.7	53.4	29	2	20	*43.5*	59.7	*32.8*	*4.88*	7.01
406316	69.8	54.2	30.9	2.5	*18.1*	48	57.4	30.3	4.3	7.18
422030	71.2	53.4	30.4	2.4	19.8	51.8	55.8	30	3.99	*5.57*
422031	72.4	52.3	28.1	2	22.5	48.4	59.2	32.2	4.12	*5.26*
433725	71.1	54.9	30.7	2.4	*18.2*	50	54.7	29.7	4.12	*4.36*
435294	70	*57.1*	*31.4*	2.4	18.9	47.6	56.4	30.3	4.09	7.29
435295	74.3	50.1	26.5	2	22.5	48.2	59.1	*32.5*	*4.49*	*5.28*
435296	76.5	47.9	25.7	1.7	22.9	49.7	56	29.4	3.78	7.15
435297	73.5	51	28.1	2	21.7	47.7	59.2	*32.6*	4.31	6.33
435298	73.8	49.9	27.6	2	22.6	50.3	54.3	29.3	3.8	6.97
435299	74.5	49.8	27.4	1.8	23.3	49	57.5	30.6	4.37	8.73
435300	71.5	54.8	30	2.2	20.2	49.6	56.5	30	3.6	*4.46*
435301	73	53.4	29.2	2.1	20.7	46.7	58.6	32.1	*4.76*	9.08
435302	70.4	55.1	30.5	2.4	*17.8*	47.9	58.9	31.4	*4.73*	9.62
435303	72.9	52.5	30.1	2.2	20.2	*42.8*	*63.5*	*34.9*	*4.84*	*4.79*
435304	74.1	51.6	28.4	1.9	22.1	48.6	59.3	31.8	4.17	8.04
435305	71.6	54.1	29.3	2.2	20.8	49.7	57.6	30.5	4.18	7.48
435307	75.6	48	25.2	1.7	23.1	47.5	56.5	30.4	4.33	8.39
435308	73.7	48.6	26	2.1	23.2	50.2	54.9	29	3.96	8.37
435309	73.2	50.3	27.8	2.1	20.5	50.7	56.8	29.4	4.18	10.07
435311	71.1	53.9	30	2.4	21.2	47.7	58.1	31	4.35	6.4
435312	73.1	50.8	27.7	2	22	47.7	57.6	30.4	4.29	7.85
440584	72.2	52	29.1	2.2	21.3	*41.7*	*63.2*	*34.8*	*5.06*	6.57
440585	71.6	55.1	30.3	2.2	18.9	*45.1*	57.9	30.8	*4.45*	7.8
505892	71.2	53.9	29.5	2.3	20.9	47.6	58.1	30	4.15	7.43
505893	71.6	52.9	29.4	2.3	19.9	52.3	54.9	28.2	4.06	7.7
539029	70.6	54.2	30	2.4	20.9	49.7	56.1	30.4	4.14	7.28
539030	72.7	50.2	27.5	2.3	22	50.1	56.8	30.5	3.96	*5.4*
557461	70.9	54.9	*31*	2.3	19.6	46.6	59.3	32	4.36	6.2

578789	70.8	54.7	30.4	2.4	19.8	47.6	57.3	30.7	3.99	5.77
578790	78.6	45.3	24.4	1.5	25.9	47.1	60.9	*34.6*	*4.95*	6.32
578791	*69.5*	*55.9*	*31.8*	*2.5*	18.9	52.3	55.2	29.1	3.97	6.97
578793	71.2	52.7	29.7	2.4	19.3	49.6	57	30.9	4.17	*5.26*
578795	77.1	47.8	24.9	1.5	26.7	54	58.5	*32.6*	4.21	6.86
578796	*69.4*	*56*	*31.7*	2.6	19.1	49.6	56.4	30.2	4.17	5.98
578797	69.9	*56.7*	*31.8*	*2.6*	18.6	50.6	55.5	29.7	4.18	7.35
597488	71.7	52.5	29.6	2.3	21.6	*45.2*	59.2	31.3	*4.47*	5.74
Bellevue	71.5	53.2	29.9	2.3	20.6	48.9	56.8	30.8	4.2	6.19
Flare	72.3	53.1	29.4	2.1	20.8	50.1	57	30.1	3.96	*5.56*
Fraser	71	52.6	29.7	2.4	20.2	52.7	52.6	27.8	3.6	7.44
High_SLW	72.6	50.7	27.5	2.2	21.6	53.7	54	28.5	3.68	*4.93*
Lo_SLW	72.8	51.8	27.9	2.2	21.5	49.9	55	30.4	4.15	6.18
Palaton	70.5	*55.9*	*31.7*	2.4	18.5	51.6	56	30	3.9	5.9
PS-3	73	52.4	29.8	2	21.4	53.3	55.1	28.8	3.71	5.88
PSC_1142	*69*	53.8	*31*	2.9	18.7	53.9	51.9	27.2	3.68	*5.6*
RC-11	74.5	50.4	27.5	2	21	51.2	54.1	28.6	3.91	6.79
RC-5	70.4	*56.8*	*32.3*	*2.4*	*16.9*	53	52.1	27.7	3.59	*5.18*
RC-6	71.9	53.2	29.6	2.2	21.7	51.8	54.5	28.6	3.86	6.86
RC-7	73	51.5	29.1	2.2	21.4	54.4	49.5	26	3.28	10.28
RH33	76.7	47.7	26	1.7	25	48.4	54.6	29	4.04	7.76
RH47	73.1	52.4	28.7	2	20.8	48.7	56.4	28.7	4.05	6.19
RH50	76.5	50.5	25.1	1.7	22.8	49.4	59.6	30.7	4.28	9.16
RH78	80.1	41.1	19.7	1.1	27.9	55.3	54.2	26.6	3.62	11.65
RH85	76.9	49.3	26.4	1.5	23.2	55.1	57.7	30.6	4.11	6.3
Rival	74.6	51.3	28.7	1.9	21.9	50.8	56.4	30	4.26	6.64
Vantage	71.4	55.2	30.2	2.2	19.4	50.5	54.9	28.6	3.84	*5.47*
Venture	70.9	*56.1*	*31.4*	2.4	19.4	49.1	57.5	30.7	4.29	*5.04*
Mean	72.5	52.5	29.0	2.2	21.0	49.9	56.5	30.1	4.1	6.9
LSD (5%)	3.1	3.7	2.9	0.5	3.0	4.4	5.1	4.1	0.8	2.7
Maximum	80.3	59.0	33.9	3.0	27.9	57.4	63.5	34.9	5.22	11.65
Minimum	66.4	41.1	19.7	1.1	15.4	41.7	49.5	26.0	3.28	4.2
Range	13.9	17.9	14.2	1.9	12.5	15.7	14.0	8.9	1.94	7.45
Std. Dev.	2.49	3.00	2.27	0.34	2.25	3.02	2.59	1.87	0.37	1.37

[†]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.

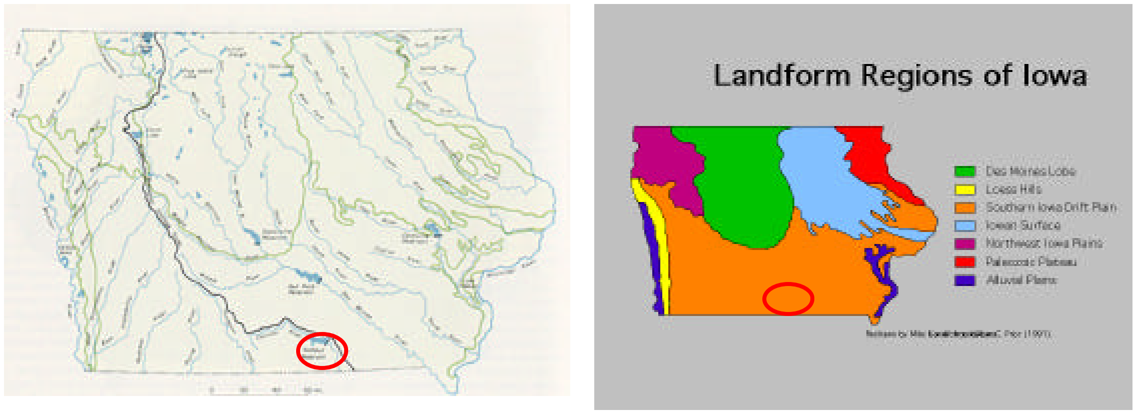

Figure 1. a: Map showing major streams and general area of study (circle) in Iowa.
b: Map showing major land use regions.

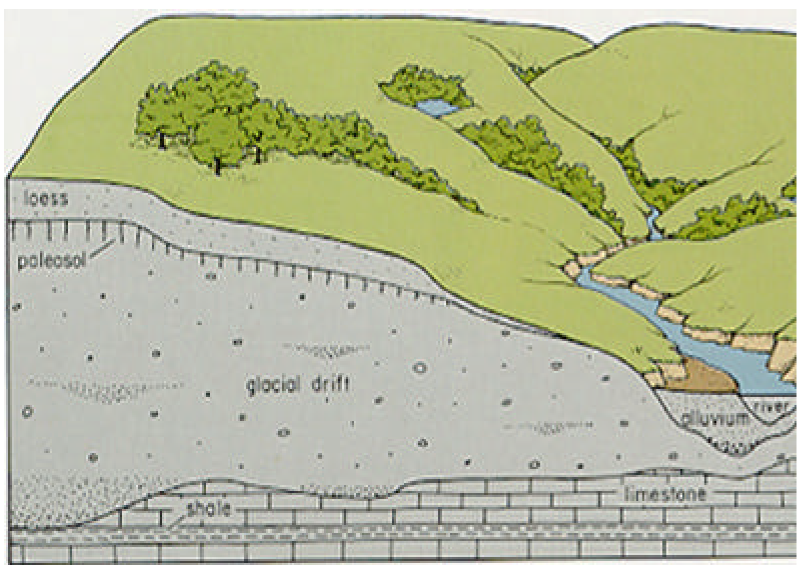

Figure 2: Cross-section showing a typical landscape and soil parent materials for the Southern Iowa Drift Plain, to which the Chariton Valley belongs.

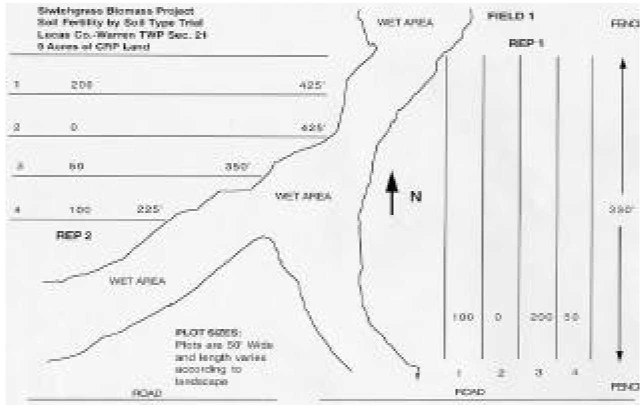

Figure 3: Layout of fertility trials at field 1 (switchgrass field is 9 acres near the east edge of the SW 1/4section 21, T71N, R22 W, Lucas County)

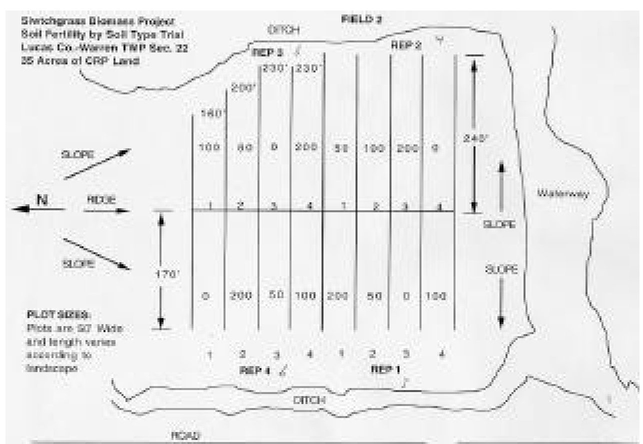

Figure 4: Layout of fertility trials at field 2 (switchgrass field is 35 acres comprising most of the SW ¼, SW1/4 of 22, T71N, R22 W, Lucas County)

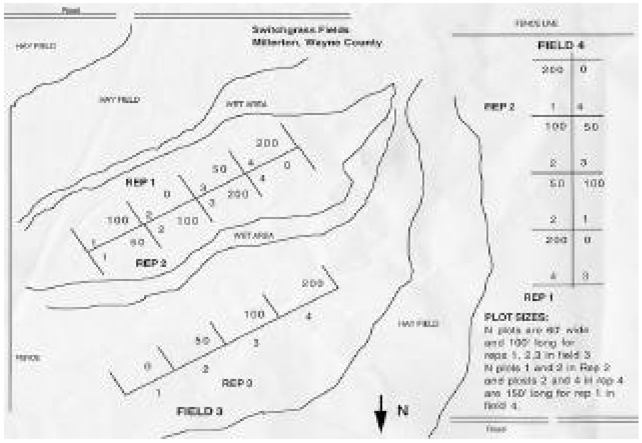

Figure 5: Fertility trials at fields 3 and 4 (distributed in the SE ¼ and southern ½ of the NE ¼, section 27, T70N, R21 W, Wayne County)

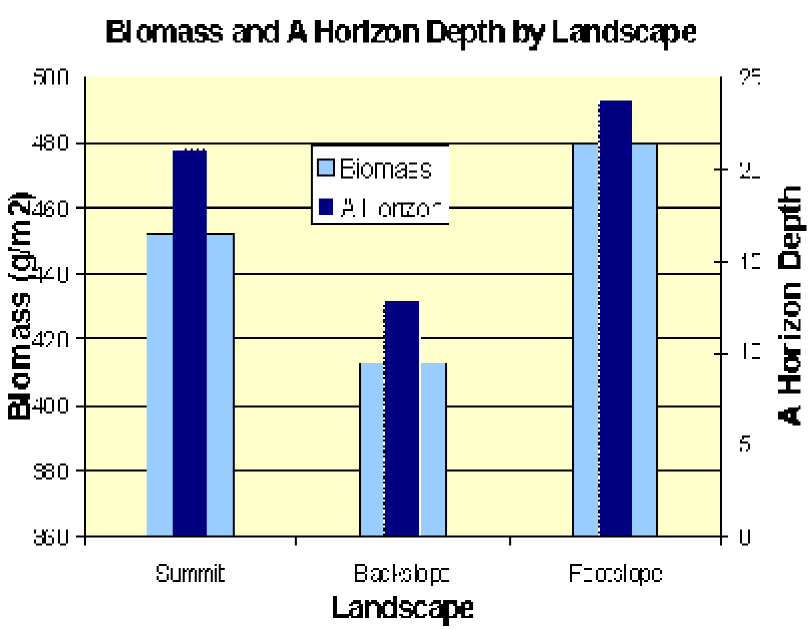

Figure 6: Schematic showing relationship between switchgrass yield and A horizon thickness (in cm) averaged across fields 1 & 2 in 1998.

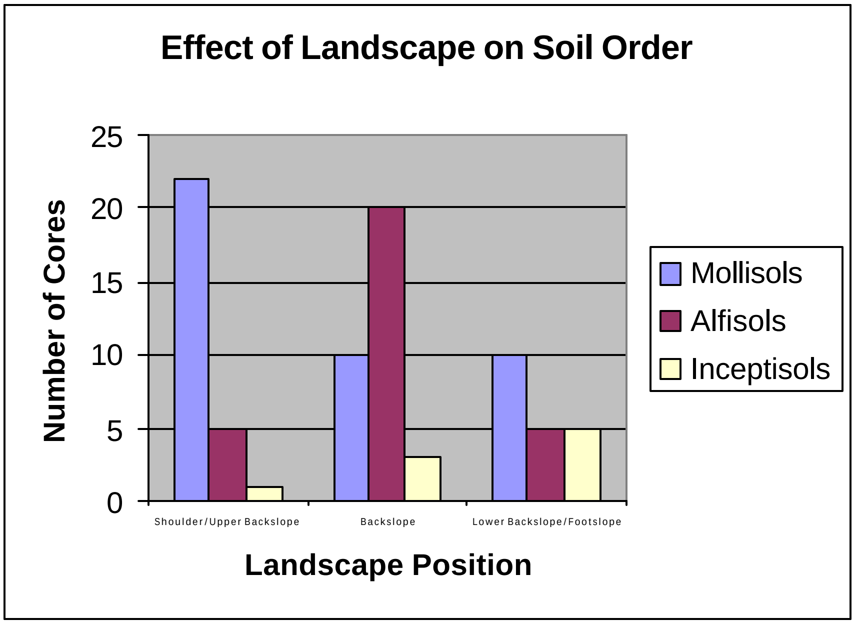

Figure 7: Relationship between landscape position and soil order at the four fields used in the nitrogen fertility trials.

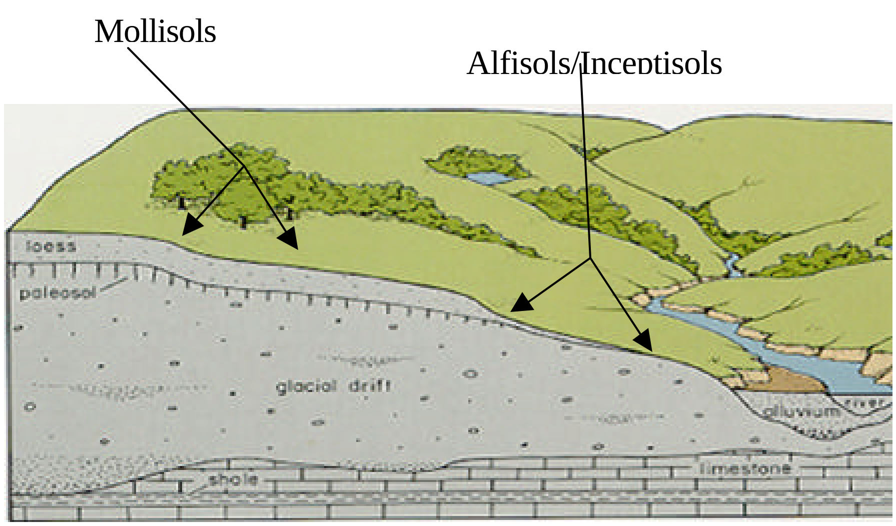

Figure 8: Distribution of soil orders across a typical landscape in the Chariton Valley.

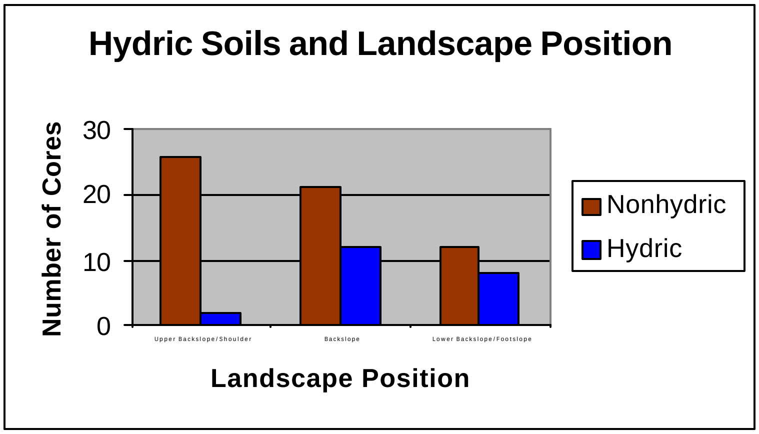

Figure 9: Relationship between landscape position and the presence of hydric soils at the four fields used in the nitrogen fertility trials.

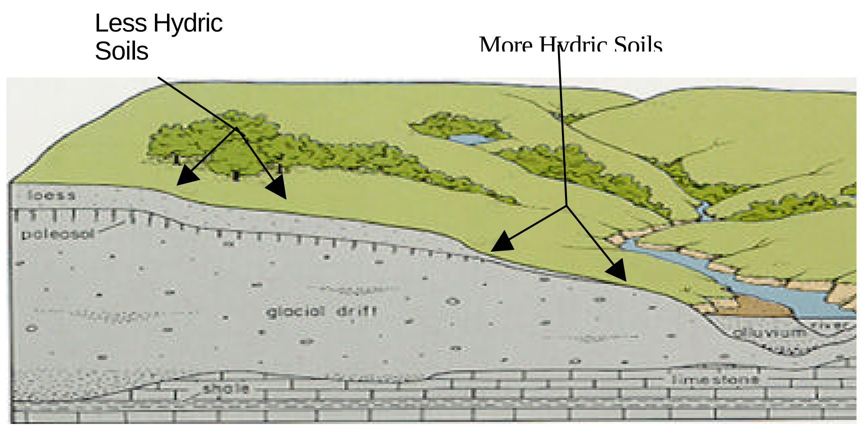

Figure 10: Distribution of hydric soils across a typical landscape in the Chariton Valley.