Development of Bioenergy Feedstocks: Agronomy Data from Eastern Canada

Final Report

R. Jannasch, P. Duxbury and R. Samson

Resource Efficient Agricultural Production (REAP) – Canada
Box 125, Ste. Anne de Bellevue, Quebec, H9X 3V9

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EXECUTIVE SUMMARY

Utilizing the surplus production capacity of the agricultural sector to produce biofuels could play an important role in improving Canada's energy security and meeting its international obligation to reduce greenhouse gas emissions. Energy farming with perennial grasses and fast growing trees appears to be an ideal means of collecting large amounts of solar energy from low quality and marginal farmland to process into biofuels. The objective of this project was to develop a comprehensive data set on the performance and agronomic limitations of several bioenergy feedstocks in Eastern Canada.

Part One of this report examines the productivity of switchgrass and short rotation forestry (SRF) willow in a side by side paired comparison study established to assess their economic and agronomic viability in eastern Canada. The study was repeated on two sites in Ste-Anne-de-Bellevue, Quebec. Seven year average annual yields were 11.5 oven dry tonnes (ODT) ha^{-1} for Cave-in-Rock switchgrass and 11.0 ODT ha^{-1} for SRF willow. Switchgrass was easier to establish, less prone to weed and insect infestation and easier to manage than SRF willow. Fall harvesting switchgrass is risky due to high plant moisture levels (41-51%) and poor conditions for field drying. Germplasm with earlier fall maturity and good lodging resistance was identified that could reduce this risk. Over-wintered switchgrass harvested in the spring contained 11-13% moisture. However, dry matter losses during the winter period can range from 30-40%. Breeding and selection efforts to reduce overwintering losses should be directed at increasing the proportion of stem components and reducing the proportion of leaf material. Overall, switchgrass is a less risky energy farming option than SRF willow for farmers and biofuel processors.

Part Two reports on three switchgrass cultivar trials established in 1996 and 1997 on two sites in Alfred, Ontario, and one in Ste-Anne-de-Bellevue, Quebec, to assess spring and fall harvesting qualities. Cultivar performance varied according to soil type, and switchgrass was generally slower to establish on clay soils compared to sandy soils. Several promising experimental plant materials developed by Oklahoma State University and REAP-Canada were identified. Two selections, REAP 921 and REAP 922, developed by REAP-Canada using recurrent phenotypic selection techniques produced slightly lower yields than the industry standard, Cave-in-Rock, but demonstrated earlier maturity, improved lodging resistance and reduced over-wintering losses. Moreover, average relative growth rates of
REAP 922, REAP 921 and NU 94 ranged from 81.7-84.0 kg ha^{-1} ,similar to that of Cave-in-Rock (84.0 kg ha^{-1}). Investing in conventional plant breeding techniques could create major improvements in the ability of perennial grasses to be utilized as low cost solar energy collectors.

Energy farming with perennial grasses has the potential to be a major new development opportunity for Canada's agricultural and energy sectors. Modest investments in research and development of energy farming feedstocks will accelerate development of this economic opportunity and its potential to mitigate global climate change and energy insecurity in North America.

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INTRODUCTION

Switchgrass (*Panicum virgatum* L.) has been identified as a potential bioenergy crop for commercialization. Switchgrass can be converted to ethanol via an enzymatic process (Samson and Omielan, 1994), or it can be compressed into fuel pellets for space and water heating (Samson and Duxbury, 2000). It is also suitable as a fibre crop for pulp and paper production (Girouard and Samson, 1995), as a substrate for mushroom cultivation and as a fibre source for construction materials. Short rotation forestry (SRF) willow (*Salix alba* sp.) is another potential bioenergy crop that grows rapidly on imperfectly drained soils. Both crops are perennial species native to North America. Growing concern over increasing greenhouse gases (GHG) emissions and rising oil prices means bioenergy crops are gaining importance in environmental as well as economic agendas (Hatton, 1999, Matisius, 2000).

With the signing of the Kyoto Protocol, Canada committed to reduce its GHG emissions by 6% below 1990 levels by the years 2008-2012. One immediate, long-term solution would be to establish bioenergy crops on marginal agricultural soils. These crops create a closed loop carbon cycle by utilizing CO_2 for photosynthesis during their growing period, and releasing it during the combustion process. However, CO_2 that is released during combustion will be re-absorbed during the next growth cycle. Perennial bioenergy crops require less fieldwork (less seeding and tilling) than annual crops such as corn (*Zea mays*), an efficiency that reduces fossil fuel consumption by farm machinery.

There were two main objectives in this study. The first objective was to further develop data covering the agronomic potential of bioenergy feedstocks for eastern Canada. This project evaluated the agronomic traits and biomass productivity of switchgrass and SRF willow, established on two sites at the Lods Research Farm, Ste. Anne de Bellevue, QC, in 1993. The data obtained from this study will help to determine which bioenergy crops hold the most potential in the immediate and long-term future for eastern Canada. The production of low cost and high yielding bioenergy feedstocks adapted to regional soils and climate will be a fundamental requirement for the successful development of Canada's bioenergy industry.

The second objective was to evaluate a broad range of switchgrass varieties for their agronomic qualities at two locations in eastern Canada with different climatic and soil conditions. The locations were at the Lods Research Farm, Ste-Anne-de-Bellevue, QC and at College d'Alfred, in Alfred College, 80 km east of Ottawa. The variety trials are used to identify productive cultivars with the agronomic characteristics necessary for introducing the crop across a broad range of soil and climatic zones in eastern Canada. This study will expand the existing database of information regarding switchgrass varieties and help to identify future directions in plant selection and breeding work.

TASK 1: BIOENERGY FARMING SYSTEMS COMPARISONS STUDY

Resource Efficient Agricultural Production-Canada
Box 125, Glenaladale House
Ste. Anne de Bellevue, Quebec
reap@interlink.ca

1.1 Methods

In 2000, the agronomic traits of bioenergy crops were evaluated at two 5 ha sites on the Macdonald Campus Emile A. Lods agronomy research farm of McGill University. Side by side comparisons of fast growing tree species and perennial grasses were located at each site. The soils were mainly St. Bernard and Chicot fine sandy loam, with pockets of Chateauguay clay loam. One site was referred to as the Seedfarm site, and the other as the Ecomuseum (Figures 1.1 and 1.2). Short rotation willow (S*alix alba x glatfelteri* L.) and switchgrass (P*anicum virgatum* L.) were each planted in a randomized complete block design with six replications. Detailed materials, methods and site descriptions used for the study can be found in Samson et al. (1995). Table 1.1 outlines the Ste. Anne de Bellevue rainfall and temperature data for 2000 and averaged over the past 30 years.

Table 1.1 – Rainfall (mm) and mean daily temperature (°C) in 2000 and 30 yr normals at Ste. Anne de Bellevue, Que.

	Normal Rainfall (mm)	2000 Rainfall (mm)	Normal Mean Daily Temp	2000 Mean Daily Temp
May	66.7	133.3	12.9	12.8
June	82.5	86.0	18.0	16.7
July	85.6	81.2	20.6	19.9
August	110.3	125.5	19.4	18.8
Sept.	86.5	84.0	14.5	13.7
Total	431.6	510.0	-	-

Three varieties of switchgrass (Cave-in-Rock, Pathfinder and Sunburst), were planted in June, 1993, in 6 m wide strips. At the Seedfarm, the switchgrass was fertilized with 45 kg N ha^{-1} (urea) in June 1994, 1995 and 1996, and with 75 kg N ha^{-1} in June 1997. In June 1994, the Ecomuseum site was fertilized with 30 kg N ha^{-1} (ammonium nitrate). The rate was increased to 45 kg N ha^{-1} in June 1995, 1996, and 1997. In 1998 both sites received 50 kg N ha^{-1} (urea). In 1999 and 2000 the application was increased to 60 N ha^{-1} (urea). The yields of each variety were assessed in the fall of each year using four 1 m^2 samples sheared to a height of 10 cm. Starting in 1996, spring biomass yields were calculated (usually in the second week of May) to determine over-wintering losses. The entire crop was then harvested and baled within one week of the plot harvest before the beginning of that season's new forage growth. In 2000, harvesting took place between May 18-20 and Sept 30-Oct 2. Representative sub-samples were harvested and oven-dried at 55 °C for 48 h to determine dry matter yields.

Three varieties of SRF willow cuttings (*Salix alba* x *glatefelteri*, *S. miyabaena, and S. viminalis*) were planted at a density of 11 000 spears per hectare in 0.92 m wide rows in June, 1993. Only one variety (*Salix alba* x *glatfelteri*) established satisfactorily and proved productive. Other materials were subsequently discarded from further evaluation. The willow plots were coppiced with thinning saws in January 1996, and fertilized with 77 kg N ha^{-1} and 84 kg K ha^{-1} in June 1996. In 1998, the willows at both sites were fertilized with 125 kg N ha^{-1}, 31 kg P $ha^{-1}$and 75 kg K ha^{-1}. In 1999 no fertilizer was applied. In the late fall of 1999, two weeks after leaf drop, the trees were coppiced again with thinning saws. The willows were fertilized in late May, 2000, with 125 kg N ha^{-1}, 31 kg P $ha^{-1}$and 75 kg K ha^{-1}. Willows were harvested on December 1, 2000, by cutting four-five meter rows per plot (20m^2) with a thinning saw to a height of 10 cm. A representative sub-sample was then weighed and oven-dried to determine the dry matter content of the material

Ecomuseum Site

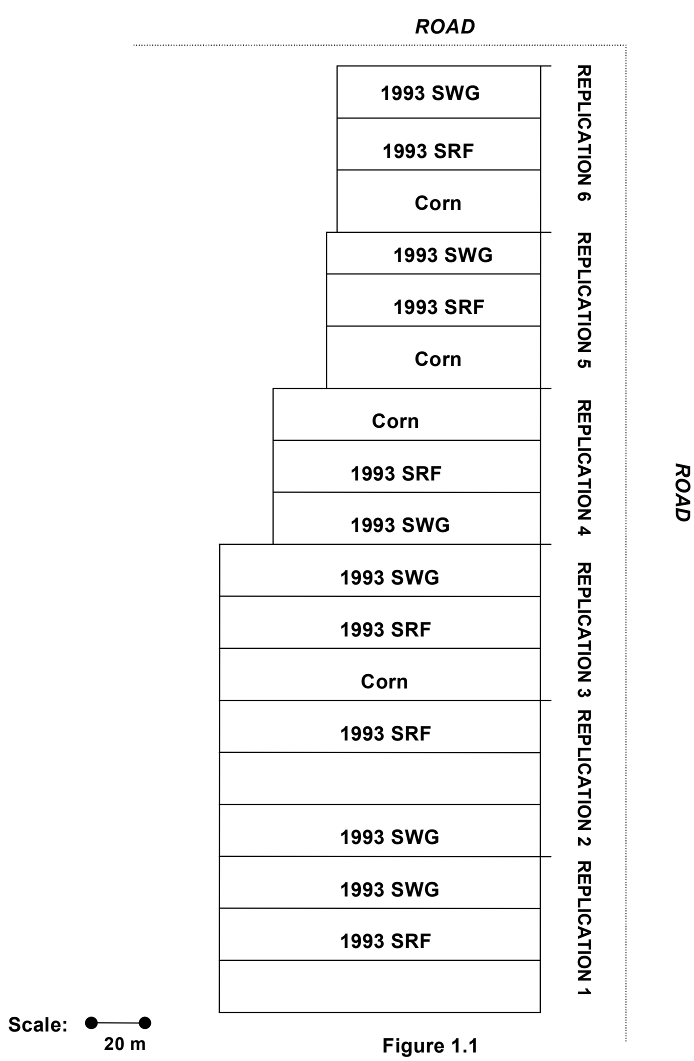


Figure 1.1

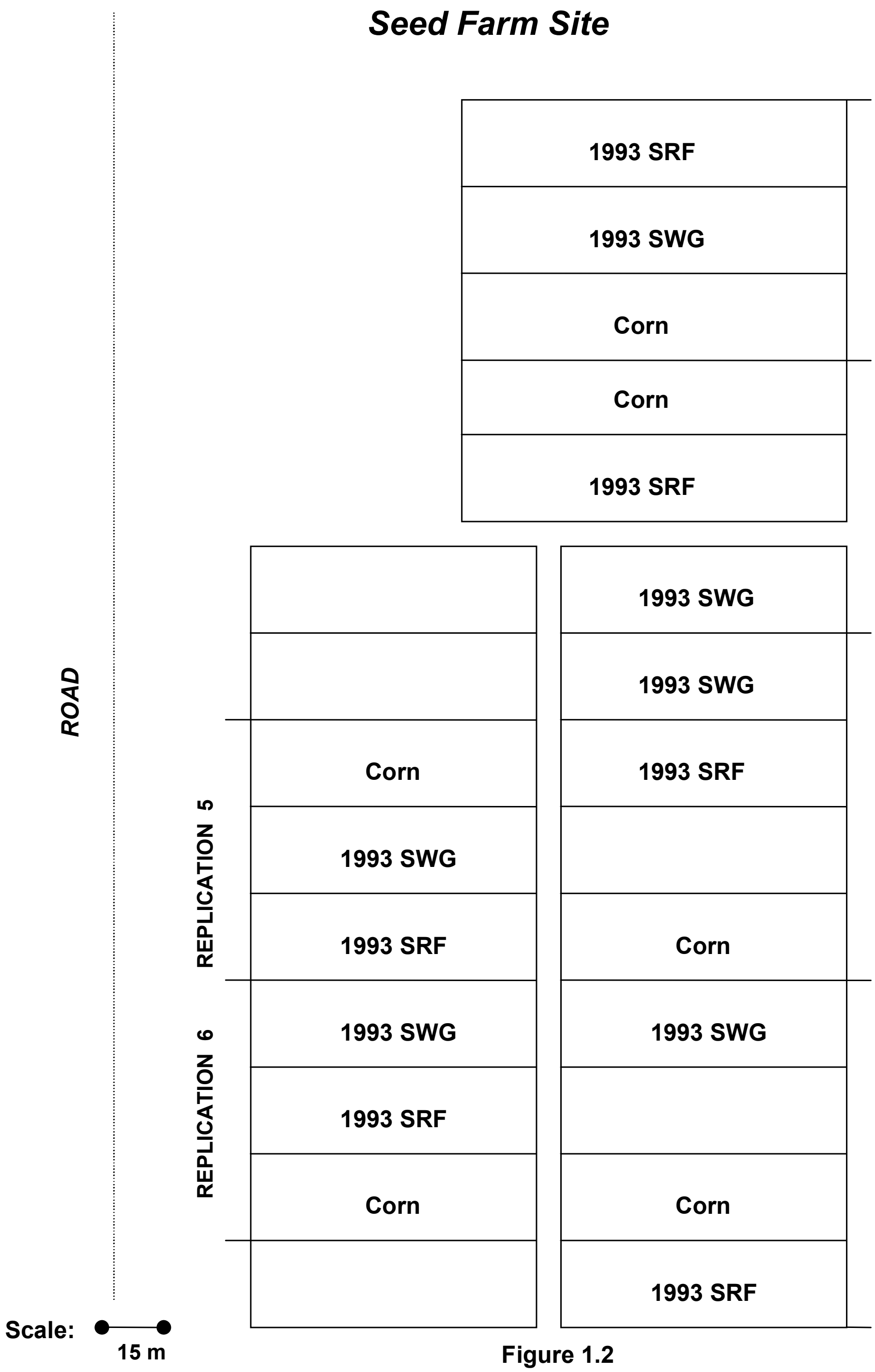

Seed Farm Site
1993 SRF
1993 SWG
Corn
REPLICATION 1
Corn
1993 SRF
REPLICATION 2
1993 SWG
1993 SWG
1993 SRF
Corn
REPLICATION 3
1993 SWG
Corn
1993 SRF
REPLICATION 4
ROAD
Corn
1993 SWG
1993 SRF
REPLICATION 5
1993 SWG
1993 SRF
Corn
REPLICATION 6
Scale:
15 m

Figure 1.2

1.2 Results

1.2.1 Fall Switchgrass Harvest

No significant disease or insect pressure was observed in the switchgrass stands during the 2000 growing season. Minor infestations of rust observed in previous years were not evident. Switchgrass ecotypes derived from the western prairies (these evolved in low humidity environments) can be susceptible to rust in Southern Ontario and Eastern Quebec. Eastern switchgrass ecotypes such as Cave-in-Rock have shown little incidence of rust.

Weed pressure was minimal throughout the eight-year study. Some encroachment by perennial weeds did occur where switchgrass established poorly. Overall, weed control was excellent even though no herbicides were applied after the seeding year. Weeds contributed no more than 2% of the total biomass harvested. At the Ecomuseum site, populations of sow thistle and to a lesser extent, milkweed have increased slightly. Weeds were least numerous in plots of Cave-in-Rock probably because it is a tall and late-maturing variety and competes vigorously for nutrients and sunlight. On the Seedfarm site, weed pressure actually declined over the study period. This site was originally heavily infested with quackgrass, but switchgrass completely dominated the stand by 1995. The fact that the stands were over-wintered each year probably helped prevent any serious level of weed encroachment. The thick mulch provided an excellent barrier to sunlight, likely preventing weed growth in fall and early spring.

Significant differences were not evident between fall harvested switchgrass cultivars at either the Seedfarm or the Ecomuseum sites between 1994 and 2000 (Table 1.2). The 2000 fall yield at the Seedfarm site was 8.6 ODT ha^{-1} compared to the 7-year average (1994-2000) of 10.8 ODT ha^{-1}. In 2000 at the Ecomuseum, the yield disparity was less with averaged fall yields of 10.3 ODT ha^{-1} compared to 10.6 ODT ha^{-1} for the 7 year average. There are two possible explanations for the lower 2000 yields. Spring growth was probably delayed by late removal of the previous season's crop and cool, wet weather in May and early June.

The 7-year average yields suggests that fairly stable yields of 11-12 ODT ha^{-1} are realistic for Cave-in-Rock and Pathfinder, whereas yields of the earlier maturing Sunburst can range from 10-11 ODT ha^{-1}. Overall, Cave-in-Rock was the most productive cultivar, producing 11.4 ODT ha^{-1} at the Seedfarm site, and 11.5 ODT ha^{-1} at the Ecomuseum site, over the 7-year period. Successful harvest and storage of this variety, however, is riskier than that of earlier maturing and drier varieties such as Sunburst (see Section 2).

Table 1.2 - Fall switchgrass yields from the Seedfarm and Ecomuseum sites 1994-2000

Cultivar	1994	1995	1996	1997	1998	1999	2000	7-year Average
				ODT ha^{-1}				
Seedfarm Site								
Cave-in-rock	9.7ab	11.0a	11.9a	11.7a	13.7a	12.9a	8.8a	11.4
Pathfinder	9.9a	10.9a	11.3b	11.6a	13.2a	10.9a	9.0a	11.0
Sunburst	8.8b	9.5a	10.9b	12.0a	11.9a	9.2a	8.1a	10.1
Average Yields	**9.5**	**10.5**	**11.4**	**11.8**	**12.9**	**11.0**	**8.6**	**10.8**
Ecomuseum Site								
Cave-in-rock	7.9a	9.6a	12.7a	13.5a	11.3a	13.6a	11.9a	11.5
Pathfinder	7.4a	9.7a	11.3b	12.8a	12.2a	12.1a	9.6a	10.7
Sunburst	7.0a	8.5a	10.1c	12.4a	10.7a	9.8a	9.5a	9.7
Average Yields	**7.4**	**9.3**	**11.4**	**12.9**	**11.4**	**11.8**	**10.3**	**10.6**

Means with the same letter, within the same column, are not statistically different according to the SNK test (*P*=0.05).

The moisture content of fall-harvested material was approximately three times higher than that of spring-harvested material (Table 1.3). At the Seedfarm site, Sunburst had a significantly lower moisture content (41.8%) than either Cave-in-Rock (55.6%) or Pathfinder (45.3%). Moisture levels need to be in the 20-25% range for fall harvest and baling. Switchgrass baled at high moisture contents is less prone to decomposition compared to cool season grasses or cereal straw because it has a lower N content. With covered storage structures, switchgrass bales could dry down to 15% during storage. As an early-medium maturing cultivar that begins turning yellow in the fall several weeks before Cave-in-Rock, Sunburst has greater potential for late summer field drying. Using the late maturing varieties currently available, field drying is necessary to reduce moisture content to levels suitable for harvesting and baling. Research trials are required to better understand field drying and storage issues, as moisture control will play a critical role in the successful development of a pellet industry in Eastern Canada.

Table 1.3. Switchgrass percent moisture at the Seedfarm and Ecomuseum sites in 2000

Time of Harvest	Variety	Moisture (%) Seedfarm	Ecomuseum
Spring	Cave-in-Rock	12.9a	14.6a
	Pathfinder	12.9a	10.3a
	Sunburst	13.7a	12.7a
	Average	**13.2**	**12.5**
Fall	Cave-in-Rock	55.6a	53.8a
	Pathfinder	53.0a	45.3a
	Sunburst	41.8b	49.3a
	Average	**49.7**	**49.2**

1.2.2 Spring Switchgrass Harvest

Spring harvesting switchgrass greatly reduces the risk of crop spoilage caused by harvesting and baling material with a high moisture content. The average spring moisture content of the three cultivars was 12.8% at the Seedfarm and 12.5% at the Ecomuseum (Table 1.3). Typically, switchgrass can be spring harvested in Eastern Canada at 11-13% moisture with little difficulty. Using conventional pelleting technologies, good quality pellets can be made with material at approximately 10-11% moisture (low moisture feedstocks increase pellet density). The recent introduction of an advanced pelleting technology by Ecotre of Florence, Italy (www.ecotresystem.com), however, appears capable of producing high quality pellets with material in a slightly higher moisture range. This would suggest that minimal supplemental energy will be required for drying spring harvested material if it is properly stored.

In 2000, the spring yield of Pathfinder (8.3 ODT ha^{-1}) was greater than yields of either Sunburst or Cave-in-Rock at the Seedfarm site (Table 1.4). Yields differences were not evident at the Ecomuseum site. The average yield was 7.1 ODT ha^{-1} at the Seedfarm site and 7.5 ODT ha^{-1} at the Ecomuseum site. Spring yields may be affected by the amount of snow cover and severe weather events such as the 1998 ice storm. In addition, any variation in fall harvest date can affect relative dry matter yields because plants translocate a significant portion of their biomass below ground during the last few weeks of the season (Parrish and Wolf, 1992). REAP is undertaking further field trials to assess other varieties for over-wintering characteristics.

1.2.3 Over-wintering Losses

Over-wintering losses (e.g. leaf fall, stem breakage, seed head loss) between 1995 and 2000 were calculated as the ratio of spring and fall yields (Table 1.4). In past seasons, Cave-in-Rock was more vulnerable to losses because it is more brittle than either Sunburst and Pathfinder. Five-year average over-wintering losses for Cave-in-Rock were 42.0% at the Seedfarm and 38.1% at the Ecomuseum. In contrast, Pathfinder, another later maturing variety had losses of 32.2% at the Seedfarm and 31.3% at the Ecomuseum site. Pathfinder is clearly more suited to spring harvesting than Cave-in-Rock. Despite surperior fall yields, the poor over-wintering qualities of Cave-in-Rock mean that a large portion of the yield is lost. Cultivars that over-winter with minimal loss should be selected to enable spring harvest of biofuels (see Section II).

Table 1.4 – Switchgrass Yields (ODT ha^{-1}) and over-wintering losses at the Ste. Anne de Bellevue Plantation Sites (1995-2000)

Variety Location	Cave in Rock		Pathfinder		Sunburst	
	Seed Farm	Eco-museum	Seed Farm	Eco-museum	Seed Farm	Eco-museum
Fall 1995	10.9	9.6	10.9	9.7	9.5	8.5
Spring 1996	7.1	7.6	7.3	8.0	6.8	8.0
Winter losses %	34.9	20.8	33.1	17.5	28.5	5.9
Fall 1996	11.9	12.6	11.2	11.3	10.9	10.1
Spring 1997	8.1	7.6	8.4	8.4	8.2	6.9
Winter losses %	31.9	39.7	25.0	25.7	24.8	31.7
Fall 1997	11.7	13.5	11.6	12.8	12.0	12.4
Spring 1998	6.6	7.5	7.7	8.1	7.6	7.0
Winter losses %	43.6	44.5	33.6	36.7	36.7	43.5
Fall 1998	13.7	11.3	13.2	12.2	11.9	10.7
Spring 1999	7.1	7.1	7.2	7.2	5.4	5.4
Winter losses %	48.2	37.2	45.2	41.0	54.9	49.5
Fall 1999	12.9	13.6	10.9	12.1	9.2	9.8
Spring 2000	6.3	7.0	8.3	7.8	6.7	6.9
Winter losses %	51.2	48.5	23.9	35.5	27.2	29.6
5-Year Average	42.0	38.1	32.2	31.3	34.4	32.0

1.3.0 Short Rotation Willow

In 2000, willows produced 3.3 and 3.0 ODT ha^{-1} of new growth at the Seedfarm and Ecomuseum, respectively (Table 1.5). The cool and wet season should have been favourable to willow growth, but the low yields were not unexpected. The 2000 growing cycle was the beginning of a new coppice cycle (coppicing occurred in late November and early December, 1999). Coppicing appears to dramatically impact productivity of this clone. In 1999, yields averaged 19.4 and 21.9 ODT ha^{-1} at the Seedfarm and Ecomuseum sites, respectively (Table 1.4). The average overall yield from 1994-2000, however, was only 11.0 ODT ha^{-1}. It is evident that growth increased substantially towards the end of the 4 year coppicing cycle. *Salix x alba glatfelteri* willows appear to produce satisfactory average yields, but biomass production fluctuates according to the coppicing cycle. After a fall coppicing in 1995, growth in 1996 was only 7.1 ODT ha^{-1}. Coppicing can delay the willow's ability to capture solar energy and increase susceptibility to insect attack.

No disease or pest incidences were observed during the 2000 growing season. Previous outbreaks of willow saw fly (*Nematus sp.*) did not reoccur. Weed pressure from perennial weeds was a problem at both sites. Quackgrass was evident at the Seedfarm and volunteer Manitoba maple was a major competitor at the Ecomuseum. A thinning saw was used to reduce weed pressure on coppiced trees by Manitoba maples, but this operation was very time consuming.

Table 1.5 - Short Rotation Willow Yields from the Ecomuseum and Seedfarm sites - 1994-2000

Site	1st Cycle		2nd Cycle				3rd Cycle	7-year
	1994[1]	1995	1996	1997	1998	1999	2000	Average
Seedfarm[2]	4.4a	11.6a	6.6a	7.2a	25.6a	19.4a	3.3a	11.2
Ecomuseum	9.4a	8.8a	7.6a	9.6a	15.3a	21.9a	3.0a	10.8
Average	6.9	10.2	7.1	8.4	20.5	20.6	3.2	11.0

[1]Total increment for 1993 and 1994.
[2] Does not include block 4
Means followed by the same letter are not significantly different at *P*>0.05 level according to Duncan's Multiple Range test.

1.4 Comparisons Between Switchgrass and SRF Willow

As a result of cool, wet growing conditions in 2000, many annual crops such as corn produced low, poor quality yields in Eastern Canada. A significant acreage of annual crops suffered from crop failure in the study region. Switchgrass produced moderate yields despite the bad weather. Willow yields were below average, but yield reductions were expected because of a coppicing event the previous season. Switchgrass and SRF willow plantations produced similar overall yields following full establishment of the stands.

Based on eight years of energy farming systems research it appears that switchgrass has greater potential as a biofuel in the short-term than SRF willows for the following reasons.

- Switchgrass was less prone to weed invasion both during establishment and the life span of the stand
- Switchgrass suffered no insect damage in contrast to willows which suffered defoliation in some years
- The productivity of switchgrass was remarkably stable despite variable growing conditions while willow yields fluctuated considerably
- Switchgrass suffered little winter mortality whereas significant decreases in stand density occurred in some willow stands
- Self -seeding makes switchgrass more conducive to long-term stand maintenance
- Switchgrass can be grown, planted and harvested with conventional farm equipment while willow requires specialized equipment for establishment, maintenance and harvest
- Switchgrass required less management than willows
- Switchgrass is potentially easier to dry and store because willow is harvested at approximately 50% moisture

Other advantages from a risk standpoint to the grower include:

- Switchgrass requires a much smaller investment to establish the crop
- Switchgrass has multiple food and non-food market options
- Switchgrass provides greater flexibility for farmers to respond to changing market conditions as the crop can be established or removed easily
- The crop has a proven history in North America with a significant existing acreage in the US

Although switchgrass and SRF willow produce similar average yields, other considerations such as ease of plantation establishment, harvest system, moisture content and the final energy transformation pathway must be accounted for. Switchgrass seems to be a more suitable energy crop from a farming perspective because in terms of establishment, maintenance and harvest it is similar to other forage crops. Its yield stability, annual harvest cycle, low investment requirements, and potential for multiple end uses (livestock bedding, mushroom substrate, cellulosic ethanol production) reduce risks to the producer.

The main limitation associated with switchgrass production is harvesting a high yielding, late maturing crop during wet fall weather in eastern Canada. Spring harvesting can eliminate this problem, but over-wintering losses by the varieties evaluated in this study can be significant. Cave-in-Rock had average lover-winter losses of 40% over a 5-year period (1996-2000). Biofuel supply systems must be designed that take into account the risks posed by over-wintering certain cultivars. These risks may be avoided entirely by fall harvesting early maturing varieties or by selecting cultivars with minimal tissue loss over winter for spring harvest. These approaches are examined in more detail in Section 2 of this report.

Yields of SRF willows fluctuated according to the coppicing cycle. Under normal production conditions harvesting occurs every four years. This may be considered economical from the standpoint of harvesting costs, but revenues collected by farmers will be limited to one year in four. SRF willow probably has potential to supplement forest residues in bioenergy heating systems in mixed agricultural and forest regions of eastern Canada. However, because switchgrass can be produced at a 25-30% lower energy cost on an equivalent yield basis (Girouard et al. 1999), the impact of SRF willow on Canada's bioenergy supply may be small compared to perennial grasses. SRF willow will probably play a more important role in future fibre markets as wood fibre increases in price and new processing technologies evolve to use lower grade wood fibres like willow chips.

For biofuel development, a large, stable, moderately priced and secure feedstock supply system is required in order for energy farming to make an important contribution to Canada's energy supply. From an agronomic standpoint, few barriers exist to develop a switchgrass feedstock supply capable of supporting a pellet industry in eastern Canada.

TASK 2: VARIETY SELECTION AND PLANT IMPROVEMENT PROGRAM

Resource Efficient Agricultural Production-Canada
Box 125, Glenaladale House
Ste. Anne de Bellevue, Quebec
reap@interlink.ca

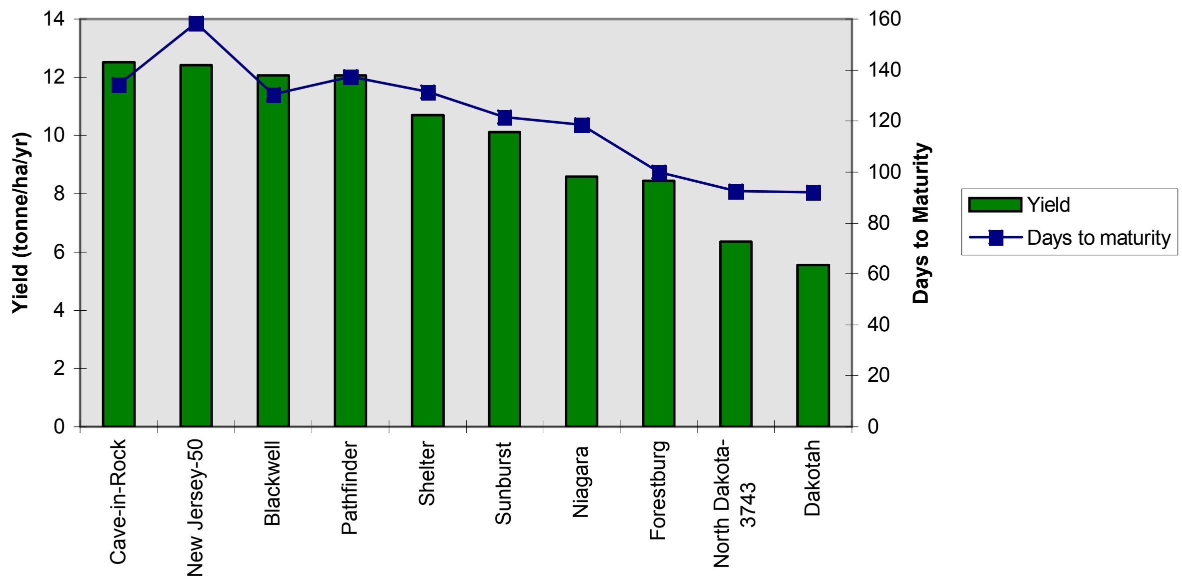
2.0 Background

Switchgrass has been used in North America for more than 50 years as a crop for soil conservation and animal fodder. Research conducted in the United States since the 1930's has generated valuable information on the suitability of different varieties for soil conservation and livestock feed. Switchgrass assessment for biofuel production was initiated in the United States during the mid-1980's, and in the early 1990's in Canada. The U.S. Department of Energy (USDOE) through its Biofuels Feedstock Development Program (BFDP) manages the U.S. program. Research in Canada has been spearheaded by REAP-Canada with initial support from Natural Resources Canada and more recently from the Agricultural Adaptation Council of Ontario and the University of Guelph.

The first switchgrass germplasm evaluation trials were established by REAP-Canada in 1992. Data was gathered from these sites over a period of 5 years. The results indicated plant productivity was largely related to the maturity date of the cultivar (Figure 2.1). Late season cultivars such as Cave-in-Rock, Carthage, Pathfinder and Blackwell averaged 12 ODT ha^{-1} while early maturing materials such as Dakota and Forestburg averaged 5-8.5 ODT ha^{-1} (Samson *et al.*, 1997). The length of the solar radiation collection period was identified as a major productivity driver for biomass accumulation.

Drying high yielding switchgrass crops to a moisture level suitable for fall harvesting is a production challenge in eastern Canada. Fall drying conditions in Eastern Canada are not conducive to harvesting late maturing materials at a moisture content below 15%. Multiple harvest windows could reduce risks associated with inclement fall weather. There appear to be two fall harvest windows: a late August-early September harvest and a harvest in early November after the plants have been frost-killed (also known as dormant fall harvesting). The strategy of spreading the harvest season also makes more efficient use of harvesting and storage infrastructure.

Figure 2.1 – Yield (oven dry tonnes ha^{-1}) of switchgrass cultivars at Ste. Anne de Bellevue, Quebec (1993-1996).



Spring harvesting (allowing crops to over-winter) is less risky because switchgrass readily dries during late fall and winter and both temperature and sunlight hours are more favourable for drying biomass in the spring. Spring harvesting also improves biomass quality because ash levels are lower than in fall harvested material and the energy content of the plant material is higher. On the other hand, over-wintering switchgrass leads to reduced yields, mainly from the loss of seed heads and leaf matter (Radiotis et al.1996). In Section 1 of this report we reported differences between cultivars for over-wintering characteristics. Some cultivars such as Cave-in-Rock are brittle and prone to field losses (Table 2.1) whereas varieties such as Sunburst tend to stay intact. Varietal susceptibility to lodging may also influence dry matter losses.

Table 2.1 - Composition of fall and spring harvested Cave-in-Rock switchgrass

Component	Fall Harvest ODT ha^{-1}	Spring Harvest ODT ha^{-1}	Over-wintering Loss ODT ha^{-1}
Infloresence	3.84	2.71	1.13
Leaf Blade	1.90	1.69	0.21
Leaf Sheath	5.44	5.23	0.21
Stem	1.82	1.37	1.45

A series of variety trials to evaluate newly available plant materials was established in 1996 at Ste. Anne de Bellevue, Quebec, and in 1997, at Alfred, Ontario. These included materials under development from USDOE funded programs at Oklahoma State University and the University of Nebraska. Selections were also obtained from Art McElroy at Agriculture and Agri-Food Canada, in Ottawa, and from REAP-Canada's plant breeding program. The development of improved, early maturing materials is needed to optimize the window for fall harvesting switchgrass. Likewise, the development of winter hardy, late maturing materials that remain relatively intact over winter is also a priority. At the outset of this project, a considerable number of lowland ecotypes were screened at both locations, but their winter-hardiness proved marginal (even if left standing over winter). The lowland ecotypes tend to have growing points at or above the soil surface making them more sensitive to winter freezing compared to upland ecotypes which have growing points below the soil surface.

Table 2.2 presents the relative maturity of switchgrass cultivars in Canada based on REAP field trials and rankings published in the literature. The maturity categories represent the days between May 1 and the date when the seed reaches the hard dough stage and is fully mature. In southwestern Quebec, the preferred plant material for reducing fall harvesting risks would be varieties within the early-medium maturity category of 120 days. These include Sunburst, REAP 921 and REAP 922. Switchgrass varieties well suited for spring harvesting in southwestern Quebec would be later maturing materials (135-155 days). Medium maturing materials such as NU 94 may be suitable for both fall and spring harvesting. In regions with shorter growing seasons such as Southern Manitoba, the preferred varieties for fall harvesting would attain maturity around 105 days, while 120 day materials could be used for over-wintering or dormant fall harvesting. Selecting more southerly originating cultivars for over-wintering will increase biomass productivity, but may not permit seeds to mature fully each year.

2.1 Switchgrass Variety Trials – Alfred, Ontario

2.1.1 Methods

Two sets of switchgrass variety trials were established in 1997 in cooperation with the Alfred College campus of the University of Guelph. The comparisons were conducted on two contrasting soil types: a sandy loam and a clay soil. The sandy loam belongs to the Gleyed Podzol soil group of the St-Thomas association. It is a fine, sandy loam that evolved under high water table conditions. The surface layer was once enriched in organic matter, but levels have been reduced by repeated cash cropping. The soil supports only moderate crop yields because of poor moisture holding ability in mid-summer. The second site was tile drained and consisted of a clay soil known as an Orthic Humic Gleysol of the Bearbrook association. The Bearbrook association occupies about 100,000 hectares in the three most eastern counties of Ontario. In regions with poor spring drainage such as Alfred, this soil has limited potential for corn and soybean production because planting is often delayed. Furthermore, the soil warms somewhat slowly in the spring and is prone to mid-summer drought. Alfalfa production is also difficult on this soil due to poor winter survival caused by ice sheet formation and spring flooding. Table 2.3 lists rainfall and temperature data for Alfred.

Table 2.2 - Relative maturity of switchgrass cultivars in Canada[1]

Very early maturing (95 days)	Origin and latitude
Dakotah	North Dakota – 46’40”
Early maturing (105 days)	
Reap 961 (Longpoint)	South Ontario 42’00”
Forestburg	South Dakota – 44’20”
Early-medium maturing (120 days)	
Sunburst	South Dakota – 43’80”
Reap 922	South Dakota – 43’80”
Reap 921*	South Nebraska – 40’80”
Nebraska 28	North Nebraska – 42’60”
Medium maturing (130 days)	
Northern Upland 94-2	Unknown
Northern Upland 95	unknown
Summer	South Nebraska – 40’80”
Medium-late maturing (135 days)	
Blackwell	North Oklahoma – 36’70”
Shawnee	South Illinois – 38’30”
C.I Rock	South Illinois – 38’30”
Shelter	West Virginia – 41’00”
Trailblazer	Nebraska – 40’00”
Pathfinder	Nebraska/Kansas – 39’90”
Late maturing (145 days)	
Southern Upland 95-1	unknown
Late Synthetic	unknown
Very late maturing (155 days)	
Carthage	North Carolina – 36’00”

[1]Rankings are based upon Madakadze et al. 1998, Samson et al. 1997, Olson, 1986

Table 2.3 - Rainfall (mm) and mean daily temp (°C) in 2000 and 30 yr normals at Alfred, Ont.

Month	Normal Rainfall (mm)	2000 Rainfall (mm)	Normal Mean Daily Temp	2000 Mean Daily Temp
May	74.8	126.6	12.8	12.4
June	76.9	104.6	17.9	17.5
July	88.1	144.6	20.8	20.3
August	92.0	46.6	19.2	18.9
September	82.9	73.2	14.3	13.6
Total	414.7	495.6	-	-

Fourteen switchgrass entries (5 lowland, 9 upland) were sown on the sandy loam site and eleven switchgrass entries (5 lowland and 6 upland) were established on the clay site The lowland varieties failed to establish on both sites due to winterkill. Each trial consisted of a randomized complete block design with four replications. Plots were 3.5 m by 5 m. Materials and methods for establishment can be found in Samson *et al.* (1997). In 2000, plots were fertilized on June 16 with 60 kg urea N. Strips four meters long were harvested with a 1 m sickle-bar cutter on October 24 and 25, 2000 to a 10 cm stubble height. The samples were weighed and oven-dried to determine dry matter yields.

2.1.2 Results

The cool, wet spring in 2000 caused unusually slow spring growth at the Alfred sites. As was the case with many switchgrass fields in Eastern Ontario, quackgrass invaded the Alfred plots, particularly on the clay soil. Well established switchgrass plots remained relatively quackgrass free. However, SU 941 appeared to be stressed from winter injury and was discarded from the clay site. This was the first time an established upland cultivar was observed to have suffered major winter injury in Eastern Canada. The SU 941 material is among the latest maturing upland cultivars under evaluation by REAP-Canada. No other upland cultivars visually appeared to suffer from winter damage on either site. Lowland ecotypes completely winterkilled on both sites.

Plant heights and lodging scores were recorded on Sept 27, 2000 (Table 2.4). As the season developed, switchgrass appeared to exhibit greater productivity on the clay soil. On average, plants were 10 cm taller on the clay soil compared to the sandy loam. On both sites, significant height differences were noted between varieties. The tallest varieties were Cave-in-Rock and REAP 921 with average heights of 1.84 and 1.78 m, respectively. These materials were also among the taller varieties tested at the Ste. Anne de Bellevue site (Section 2.2).

Table 2.4 - Plant heights and lodging scores at the Alfred sites – Fall 2000

Variety	Clay Site		Sandy Loam Site	
	Height (m)	Lodging Scale of 0-10	Height (m)	Lodging Scale of 0-10
Cave-in-Rock	1.86 a	0.5	1.81 a	7.0
REAP 921	1.82 ab	0.0	1.73 ab	1.5
NU-94-2	1.68 abc	2.5	1.63 ab	8.0
SU-94-1	1.53 c	5.0	1.62 abc	6.0
Path. x Blackwell	NA	NA	1.61 abc	5.5
REAP 922	1.68 abc	2.5	1.59 abc	2.5
Late Synthetic Hyld	NA	NA	1.53 bc	7.0
Sunburst	1.62 bc	1.0	1.51 bc	3.0
Pathfinder	1.63 bc	5.0	1.47 c	8.0
Path. Hyld	NA	NA	1.44 c	8.5
Average	**1.69**	**2.4**	**1.59**	**5.7**

- A lodging score of 0 denotes material standing upright with no apparent lodging and 10 denotes complete lodging.
- Means followed by the same letter within a column are not significantly different according to the SNK test (P=0.05).

Plant susceptibility to lodging was greater on the sandy loam (5.7) than on the clay (2.4) soil even though plants were shorter and biomass yields were lower. This observation may be explained by higher soil silica reserves. Clay soils contain higher levels of silicic acid and silica increases structural support in the plant. (Samson and Mehdi, 1998). REAP 921 demonstrated the greatest lodging resistance despite being one of the tallest entries. REAP 921 has an upright growth habit and its stems tend to be relatively thick compared to more fine stemmed and leafy cultivars such as Pathfinder or Late Synthetic Hyld. Previous studies at this site (Samson *et al*., 1997) indicated that only 31% of the REAP 921 biomass was in the leaf fraction compared to an average of 42% for all other varieties under evaluation. The selection of plant materials for low leaf blade composition would probably contribute to improved lodging resistance and reduced over-wintering losses.

Fall harvest yields for 1998-2000 are presented in Table 2.5. Yields were low on the clay site in the first production year (1998) due to slow stand establishment and strong weed competition. First harvest yields averaged 4 ODT ha^{-1} on the clay soil, 36% lower than when the same stands were fully established. On the sandy site, first harvest yields comprised 88% of the established yield. Switchgrass generally establishes more rapidly on light soils. In 2000, average fall yields on the sandy loam and clay sites were 7.7 and 9.9 ODT ha^{-1}, respectively. These were approximately 20% below 1999 yields, a result that is probably attributable to wet and cool weather early in the growing season. No yields were recorded on the SU 94-1 material on the clay site in 2000 because of reduced plant populations and subsequent weed invasion by quackgrass on two of the four plots. The SU 94-1 appears to be too late maturing for this location, and was discarded from further assessment.

Table 2.5 – Summary of fall switchgrass yields at the Alfred clay and sandy loam sites

Variety	Days to Maturity	Switchgrass Yield ($ODTha^{-1}$)			
Clay Site		**1998**	**1999**	**2000**	**Average**
Cave-in-Rock	135	4.5 ab	13.7 a	11. 9a	10.0
REAP 922	120	4.8 a	12.1 a	10.1 a	9.0
Pathfinder	135	4.1ab	12.0 a	10.4 a	8.8
NU 94-2	130	3.3 b	12.2 a	9.1a	8.2
Sunburst	120	4.3 ab	11.1 a	9. 2 a	8.2
REAP 921	120	3.2 b	10.7 a	8.7 a	7.5
SU 94-1	145	3.9 b	12.4 a	-	na
Average		**4.0**	**12.0**	**9.9**	
Sand Site					
NU 94-2	130	8.5 a	11.4 a	10.4 a	10.1
REAP 921	120	8.2 a	11.2 a	8.6 ab	9.3
Pathfinder	135	8.7 a	11.8 a	7.3 ab	9.3
Cave-in-Rock	135	7.2 a	11.0 a	9.0 ab	9.1
Path x Blackwell	135	8.9 a	11.6 a	6.7 b	9.1
Path. Hyld	135	8.7 a	11.8 a	5.9 b	8.8
SU 94-1	145	7.2 a	9.9 a	7.9 ab	8.3
REAP 922	120	6.5 a	9.9 a	8.2 ab	8.2
Late Syn Hyld	145	7.6 a	9.6 a	6.4 b	7.9
Sunburst	120	6.4 a	9.4 a	6.6 b	7.5
Average		**7.8**	**10.8**	**7.7**	

Means followed by the same letter within a column (by site) are not significantly different according to the SNK test (P=0.05).

Yield differences between cultivars were small on the clay site compared to the sandy loam site. Yields of REAP 921 were reduced because of low plant density. REAP 921 has a small seed size, resulting in poor seedling vigour compared to other larger seeded cultivars. The establishment problem with REAP 921 mainly occurs in clay soils where seedling growth is slow. Cave-in-Rock has been one of the best performing cultivars on the clay site, averaging 12.8 ODT ha^{-1} over the past two years. On the sand site, NU 94-2 (10.1 ODT ha^{-1}) and REAP 921 (9.3 ODT ha^{-1}) have been among the highest yielding varieties. Yields of Pathfinder and the two lines derived from Pathfinder (Path x Blackwell and Path Hyld) declined considerably in 2000 on the sandy loam.

Another method for assessing productivity is to calculate the relative growth rate per day based on the maturity rating of a particular variety or selection. Previous research has indicated that the length of growing season is a good predictor of yield performance. Developing a relative growth rating for each entry (total yield in kg/# days to maturity) is one of the most effective means of assessing the relative genetic superiority of various plant materials. Several of the experimental materials are extremely promising (Table 2.6). When averaged over both sites, REAP 922, NU 94-2 and REAP 921 had daily growth rates similar to Cave-in-Rock switchgrass, the standard material recommended in Eastern Canada.

Table 2.6 – Relative growth rates of switchgrass cultivars at the Alfred sites in 1999-2000

Variety	Days to Maturity	Average Yield 1999-2000 (ODT ha^{-1})	Average Relative Growth Rate (kg day ha^{-1})
Clay Site			
Cave-in-Rock	135	12.80	94.8
REAP 922	120	11.10	92.5
Sunburst	120	10.15	85.0
Pathfinder	135	11.20	83.0
NU 94-2	130	10.65	82.3
REAP 921	120	9.70	80.8
Sand Site			
NU 94-2	130	10.90	83.8
REAP 921	120	9.90	82.5
REAP 922	120	9.05	75.4
Cave-in-Rock	135	10.0	74.1
Path. x Blackwell	135	9.15	67.4
Pathfinder	135	9.55	70.7
Sunburst	120	8.00	66.7
Path. Hyld	135	8.85	65.6
Late Syn Hyld	145	8.00	55.2
Average Between Sites			
Cave-in-Rock	135	11.40	84.4
REAP 922	120	10.08	84.0
NU 94-2	130	10.78	82.9
REAP 921	120	9.80	81.7
Pathfinder	135	10.38	76.9
Sunburst	120	9.08	75.7

2.2.0 Variety Trials – Lods Seed Farm, Ste. Anne de Bellevue

2.2.1 Methods

A switchgrass variety trial was established in 1996 at the Macdonald Campus of McGill University's Lods Agronomy Research Farm, in Ste. Anne de Bellevue, Quebec. The soil was a Chicot fine sandy loam. Mean precipitation, from May to October 2000, was 538.9 mm and the mean monthly temperature from May to October 2000 was 14.9^{o}C. Rainfall and temperature data for Ste. Anne de Bellevue was presented in part 1 (Table 1.1) of this report. Thirteen varieties of switchgrass, 11 upland varieties and 2 lowland varieties, were established in a randomized complete block design, with four replications. Each plot measured 4 m by 4 m. The lowland varieties, Kanlow and NL94 were discarded from the trial because of severe winter damage. All other varieties were evaluated for height, lodging resistance and spring and fall biomass yields.

A manual-cut spring harvest was conducted on May 24, 2000. Three 1 m^2 samples were taken per plot and sheared at a 10 cm stubble height. The plots were fertilized on June 9, with 60 kg ha^{-1} of urea N. Late season heights were measured at four random locations per plot on Sept 10, 2000. Visual lodging scores were also recorded at this time. The fall harvest took place on Oct. 20. A 1 m wide sickle-bar cutter was employed to harvest strips approximately 3 m long. The material was weighed and sub-samples were oven dried for dry matter determination.

2.2.2 Results

Spring Harvest

Three years of spring harvest data from the Ste. Anne de Bellevue are reported in Table 2.7. Following the first production year, Cave-in-Rock, NU 95 and REAP 921 were among the highest yielding cultivars. The variety SU 95-1showed remarkably good seedling vigour and has the potential to reach full production the year after seeding. The highest yields after full establishment were produced by REAP 921, NU 94-2 and Carthage at 9.1, 9.3 and 9.3 ODT, respectively (Table 2.8).

Improving Over-wintering Properties in Switchgrass

Previous studies have indicated that Cave-in-Rock is brittle and suffers from excessive winter losses compared to other varieties. Average losses of 40% have been reported at the Lods Agronomy Seed Farm site (see Section 1). A previous study of 10 switchgrass cultivars at Alfred College indicated that over-winter dry matter losses were almost entirely related to loss of seed heads and leaves (Samson et al. 1999). On average, 71% of seed head dry matter and 53% of leaf dry matter were lost by all cultivars. In comparison, only 4% of leaf sheath and stem material was lost over winter. Nonetheless, there were substantial differences among materials at the Alfred sites. Leaf loss by NU-94 was only 25.6% whereas Cave-in-Rock lost 58.9% of its leaf matter during the winter.

High winter losses could be reduced significantly by selecting varieties with a high proportion of stem and sheath components and high leaf retention. Approximately 1.5% of over-wintering loss is ash, which has no energy value. The climate throughout much of Canada is well suited to over-wintering grasses because the materials remain in a frozen state. More extensive evaluation of plant materials and the creation of breeding programs with the objective of reducing over-wintering losses need to be developed. In Eastern Canada, over-wintering quality may be a critical factor in the successful establishment of a pellet fuel industry not dependent on external energy inputs (i.e natural gas) for drying feedstock. This issue is less critical in western Canada where ambient moisture levels are lower. Spring harvested biomass is ideal for pellet manufacturing because it can be direct harvested at approximately 12% moisture. The material also has an energy content about 3.5% higher than that harvested in the fall due to lower ash levels.

Table 2.7 – Ste. Anne de Bellevue Variety Trial – Spring Harvest Yields

Variety	Relative Days to maturity	1998 (ODT ha^{-1})	1999 (ODT ha^{-1})	2000 (ODT ha^{-1})	Average (ODT ha^{-1})
Cave-in-Rock	135	8.1 a	9.1 ab	8.5 ab	8.6
NU 94-2	130	6.9 ab	9.8 a	8.7 ab	8.5
REAP 921	120	6.7 ab	9.7 a	8.5 ab	8.3
NU- 95	130	6.7 ab	9.1 ab	8.4 ab	8.1
Carthage	155	5.2 b	9.2 ab	9.3 a	7.9
Shawnee	135	7.7 a	7.8 ab	7.9 ab	7.8
SU 95-1	145	7.4 a	8.7 ab	6.5 b	7.5
REAP 922	120	6.4 ab	7.1 b	7.3 ab	6.9
Sunburst	120	6.8 a	6.6 b	6.9 ab	6.8
Late Syn	145	3.6 c	8.7 ab	6.6 b	6.3
Long Point	105	3.1 c	6.9 b	6.6 b	5.5
Average	**131**	**6.2**	**7.7**	**7.7**	**7.5**

Means followed by the same letter within a column are not significantly different according to the SNK test (P=0.05).

Table 2.8 - Relative Growth Rates of Spring Harvested Materials

Variety	Relative Days to maturity	Switchgrass Yields (ODT ha^{-1})1999-2000	Growth rate (kg day ha^{-1})
REAP 921	120	9.12	76.0
NU 94-2	130	9.27	71.3
NU- 95	130	8.71	67.0
Cave-in-Rock	135	8.77	64.9
Long Point	110	6.75	61.4
REAP 922	120	7.21	60.1
Carthage	155	9.25	59.6
Shawnee	135	7.82	57.9
Sunburst	120	6.74	56.2
Late Syn	145	7.73	53.3
SU 95-1	145	7.57	52.2
Average	**131**	**8.1**	**61.8**

Fall Harvest

There were no significant weed, insect or disease problems in the summer of 2000. Plant heights measured on September 10 indicated significant differences between varieties. Cave-in-Rock and REAP 921 were among the tallest varieties and Sunburst and Late Syn were shorter (Table 2.9). Shawnee (a derivative of Cave-in Rock) was about 20 cm taller than Late Synthetic. Similar results were reported at the Alfred site. Carthage, REAP 921 and NU 94-2 had the lowest lodging scores at 1.4, 2.0 and 2.0, respectively. The late maturing Carthage had a relatively immature seed head at the time lodging was assessed. Late maturity tends to reduce lodging problems commonly associated with mid-summer thunderstorms in the Montreal area. Lodging at the Ste. Anne de Bellevue, Quebec site is generally more severe than that experienced at other bioenergy research sites in North America. The relatively luxuriant and rapid summer growth combined with relatively low silica levels in the plant materials (due to the light soil and minimal mid-summer water stress) causes high lodging rates. Shawnee (a selection from Cave-in-Rock for improved forage quality), Longpoint, the unselected native strain from Long Point, Ontario, and the leafy varieties of SU 95-1 and Late Syn had the highest lodging scores ranging from 6.0-7.5. Lodging was probably a contributing factor to the modest yields of these materials.

Table 2.9 - Plant height and lodging rates in Ste. Anne de Bellevue – Fall 2000

Variety	Height (metres)	Lodging score (Scale of 0 to 10)
Shawnee	1.96 a	7.5
Long Point	1.95 ab	7.5
Cave-in-Rock	1.92 ab	5.5
REAP 921	1.92 ab	2.0
REAP 922	1.91 ab	4.0
NU- 95	1.89 ab	4.0
NU 94-2	1.86 ab	2.0
SU 95-1	1.83 ab	6.0
Carthage	1.76 ab	1.4
Sunburst	1.74 ab	5.0
Late Syn	1.71 b	6.0
Average	**1.86**	**4.6**

Means followed by the same letter within a column are not significantly different according to the SNK test (P=0.05).

The yields and moisture levels of the fall harvest are presented in Table 2.10. Reap 921 had the highest yield ranking of 11.8 ODT ha^{-1}. NU 95 (10.4 ODT ha^{-1}), NU 94 (9.7 ODT ha^{-1}), and REAP 922 (9.5 Mg ha^{-1}) were also productive materials which had high relative growth rates. REAP 921 appears to be an outstanding material for this site which combines high productivity, good lodging resistance and early maturity. Efforts need to be placed on improving seedling vigor to facilitate planting on clay soils.

Table 2.10 - Ste. Anne de Bellevue Variety Trial– Fall 2000 Yields

Variety	Days to Maturity	Yield (ODT ha^{-1})	Relative Growth rate Kg day^{-1}	Moisture %
Reap 921	120	11.8 a	98.3	40.6 bc
NU 95	130	10.4 ab	80.0	46.5 abc
NU 94-2	130	9.7 ab	74.6	45.1 abc
Reap 922	120	9.5 ab	79.2	38.4 c
Carthage	155	9.5 ab	61.3	45.7 abc
Cave-in-Rock	135	9.2 ab	68.1	52.0 a
Late Syn	145	9.0 ab	62.0	44.8 abc
Longpoint	105	8.5 ab	81.0	45.8 abc
Shawnee	135	8.3 ab	61.5	48.3 ab
Sunburst	120	7.9 b	65.8	40.2 bc
SU 95-1	145	7.7 b	53.1	42.4 bc
Average	**131**	**9.2**	**71.3**	**44.5**

Means followed by the same letter within a column are not significantly different according to the SNK test (P=0.05).

2.3.0 Directions for Further Research

Further research efforts should be dedicated to improving lodging resistance and overwintering qualities of switchgrass varieties by selecting for a greater proportion of stem tissue. Early maturity to facilitate fall harvesting is also an important breeding goal. Further efforts to coincide with early commercialization of a pellet industry should focus on increasing seed supplies of promising switchgrass varieties and testing for possible differences in pelleting quality.

2.4.0 Summary

The results of the three switchgrass variety trials presented in this report help provide criteria for cultivar selection and improvement in Eastern Canada. Lowland ecotypes are not winter hardy in eastern Canada. First year yields appear to be lower on clay soils compared to sandy loam soils, but subsequent yields seemed to be greater on the heavier soil and plants were somewhat taller.

The top five spring harvest yields after full establishment ranged from 6.75-9.12 ODT ha^{-1}, with REAP 921 and NU 94 producing the highest ranking yields. Selection for low leaf blade fractions and greater stem bulk should decrease lodging and over-wintering losses.

Cave-in-Rock switchgrass continues to be a consistent performer across sites. Its major faults are a brittle plant structure and large over-wintering losses when spring harvested. REAP 921 (an early season selection of Summer switchgrass) is a highly productive, early maturing material resistant to lodging. When fall harvested, REAP 921 had a relative growth rate of 92.5 kg ha^{-1}, slightly lower than Cave-in-Rock, but 8% higher than the next fastest growing variety. Due to its small seed size and poor seedling vigour, establishment was slow on clay soils and this selection appears more suited to lighter soil types. Seed supplies are limited until more extensive propagation efforts are undertaken.

NU 94-2 is a promising new material that matures slightly earlier than Cave-In-Rock. It has no major faults and was productive across sites. Improving lodging resistance would be a worthwhile breeding goal to further improve this germplasm. REAP 922 is an improved selection from the Sunburst variety. Average mean yield increases of 8.8%, 13.8% and 7.0% were observed for the Alfred clay and sand sites and spring harvested Ste. Anne de Bellevue sandy loam site, respectively. This data indicates that an approximate 5% yield increase has been gained through each of the two recurrent restricted phenotypic breeding cycles conducted.

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Appendix 1

- It is important to select switchgrass cultivars that are adapted to the climatic conditions where they are intended to be established. Switchgrass is widely adapted to different regions of Canada, but in some areas, particularly southeastern Saskatchewan and southern Manitoba, the number of suitable cultivars is limited due to the short growing season.

* Early selection from Summer switchgrass

Variety Code	Full Name	Source
REAP 921	REAP Exp. 921-Summer Selection	REAP-Canada
REAP 922	REAP Exp. 922-Sunburst Selection	REAP-Canada
Late Syn	Late Synthetic	U. of Nebraska
Late Syn Hyld	Late Synthetic High Yield C3 #1105	U. of Nebraska
Path. Hyld	Pathfinder High Yield -HDMD C3 #1778	U. of Nebraska
Path. x Blackwell	Pathfinder and Blackwell Cross	Ag. Canada
NU 94-2	Northern Upland 94 2 Clone	U. of Oklahoma
SU 94-1	Southern Upland 94 2 Clone	U. of Oklahoma
NU- 94	Northern Upland 94	U. of Oklahoma
NU- 95	Northern Upland 95	U. of Oklahoma
SU- 95	Southern Upland 94	U. of Oklahoma