Switchgrass Plant Improvement Program for Paper and Agri-Fibre Production in Eastern Ontario

Final Report

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TABLE OF CONTENTS

REFERENCES

LIST OF TABLES

LIST OF FIGURES

1.0 AGRONOMIC STUDY

1.1. Variety Trials

Location: College D'Alfred - University of Guelph, Ontario

1.1.1. Plot Maintenance and Monitoring

The plots at both sites were fertilized on June 10, 1999 with 75 kg N ha^{-1} as ammonium nitrate (34-0-0). No other chemicals were applied to any of the plots. Three visits were made to College d'Alfred during the course of the growing season on July 13th, August 19th and September 27th.

On July 13th, a detailed stand evaluation for growth vigor, pest and disease outbreaks was made. On the clay site, the switchgrass had filled in the previously bare spaces in the plots almost completely. The switchgrass was a lush green colour and therefore did not appear to lack nitrogen. There were no weeds in the places where it was established. No insect or disease problems were noticed.

The varieties that had initiated heading on July 13th, on the clay site were Cave-in-Rock, UP 942N, REAP 922 and Sunburst. Contrary to previous seasons, the prairie cord grass was approximately 50 cm tall and appeared to be slowly establishing in the plots. Cave-in-Rock, UP 942N, UP 941S, REAP 922, and Sunburst varieties all had full stands.

At the sand site all varieties were fully established, and continued to look very promising. Very few weak spots were noticed with some weed growth on July 13th, in plots which had quackgrass occurrences. No insect or disease problems were noticed. Cave-in-Rock, REAP 922, Pathfinder x Blackwell, Sunburst and REAP 921 varieties had initiated heading. The Northern Upland 942 and Pathfinder Hyld varieties appeared to be starting to lodge.

1.1.2. Lodging rates

Lodging was assessed on May 5, on the sand site and on May 6, on the clay site, as well as on October 26 at both sites (Table 1.1.1). In spring, the clay site had significantly less lodged material, possibly due to a sparser population density. Consequently, there were proportionally greater numbers of shorter plants, which tended to stay upright, thereby not weighing the neighboring plants down. Additionally, the increased silicic acid content in clay soils may promote physically stronger stems (Samson and Mehdi, 1998), and thereby be less prone to bending.

In fall, no lodging differences were noticed on the sand site, however, on the clay site, UP 941S had the highest lodging rate, with the other varieties not being statistically different from each other. No difference in lodging rates was measured between the sand site and the clay site.

Table 1.1.1. Lodging rates (evaluated from 1-10, with 1 being least lodged) in 1999

	Lodging Ratings			
	Spring 1999		Fall 1999	
Ecotype	Sand Site	Clay Site	Sand Site	Clay Site
Sunburst	7 a	2 a	2 a	1 b
Pathfinder * Blackwell	6 a		3 a	

REAP 922	7 a	2 a	2 a	1 b
REAP 921	8 a	3 a	1 a	1 b
Cave in Rock	4 a	4 a	2 a	2 b
Late Synthetic Hyld	3 a		3 a	
Pathfinder Hyld	3 a		3 a	
Pathfinder	5 a	3 a	4 a	3 ab
UP 941S	4 a	6 a	4 a	4 a
UP 942N	4 a	3 a	3 a	2 b
Kanlow			1 a	
Low 932S			4 a	
Low 931S			1 a	
Low 931N			2 a	
Mean	**5**	**3**	**3**	**2**

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

1.1.3. Switchgrass Yields

Spring yield assessments were conducted on May 5, for the sand site, and on May 6 for the clay site. Fall yields were assessed on October 26, at both sites. The spring yields at the sand site averaged 5.9 oven dry (od) Mg/ha (Table 1.1.2). It appeared that overwintering losses were approximately 25%, as the 1998 fall yields on the sand site averaged 7.8 od Mg/ha. Fall yields in 1999 were measured at an average of 9.8 Mg/ha on the sand site, and 10.0 Mg/ha on the clay site.

Table 1.1.2. Switchgrass Yield (Mg ha^{-1}) Evaluation in 1999

	Mean oven dry Yields (Mg ha^{-1})			
	Spring 1999		Fall 1999	
Ecotype	Sand Site	Clay Site	Sand Site	Clay Site
Sunburst	4.9 a	4.3 a	9.4 a	11.1 a
Pathfinder * Blackwell	6.9 a		11.6 a	
REAP 922	5.0 a	4.0 a	9.9 a	12.1 a
REAP 921	5.5 a	2.2 b	11.2 a	10.7 a
Cave in Rock	4.9 a	4.3 a	9.4 a	13.7 a
Late Synthetic Hyld	5.9 a		9.6 a	
Pathfinder Hyld	6.6 a		11.8 a	
Pathfinder	5.9 a	4.1 a	10.7 a	12.0 a
UP 941S	6.3 a	3.7 a	9.9 a	12.4 a
UP 942N	6.8 a	3.7 a	11.4 a	12.2 a
Mean	**5.9**	**3.8**	**10.5**	**11.9**

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

Overwintering losses are mainly due to the falling off of leaves and inflorescence. The yields on the clay site averaged 3.8 od Mg/ha, compared to 4.0 od Mg/ha in the fall of 1998. Hence, overwintering losses were 5%. These losses were less than on the sand site, as the plants at the clay site had fewer leaves and proportionally greater stem fractions than at the sand site (refer to Tables 1.4.1 and 1.4.2).

In spring, the sand site was found to have significantly greater yields than at the clay site because switchgrass establishes easier on finer textured, well-drained soils. In fall, however, the clay site had average yields of 11.9 Mg ha^{-1}, which was significantly higher than at the sand site, with yields of 10.5 Mg ha^{-1}. Clay soils tend to be more productive, as they have a greater capacity to retain nutrients, and water. Sand soils have loose textures, which may aid during the establishment of the seedlings, but provides low levels of nutrients, which tend to be drained and leached out of the soil profile relatively easily. However, due to the protracted switchgrass establishment on clay sites, as well as the weed pressure, most targeted sites are sandy soils. With future breeding programs, varieties with improved seedling vigor will be developed that may be more suitable to grow on clay soils. The highest yield obtained was with Cave in Rock, on the clay soil, at 13.0 Mg ha^{-1}, which is excellent considering the soil is relatively poor for corn production.

1.1.4. Switchgrass Heights

Height measurements were taken on June 10 and on October 26. The heights were measured by randomly selecting 5 plants per plot, and measuring them from the base of the plant to the tip of the extended leaf. Height rankings in spring were similar at both sites (Table 1.1.3). Cave in Rock had some of the tallest plants, whereas Pathfinder, and UP 941S had some of the lowest heights. Although the sand site had significantly more biomass in the spring harvest, the clay site had significantly taller plants compared to the sand site. This may be due to the sparser population on clay, which minimized competition. The lower stand population also created a thinner mulch in the spring and allowed the soil to warm up more rapidly.

Table 1.1.3. Switchgrass Height Evaluation (cm) in 1999

	Mean Height (cm)			
	Spring 1999		Fall 1999	
Ecotype	Sand Site	Clay Site	Sand Site	Clay Site
Sunburst	63 abc	70 ab	141 a	152 a
Pathfinder * Blackwell	64 abc		144 a	
REAP 922	64 abc	71 ab	157 a	157 a
REAP 921	73 a	69 ab	157 a	156 a
Cave in Rock	73 a	76 a	142 a	160 a
Late Synthetic Hyld	60 bc		135 a	
Pathfinder Hyld	59 bc		136 a	

Pathfinder	57 bc	59 c	139 a	149 a
UP 941S	54 c	62 bc	150 a	156 a
UP 942N	67 ab	65 bc	150 a	148 a
Mean	**63**	**67**	**145**	**153**

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

In fall, no significant height differences were observed between any of the varieties, at either of the sites. However, the clay site had average heights of 153 cm, which was significantly higher than the sand site, which had an average height of 145 cm.

Although switchgrass establishes better on well-drained soils, nutrient supply is imperative for vigorous stand growth. One explanation for higher productivity on clay soils, is the ability for these soils to provide more nutrients, cations, as well as water to a high biomass producing crop, compared to sand soils.

1.1.5. Composition Study

The composition study was carried out by researchers of College d'Alfred, at the University of Guelph. Before the spring and fall harvest in each treatment, 15 plants were randomly chosen and separated into leaves, stem, sheath and inflorescence to determine their percent composition on the 2 sites. In switchgrass, the most desirable component for high pulp yield and quality is the stem fraction, followed by the sheath and then the leaves.

In spring 1999, the REAP 921 variety had a greater fraction of seed head than the other ecotypes, as well as a significantly smaller leaf fraction (Table 1.1.4). It also possessed one of the largest stem fractions. The remaining ecotypes did not differ greatly from each other.

Table 1.1.4. Spring 1999 Switchgrass Composition on the Sand Site

	% composition				
Ecotype	Seed Head	Leaves	Stem	Leaf Sheath	Leaf Sheath & Stem
Sunburst	1.3 b	26.3 a	55.0 ab	17.4 a	72.4 ab

Pathfinder*Blackwell	2.3 b	25.7 a	54.7 ab	17.3 a	72.0 ab
REAP 922	1.3 b	26.5 a	55.7 ab	16.5 a	72.2 ab
REAP 921	6.7 a	14.6 b	62.9 a	15.8 a	78.7 a
Cave in Rock	3.7 b	27.2 a	53.7 ab	15.4 a	69.1 ab
Late Synthetic Hyld	2.5 b	29.6 a	52.4 ab	15.5 a	67.9 ab
Pathfinder Hyld	2.0 b	34.3 a	48.0 b	15.7 a	63.7 b
Pathfinder	1.3 b	30.2 a	52.7 ab	15.8 a	68.5 ab
UP 941S	1.2 b	32.3 a	48.5 b	17.9 a	66.4 b
UP 942N	2.0 b	35.1 a	46.9 b	16.0 a	62.9 b
Mean	**2.4**	**28.2**	**53.1**	**16.3**	**69.4**

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

On the clay site in the spring of 1999, the UP 941S and UP 941N varieties had significantly greater leaf fractions than the other varieties, at the same time they had the lowest stem fractions (Table 1.1.5). It appears that these would not be ideal choices for fibre production if grown on clay soils.

Table 1.1.5. Spring 1999 Switchgrass Composition on the Clay Site

	% composition				
Ecotype	Seed Head	Leaves	Stem	Leaf Sheath	Leaf Sheath & Stem

Sunburst	5.1 a	19.9 b	57.0 a	17.9 a	74.9 a
REAP 922	4.9 a	19.9 b	53.9 ab	21.3 a	75.2 a
REAP 921	5.8 a	24.7 b	51.9 ab	17.6 a	69.5 ab
Cave in Rock	4.7 a	19.4 b	58.3 a	17.6 a	75.9 a
Pathfinder	5.0 a	25.4 b	50.6 ab	19.0 a	69.6 ab
UP 941S	6.3 a	32.9 a	42.3 c	18.5 a	60.8 ac
UP 942N	3.2 a	32.7 a	45.8 bc	18.3 a	64.1 ac
Mean	**5.0**	**25.0**	**51.4**	**18.6**	**70.0**

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

When comparing sites, the clay site was found to have a significantly greater seed head percentage (5.0% versus 2.4% for clay and sand, respectively) and leaf sheath fraction (18.6% versus 16.3% for clay and sand, respectively) than the sand site. Whereas the sand site had a greater leaf fraction (28.2% versus 25.0%, for the sand and clay site, respectively). The stem and leaf sheath & stem fraction did not differ at either of the sites.

Table 1.1.6. Fall 1999 Switchgrass Composition on the Sand Site

	% composition				
Ecotype	Seed Head	Leaves	Stem	Leaf Sheath	Leaf Sheath & Stem
Sunburst	5.0 c	28.7 a	46.6 a	19.7 a	66.4 a
Pathfinder*Blackwell	10.9 abc	25.8 a	47.6 a	15.8 abcd	63.4 a

REAP 922	4.8 c	26.4 a	49.7 a	19.1 ab	68.8 a
REAP 921	9.8 abc	25.3 a	47.3 a	17.7 abcd	64.9 a
Cave in Rock	8.9 bc	24.0 a	53.8 a	13.3 de	67.1 a
Late Synthetic Hyld	10.9 abc	25.2 a	47.2 a	16.6 abcd	63.8 a
Pathfinder Hyld	6.5 c	31.1 a	43.8 a	18.5 abc	62.3 a
Pathfinder	8.3 c	27.3 a	47.5 a	16.9 abcd	64.4 a
UP 941S	13.5 abc	27.0 a	43.9 a	16.3 abcd	60.3 a
UP 942N	10.1 abc	23.9 a	50.3 a	15.7 abcd	66.0 a
Low 931 N	11.9 abc	20.5 a	53.4 a	14.3 cde	67.7 a
Low 932 S	17.9 a	19.6 a	51.0 a	11.6 e	62.6 a
Low 931 S	17.1 ab	19.5 a	48.4 a	15.0 bcde	63.4 a
Mean	**9.8**	**25.4**	**48.4**	**16.5**	**64.8**

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

Table 1.1.7. Fall 1999 Switchgrass Composition on the Clay Site

	% composition				
Ecotype	Seed Head	Leaves	Stem	Leaf Sheath	Leaf Sheath & Stem

Sunburst	5.2 c	22.5 a	56.7 a	15.6 a	72.3 a
REAP 922	5.7 bc	22.7 a	55.2 a	16.3 a	71.6 a
REAP 921	5.5 bc	21.7 a	57.6 a	15.3 a	72.9 a
Cave in Rock	10.3 a	22.6 a	53.8 a	13.3 a	67.1 a
Pathfinder	8.6 abc	23.9 a	54.3 a	13.2 a	67.5 a
UP 941S	9.5 ab	21.6 a	54.5 a	14.4 a	68.9 a
UP 942N	7.0 bc	26.1 a	53.5 a	13.4 a	66.9 a
Mean	**7.4**	**23.0**	**55.1**	**14.5**	**69.6**

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

In the fall of 1999, the main variation observed took place in the seed head composition. On the sand site, some of the upland varieties had seed head percentages as low as 5%, while other varieties were in the 10% to 13.5% range. In those varieties which had low seed head fractions, there appeared to be a high leaf sheath and stem percent. At the clay site, variation in the seed head fractions were also observed, however these did not appear to influence the other components.

Some of the surviving lowland varieties were included in the assessment. Lowland varieties have a very high proportion of seed head, probably owing to the relatively thin stands.

When comparing sites in the fall of 1999, the sand site was found to have significantly greater seed head (9.8% versus 7.4% for sand and clay sites, respectively), leaf sheath (16.5% versus 14.5% for sand and clay, respectively) and leaf (25.4% versus 23.0% for the sand and clay, respectively) percentages than the clay site. Whereas the clay site had a greater stem fraction (55.1% versus 48.4%, for the clay and sand site, respectively), and a greater stem + leaf sheath proportion (69.6% versus 64.8% on the clay and sand, respectively).

1.2. Commercial Site

Location: Rick Rutley's Farm - Berwick, Ontario

This site was seeded with Cave-in-Rock switchgrass variety in the spring of 1996. The field consists of a 5.2 ha area, of a clay loam soil texture. Yield sampling was carried out on April 28 and September 28, 1999 for the spring (overwintered) and fall assessments, respectively. Fifteen samples were taken over the whole field (5.2 ha) at each sampling (Table 1.2.1). Some weed outbreaks from the previous season were noticed in the southern third of the field. The site was fertilized with 60 kg N ha^{-1} as ammonium nitrate, on June 11, 1999. Some modest levels of lodging occurred in the field during the growing season.

Table 1.2.1. Yield Assessment at Rutley Farm, Berwick, Spring and Fall 1999

Sample #	Overwintered Yield Spring 1999*	Harvest Fall 1999
	Mg ha^{-1}	
1	10.77	12.67
2	8.89	12.25
3	10.01	14.23
4	7.18	16.40
5	7.26	11.58
6	9.51	11.89
7	9.74	12.21
8	5.56	11.36
9	8.89	10.08
10	9.33	9.81
11	8.57	11.00
12	9.82	12.23
13	10.10	14.19
14	10.59	6.42

15	8.30	12.15
Mean	**8.97**	**11.89**

*Eight subsamples were used to determine the moisture content for the spring harvest, which averaged 10.25%.

The yields in the spring of 1999 were relatively high at 9.0 Mg ha^{-1}, furthermore, overwintering losses represented merely 8% of the fall 1998 harvest (average 9.7 odMg ha^{-1}). In previous years, switchgrass yield losses over winter experienced by REAP-Canada were measured at approximately 25%. A possible explanation for the lower losses may be the maturing stand, which has a lower fraction of leaf biomass with stand age, and therefore causes overwintering losses to be reduced. The previous switchgrass stand (summer of 1998) was relatively small, with much leafy material that had been heavily lodged by the ice storm of January 1998, and which was therefore more prone to falling.

The commercial site appeared to be fully occupying the field in the fall of 1999. At the time of fall sampling on September 28, 1999 the switchgrass was relatively weed free, and stood at a height of 1.7 – 2.0 metres. The stand appeared visually more productive than in 1998 and was difficult to walk through. Yields in the fall of 1999 were measured at 11.9 Mg/ha (Table 1.1) which were, effectively, higher than the fall yield in 1998 of 9.7 Mg/ha (Table 1.2). The 1999 harvest represented an increase of 23% compared to the 1998 fall harvest. Based on previous experience at other sites, switchgrass yields should now stabilize at this site at approximately the 12 od Mg/ha.

Table 1.2.2. Progression of Switchgrass Yields (Mg ha^{-1}) at Rutley Farm, Berwick

	Switchgrass yield (od Mg ha^{-1})		
Year	**1997**	**1998**	**1999**
Fall Harvest	6.1	9.7	11.9
Spring harvest (overwintered)	3.0	9.0	n.a.
Spring machine harvest (overwintered)	2.5	6.8	n.a.

The amount of switchgrass machine harvested on April 5, 1998 was 60 bales at 525 lbs per bale.

On May 5, 1999, 160 bales were harvested at 540 lbs per bale. Assuming a moisture content of 10%, the spring yields in 1999 were approximately 6.8 Mg ha^{-1}. However, the average yields from 1998 and 1999 were 4.7 Mg ha^{-1}.

2.0 WEED CONTROL STUDY

2.1. Biosolid Study

Location: College D'Alfred - University of Guelph, Ontario

2.1.1. Introduction

Switchgrass (*Panicum virgatum* L.) is a warm season, perennial, tallgrass prairie species, which requires approximately 4 years to reach full stand maturity. Switchgrass is not a successional plant, it is a stage 2 colonizer, therefore during the first year of establishment competition for nutrient availability with other perennial grass species can lead to lower switchgrass stand densities than expected. However, under conditions of limiting soil N, tall prairie grasses have demonstrated the ability to outcompete weeds (Wedin and Tilman, 1990a).

The N utilization of switchgrass is relatively small, at the end of the second year growing season switchgrass was found to have a leaf N concentration of approximately 0.7 % (Madakadze et al., 1998). Tall grass prairie species have an extensive perennial root system and allocate significant amounts of their resources below ground (37% to 53% of the total biomass was measured to be below ground three years after the establishment year (Zan, 1998)), in addition, switchgrass is a C_4 species, allowing it to use water more efficiently. These traits lend switchgrass to be good competitors in N limited environments (Wedin and Tilman, 1990a).

In 1993, REAP-Canada and the pulp and paper industry began assessing switchgrass as a high yielding, environmentally friendly fibre alternative. The results were promising, however no company has yet committed to the commercialization process. In the mean while, the pursuit to create a closed-loop cycle from the feedstock to the end product remains a long-term goal. One of the byproducts of the pulp and paper processing is an organic biosolid. With the introduction of cleaner processing technologies, some of the biosolids are recycled onto farm land.

The paper mill biosolid utilized had a C:N ratio of 640:1, and conformed to the Ontario guidelines for the utilization of biosolids and other wastes on agricultural land (Ontario Ministry of Environment and Energy, 1996). The material stemmed from the primary treatment of the Domtar pulp and paper mill in Trenton, Ontario. Normally, it would have been incorporated into the recycling process of the paper processing. This particular biosolid is normally further processed by the mill and is sometimes supplied to farmers as an active organic residue, which is suitable as a compost substitute. The use of the biosolid was comparable to the use of a high C:N ratio cover crop (e.g. winter rye grain) that is left in place to tie up N. The experiment determines the nitrogen immobilizing effect of the biosolid, to reduce weed pressure during switchgrass establishment.

Switchgrass is not harvested in the establishment year, as yields are not substantial. In the second year however, average Cave in Rock variety yields of 10.0 Mg ha^{-1} in fall, and 8.0 Mg ha^{-1} in spring have been obtained, on sandy soils, at a site in Pintendre and in Ste. Anne de Bellevue, respectively.

2.1.2. Objectives

To determine the rate at which an organic biosolid, with a high C:N ratio, can immobilize soil nitrogen to suppress weed growth and still allow productive amounts of switchgrass to be harvested.

2.1.3. Methodology

The site was located at Collège d'Alfred, in Alfred, Ontario (45^{o}33.5'N 74^{o}53'W). The soil consisted of an Orthic Humo-ferric Podzol, belonging to the St-Thomas association. Six rates of the biosolid were applied; 0_1 Mg ha^{-1} (control 1), 0_2 Mg ha^{-1} (control 2), 5 Mg ha^{-1}, 10 Mg ha^{-1}, 20 Mg ha^{-1}, and 30 Mg ha^{-1}. The treatments were assigned in a randomized complete block design (RCBD), consisting of 4 blocks with 1 m spacing between each block, and 6 plots in each block. Individual plots measured 4 m x 5 m.

The biosolid was evenly distributed in each treatment on May 25, 1998. Pails containing 6.25 kg (± 0.05 kg) of fresh biosolid were used to distribute the material on the treatments, at the required rates. Any biosolid peds were broken up by hand crushing. Some inconsistencies were noticed in the homogeneity of the material, such as recognizable tissue matter. A rake was used to evenly distribute the material in each treatment.

All plots were roto-tilled on May 27, 1998, using a tractor pulled 1.2 m wide roto-tiller (John Deere), to a depth of 10 to 15 cm. On May 28, the soil was rolled with a corrugated steel roller.

The soil was seeded with Cave in Rock switchgrass variety on May 29, 1998, at a rate of 7.2 kg ha^{-1} of pure live seed. A 3-m wide tractor mounted Brillion broadcast seeder (consisting of 2 heavy corrugated steel rollers) was used for seeding. The seeds were covered with 1 to 5 mm of surface soil by the second roller on the seeder. Due to light rain the following day, no further compaction of the seedbed was performed.

Soil Nitrogen Sampling

The soil was sampled five times during the course of the 1998 growing season, and once in 1999. Four soil core samples were randomly obtained with a 19-mm diameter T-sampler, to a depth of 0 to 20 cm, in each plot. The 4 samples were composited and stored at –16^{o}C within the hour. The first sampling took place 3 days after the application of the biosolid (May 28), and represented benchmark values for soil total inorganic N (NO_3^- and NH_4^+), total N, and total C. The remaining soil samplings were analyzed for inorganic N only. These were taken 2, 4, 6 and 21 weeks after the application of the biosolid (June 15, July 3, July 21, and October 23, respectively). Samples were also obtained on September 27, 1999 to determine if N levels had receded to benchmark values. Total N and total C were measured using a LECO (Model SC444, Leco Corp., St. Joseph, MI) combustion furnace. Inorganic N was analyzed using a modified KCl extraction procedure (Keeney and Nelson, 1982).

Bulk Density Sampling

Samples for bulk density were taken on July 3, July 16, and August 4, 1998 at 0 to 10 cm depth, with a 10 cm diameter cylinder, to correct for inorganic soil N concentrations.

Soil Strength

A cone penetrometer (Bradford, 1986) was used to measure soil strength on August 4, 1998 at 4 random locations in each treatment. Readings were taken at 10 cm and at 20 cm depth.

Weed Sampling

Due to the difficulties in distinguishing switchgrass from monocotyledon weeds, dicotyledon weed counts exclusively were conducted in each treatment 2, 4, and 6 weeks (June 17, July 3, and July 20, respectively) after the application of the biosolid. Three 0.1 m^2 quadrats were used to count the weeds in each treatment. In addition, a visual estimate of dicotyledon coverage in each plot was conducted 8 weeks after the application of the biosolid (August 4).

A complete destructive weed harvest of dicotyledon and monocotyledon weeds was carried out 10 weeks (August 13) after the application of biosolid. In each treatment, the aboveground dicotyledon and monocotyledon weed biomass in 4 x 0.1 m^2 quadrats was harvested and separated according to monocotyledons and dicotyledons. The number of monocotyledon weeds and dicotyledon weeds were counted and the biomass was dried for yield calculations.

On September 27, 1999, a complete aboveground harvest was carried out in two 1-m^2 quadrants per treatment, to determine the total weed and switchgrass biomass.

2.1.4. Results and Discussion

Soil Strength

The biosolid had a moisture content of 61.1% at the time of application. Once incorporated, it formed a dry mulch, with small, hard peds. However, since the biosolid was roto-tilled into the soil, it did not act as a physical barrier to weed growth. Nevertheless, soil strength was measured to determine whether the biosolid increased soil penetrability and hindered the emergence of seedlings. No significant difference in soil strength was recorded at either of the two depths (Table 2.1.1), 9 weeks after the application of biosolid, in any of the treatments.

Table 2.1.1. Soil Strength (kPa) measured on August 4, 1998 with a Cone Penetrometer

Treatment	Soil Strength (kPa)	
(Mg ha^{-1})	0-10 cm	10-20 cm
0_1	1 011.6 a	1 359.4 a
0_2	1 176.6 a	1 382.8 a
5	1 125.0 a	1 232.9 a

10	1 111.0 a	1 415.7 a
20	1 040.6 a	1 153.2 a
30	993.8 a	1 209.4 a

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

Total Carbon

The benchmark percent total soil carbon on May 28 was found to be 3.5 %, and the total percent nitrogen was 0.2 %. The C:N of the soil was therefore 18:1, which is a range where soil N immobilization does not predominate.

Soil Inorganic Nitrogen

Soil nitrite (NO_2^--N) values at all sampling dates were below 0.3 kg ha^{-1}, and therefore were omitted from the discussion. Soil ammonium (NH_4^+-N) did not differ between treatments at any given sampling date, probably due to the high standard errors obtained (0.34 to 44.3 kg ha^{-1}), which may have masked any treatment effects. Soil ammonium has a high turn over rate, and does not reside for a prolonged time in the soil; it is easily adsorbed or exchanged, and taken up by microorganisms and plants.

Nitrate is a better indicator for the potential amount of available soil N. Due to its solubility and mobility in soils, nitrate is readily accessible for plant uptake, and as it is an anion it is not adsorbed by the soil as rapidly as ammonium is. The benchmark soil nitrate values were not found to be significantly different amongst the treatments, the average nitrate value at the onset of the experiment was 31.05 kg NO_3^--N ha^{-1}. The high C:N ratio (640:1) of the biosolid immobilized soil N fairly rapidly after application. Two weeks after application (June 15) the 10, 20, and 30 Mg ha^{-1} treatments had significantly less soil nitrate than the control treatments (Table 2.1.2).

Table 2.1.2. Soil Nitrate during the 1998 growing season and in September 1999 from 0 to 20 cm

Treatment (Mg ha^{-1})	**Mean soil nitrate (NO_3^--N) concentrations (kg ha^{-1})**					
	May 28 (B.M.)	**June 15**	**July 3**	**July 21**	**October 23**	**September 27**
	1998					**1999**

0	29.19	37.18 a	18.88	22.86 a	18.40 ab	15.30
5	32.17	32.49 ab	18.64	23.46 a	23.19 a	18.06
10	24.55	19.89 b	13.50	15.85 ab	13.85 ab	12.06
20	42.15	18.73 b	18.03	17.01 ab	13.30 ab	24.63
30	27.20	18.11 b	14.51	7.82 b	9.65 b	11.36

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

Four weeks (July 3) after the application of the biosolid, no treatment differences were apparent. However, it appeared unlikely that mineralization of the immobilized N from the biosolid was already taking place, as the NO_3^--N levels in the 20 and 30 Mg ha^{-1} treatments were similar to levels two weeks earlier (June 15). In a study conducted by Das et al. (1993), a residue with a C:N ratio of 72:1 took 100 days (14 weeks) for the immobilized N to be mineralized. A more plausible explanation is the rapid weed growth observed in the lower biosolid treatments (0 Mg ha^{-1}, 5 Mg ha^{-1} and 10 Mg ha^{-1}), which may have reduced soil N to levels similar to those in the 20 and 30 Mg ha^{-1} treatments, where N levels were low due to immobilization. Low NO_3^--N levels on July 3, in the low biosolid treatments, can be caused by the peak demand for plant N uptake combined with low rates of net N mineralization.

Six weeks after the biosolid application (July 21), the soil in the control treatments demonstrated a flux of NO_3^--N, probably due to mineralization from the high concentration of weeds which caused N turn over to be high. (Table 2.1.2, Figure 2.1.1).

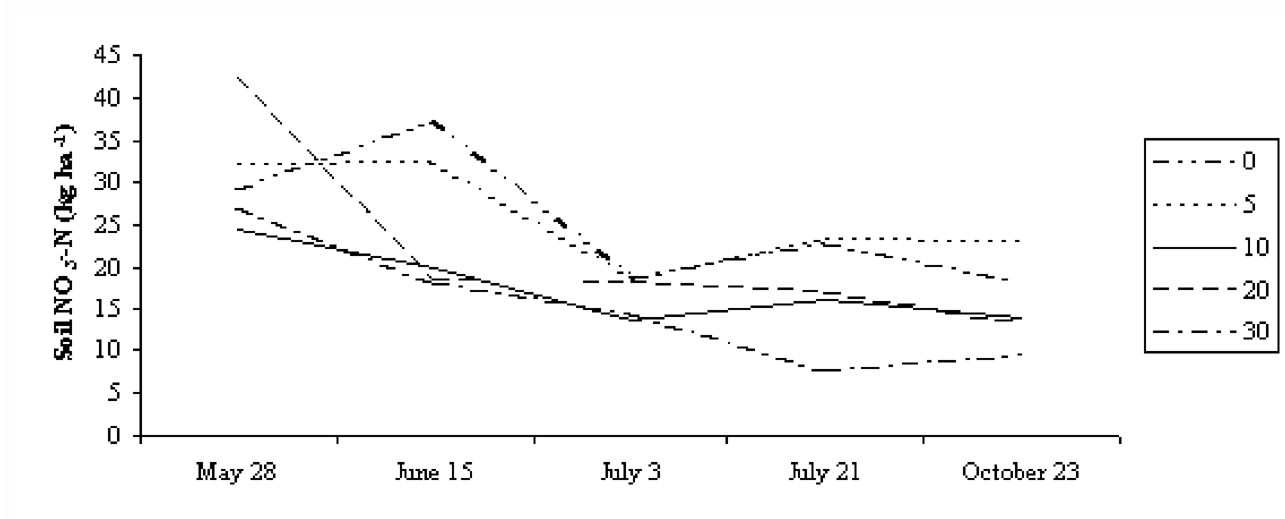


Figure 2.1.1. Average Soil Nitrate Nitrogen (kg ha^{-1}) at 0-20 cm, in all treatments

After 6 weeks (July 21), N immobilization was occurring in the 30 Mg ha^{-1} treatments and caused soil nitrate levels to reach 7.8 kg ha^{-1} (Table 2.1.2). After 21 weeks (October 23), evidence of soil N being immobilized in the 30 Mg ha^{-1} treatment was still apparent; soil nitrate levels reached 9.7 kg ha^{-1}, which was significantly lower than in the 5 Mg ha^{-1} treatment, which had levels of 23.1 kg NO_3^--N ha^{-1}. On the same date (October 23), NO_3^--N levels in the 10 and 20 Mg ha^{-1} treatments were not significantly different from the control treatments (Table 2.1.2), which may have been due to mineralization taking place from previously immobilized N.

A soil sampling was conducted on September 27, 1999 to verify whether nitrate levels had returned to initial levels of May 28, 1998. Although nitrate levels were not significantly different between the treatments (mean values of 16.3 kg NO_3^--N ha^{-1}), they were still significantly ($P<0.05$) lower than the benchmark values in May 1998 (mean values of 31.1 kg NO_3^--N ha^{-1}) (Table 2.1.2).

Plant Counts and Biomass

The site showed signs of high variability in terms of weed population. In the treatments located on the west side of the field, a higher weed pressure was observed. The weed variability in the field is demonstrated statistically by control 1 and control 2 being significantly different from each other on both June 17 and on July 3 (Table 2.1.3). During the course of the experiment, the main dicotyledon weeds observed were Canada fleabane (*Erigeron canadensis* L.), mustard (*Sinapis arvensis* L.), some lamb's-quarters (*Chenopodium album* L.), and some dandelion (*Taraxacum officinale*). The main monocotyledon weeds observed were foxtail (*Setaria glauca* L.) and barnyard grass (*Echinochloa crusgalli* L.).

Table 2.1.3. Total Dicotyledon Weed Counts in 1998

Treatment ($Mg\ ha^{-1}$)	June 17	July 3	July 20
0_1	179 b	116 b	105 ab
0_2	258 a	164 a	147 a
5	192 b	108 b	104 b
10	145 bc	78 bc	83 b
20	133 bc	48 c	53 bc
30	85 c	24 c	27 c

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

The differences in dicotyledon weed numbers can be attributed to the differences in soil N concentrations. A significant (P<0.05) correlation between the number of total weeds and the amount of soil nitrate was found (r=0.51). Consequently, the 30 Mg ha^{-1} treatment had significantly fewer dicotyledons compared with the other treatments, at all three sampling dates (Table 2.1.3). On July 3, no difference in soil nitrate was detected between the treatments (Table 2.1.1), however the weed counts were significantly lower in the 20 and 30 Mg ha^{-1}. Soil nitrate appeared to be unavailable (due to immobilization) in these higher treatments and therefore hindered plant growth, but in the lower treatments (5 and 10 Mg ha^{-1}), soil nitrate was probably being depleted by weed growth.

A visual assessment of the weed cover was conducted on August 4, by estimating the total percent area covered by dicotyledons (Figure 2.1.2). Percent monocotyledon weed cover was not estimated due to the difficulty distinguishing between the switchgrass and the monocotyledon weeds at such an early stage. The visual assessment reflected the same trend observed in the destructive dicotyledon harvest on August 13 (Figure 2.1.3); the lower biosolid treatments (0, 5 and 10 Mg ha^{-1}) had significantly higher dicotyledon numbers.

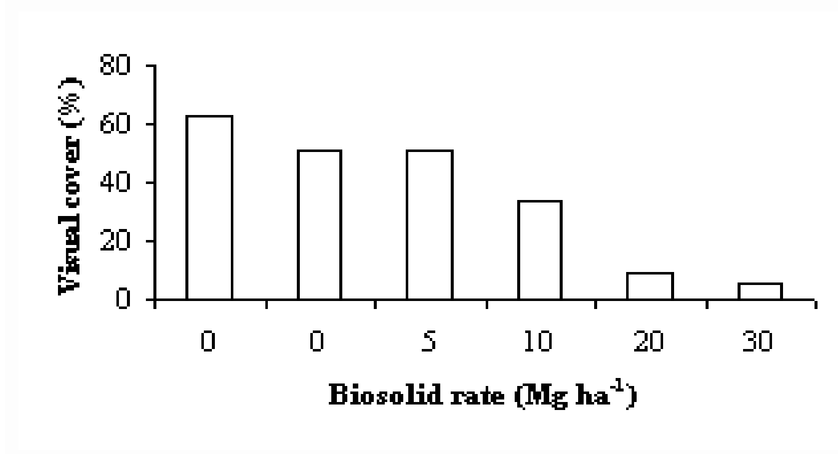


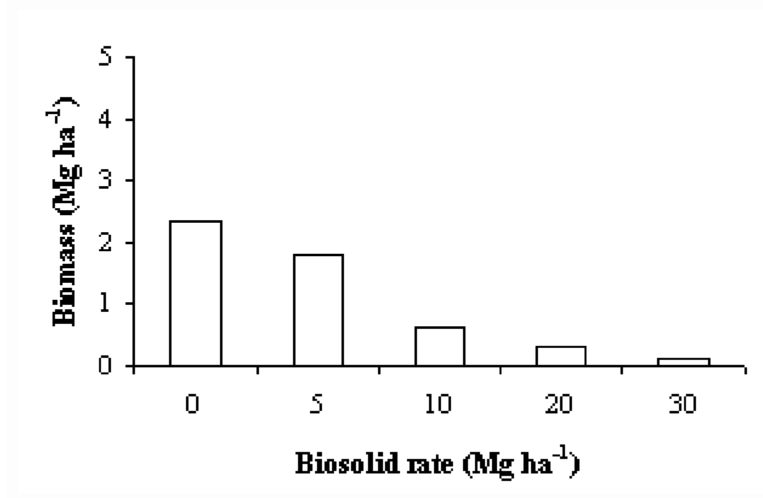
Figure 2.1.2. Visual Assessment of Dicotyledon Cover

Means followed by the same letter are not statistically significantly different according to the SNK test (P>0.05)

From the destructive weed harvest conducted on August 13, 1998, it was evident that the biosolid had a significant effect on the amount of dicotyledon biomass (P<0.05) (Figure 2.1.3), but not on the monocotyledon weed biomass (P=0.71) (Figure 2.1.4). This could be attributed to several factors. Dicotyledon weeds, such as lambsqarter, have lower seed weights than monocotyledons, such as foxtail, and therefore are more dependent on soil nutrients for early establishment. As well, monocotyledons have inherently lower N contents than most dicotyledon weeds hence, they are able to survive in lower soil N environments (Marten and Andersen, 1975; Vengris et al., 1952). Finally, monocotyledons have a more extensive root system compared to dicotyledon weeds, and thus, are more efficient nutrient scavengers.

Biosolid rates of 10 to 30 Mg ha^{-1} were effective as a dicotyledon weed control strategy. Switchgrass and monocotyledon weeds responded similarly to the organic biosolid. Nevertheless, monocotyledon weeds did not dominate the high treatments, in the seeding year, and a relatively weed free switchgrass crop was harvested in the first production year, compared with the control plots, which were weed dominated. Under normal weed management situations, when dicotyledon weeds are suppressed, monocotyledon weed pressure would intensify. This was not the case, as the amount of monocotyledon weeds was constant across all treatments (Figure 2.1.4). However, additional weed control strategies, such as mowing, cultivating the soil at 5-7 day intervals before seeding, or developing improved seedling vigor in switchgrass will have to be used in combination with the biosolid to minimize annual grass weed competition where weed pressure is high.

Figure 2.1.3. Dicotyledon Weed Biomass Harvest (Mg ha^{-1}) in fall 1998



Means followed by the same letter are not statistically significantly different according to the SNK test (P>0.05)

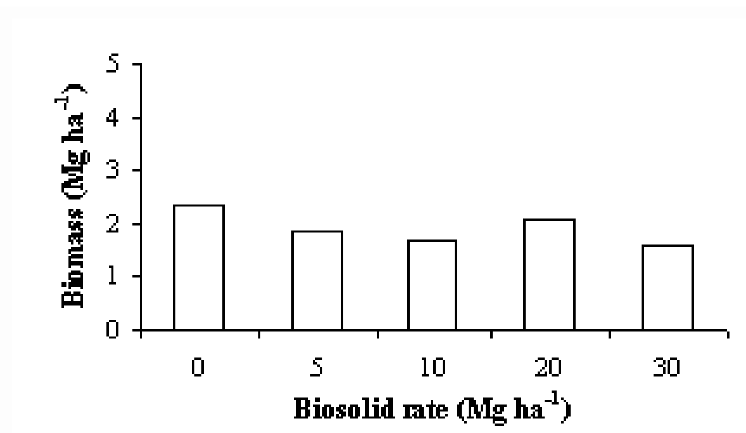


Figure 2.1.4. Monocotyledon Weed Biomass Harvest (Mg ha^{-1}) in fall 1998

Means followed by the same letter are not statistically significantly different according to the SNK test ($P>0.05$)

2.1.5. Observations in switchgrass growth

At the beginning of the season, from June to August 1998, very few switchgrass plants were observed in any of the treatments. A general yellowing of all the weeds and switchgrass was observed in all the biosolid treatments, regardless of the rate, on August 4, 1998. The rapid weed growth in the control and low biosolid treatments contributed to shading of the establishing switchgrass seedlings. Another observation was the height difference between the lower biosolid rates and the higher rates. The 20 and 30 Mg ha^{-1} treatments had shorter plant growth compared to the 0, 5 and 10 Mg ha^{-1} treatments.

Although few or no switchgrass was observed, the energy reserves of the switchgrass may have been used to increase their belowground biomass. Tilman and Wedin (1991) found soil nitrate concentrations to be inversely correlated with the root biomass of tall grass prairie species. Therefore, shoot emergence may not be an adequate indicator of the competitive potential of the switchgrass. Switchgrass was found to colonize soils containing as little as 2.1 kg NO_3^--N ha^{-1} in the 0 to15 cm depth (Rice, 1984), therefore N should not have been a limiting factor for switchgrass establishment in any of the treatments in this experiment. However, low N may delay switchgrass development.

In 1999, on September 27, a complete aboveground biomass harvest was carried out for switchgrass and weeds, in all plots (Table 2.1.4). The results showed switchgrass yields to be significantly higher in the 20 Mg ha^{-1} treatment, and lowest in the control and 5 Mg ha^{-1} treatments. Conversely, the total weed biomass was significantly higher in the control and in the 5 Mg ha^{-1} treatment, whereas the 20 and 30 Mg ha^{-1} treatments had the lowest weed biomass. A Pearson correlation ($P<0.05$) showed a significant negative correlation of r=0.77 between the amount of switchgrass biomass and weed biomass.

Table 2.1.4. Switchgrass and Weed Biomass in September 1999

Biosolid treatment	Switchgrass	Weed
Mg ha^{-1}	Dry biomass (Mg ha^{-1})	
0 (control)	0.7 c	3.1 a
5	0.9 c	3.3 a
10	1.9 bc	2.5 ab
20	5.3 a	0.9 b

30	3.5 ab	1.0 b

Switchgrass yields were still below the average obtained from similar soil types, of approximately 8.0 Mg ha^{-1}. However, compared to the control treatment, the 20 Mg ha-1 treatment appeared to be the most satisfying treatment in terms of switchgrass biomass and the lowest weed pressure. With the development of improved seedling vigor in switchgrass, the biosolid control approach may be suitable on sites without significant annual monocotyledon weed pressure.

2.1.6. Conclusion

The immobilization effect of the biosolid with a C:N of 640:1 suppressed dicotyledon weed populations up to 6 weeks after the biosolid application, at rates of 10, 20 and 30 dry Mg ha^{-1}, and up to 21 weeks after biosolid application when applied at rates of 30 Mg ha^{-1}. Applying rates of 10 to 30 Mg ha^{-1} of biosolid appears to be an effective strategy for controlling dicotyledon weeds in switchgrass and may be suitable for use in crops able to fix N, such as soybean. There was little selection difference between the rates of biosolid application and annual monocotyledon weeds. Other weed control strategies, such as mowing or grass herbicides, are required to effectively control monocotyledon weeds in switchgrass.

The switchgrass demonstrated little competitive ability against the intense monocotyledon and dicotyledon weed pressure at lower rates of biosolid application in 1998, nevertheless, switchgrass was distinctly present at the end of the growing season on the 20 and 30 Mg ha^{-1} treatments. In 1999, switchgrass yields were found to be inversely correlated to weed biomass, which was significantly higher in the lower biosolid treatments (0, 5, 10 Mg ha^{-1}).

2.2. Switchgrass Herbicide Trials 1999 By Wendy Asbil

Location: Kemptville College – University of Guelph

2.2.1. General Information

Three switchgrass experiments were seeded at Kemptville College Agronomy Research Centre in 1999 to: a) evaluate the tolerance of seedling switchgrass to selected grass and broadleaf herbicides; b) determine whether annual grass weeds can be adequately controlled without harming the seedling crop; c) to identify herbicides for tank mixes or sequential applications in similar experiments for 2000; and, d) to provide an established switchgrass stand for further testing in 2000.

Experiment # 1: Tolerance of switchgrass cultivars ‘Cave-in-Rock’ and ‘Sunburst’ to selected post-emergence herbicides.

- **Seeded:** June 26, 1999
- **Sprayed:** July 22, 1999 (4-5 leaf stage of crop)
- Plots are 3 m x 5 m and sprayed the full size of the plot. Each plot is half Cave-in-Rock and half Sunburst for a side-by-side comparison. Seeding rate: 12 kg PLS/ha

Experiment # 2: Pre-emergence and post-emergence herbicides for seedling switchgrass (cv. Sunburst)

- **Seeded:** July 1, 1999
- **Sprayed:**PRE July 22 POST August 3 (3-4 leaf stage)
- Plots are 2 m x 5 m and sprayed the full size of the plot.
- Seeding rate: 12 kg PLS/ha

Experiment # 3: This test is establishing and will be used in 2000 to evaluate herbicides for use on an established switchgrass

- **Seeded:** August 16, 1999 at 12 kg PLS/ha
- Plot size will be determined by overwintering success and the number of treatments required in 2000.

Experimental Design: Randomized complete block design with 3 replicates

Evaluations:

- Crop tolerance at 1, 2, and 4 WAT (weeks after treatment).
- Crop height and density from a 1 m x 1 m area in fall 1999 and spring 2000.
- Crop stand, vigour and yield in 2000.

Note: The weeds controlled for each herbicide are known and listed on the label. A general broadleaf weed and grass weed visual efficacy evaluation will be made in late August 1999. The assessment will provide information on potential effects of competition on the crop.

Other: water volume: 250 L/ha

2.2.2. Preliminary Results

Experiment 1.

Table 2.2.1. Visual Side-by-side comparison of the tolerance of switchgrass cultivars 'Cave-in-Rock' (CIR) and 'Sunburst' (SB) to selected post emergence herbicides

			Crop Injury 1 WAT. (July 29,1999)		*Cost of Treatment*
			*Visual (0-100)**		
#	*Treatment*	*Rate (g or mL of product/ha)*	*CIR*	*SB*	*$/ha*

1	Weedy Check		0	0	n/a
2	Weed-free		0	0	n/a
3	Atrazine 480 + oil	1000 + 10 L	0	0	17.00
4	Atrazine 480 + oil	2000 + 10 L	0	5	23.00
5	Pursuit + Agral 90 + 28% UAN	210 + 0.25% + 2 l/ha	10	5	46.00
6	Pursuit + Agral 90 + 28% UAN	315 + 0.25% + 2 l/ha	20	15	65.50
7	Plateau	290	50	45	n/a
8	Plateau	580	90	90	n/a
9	Distinct + Agral 90 + 28% UAN	286 + 0.25% + 1.25 L/ha	5	0	28.50

* 0 = no damage and 100 = completely killed

The 2 WAT rating was similar to the 1 WAT rating for crop tolerance

Table 2.2.2. Height and density Side-by-side comparison of the tolerance of switchgrass cultivars 'Cave-in-Rock' (CIR) and 'Sunburst' (SB) to selected post emergence herbicides

			Crop Height August 24)		***Crop Density (October 14)***		***Weed Control (September 3)***	
			(cm)		***plants/m^2***		***Visual (0-100)****	
#	***Treatment***	***Rate (g or mL of***	***CIR***	***SB***	***CIR***	***SB***	***BLW¶***	***GRW***

		product/ha)						
1	Weedy Check		3 e §	5 e	21 bc	14 bc	0	0
2	Weed-free		38 a	45 a	51 a	48 a	100	100
3	Atrazine 480 + oil	1000 + 10 L	32 ab	40 a	34 abc	32 ab	90	10
4	Atrazine 480 + oil	2000 + 10 L	30 ab	26 ab	25 abc	13 bc	95	20
5	Pursuit + Agral 90 + 28% UAN	210 + 0.25% + 2 l/ha	28 ab	23 bc	23 abc	29 ab	87	92
6	Pursuit + Agral 90 + 28% UAN	315 + 0.25% + 2 l/ha	22 bc	18 c	15 bc	17 ab	92	95
7	Plateau	290	9 d	16 c	8 c	10 c	93	95
8	Plateau	580	3 e	2 e	2 c	6 c	95	100
9	Distinct + Agral 90 + 28% UAN	286 + 0.25% + 1.25 L/ha	40 a	52 a	45 a	47 a	93	70

□ Average height in plot

§ Means followed by the same letter within a column are not significantly different ($p<0.05$) according to the Duncan's Multiple range test.

* 0 = no control and 100 = complete control (no weeds visible or all weeds brown and dead)

¶ BLW = broadleaf weeds (redroot pigweed, lamb's quarters and stinkweed); GRW = annual grass weeds (yellow and green foxtails and barnyardgrass

Experiment 2.

Table 2.2.3. Effect of selected pre-emergence and post emergence herbicides on switchgrass cultivar 'Sunburst'

	Application	*Crop Injury 1*	*Crop Injury 8*	*Crop*	*Crop*

		Timing	***WAT***	***WAT***	***Tolerance 4 WAT***	***Tolerance 8 WAT***
Treatment	***Rate (g or mL of product/ha)***		***Visual (0-100)****	***Visual (0-100)***	***Crop Height (cm)***□	***Crop Height (cm)***□
Weedy Check			0	0	6 j §	18 c
Weed-free			0	0	38 b	52 a
Achieve + Turbocharge	250 + 0.5%	POST	70	40	2 lm	10 d
Atrazine 480	1000	PRE	0	0	31 c	50 a
Atrazine 480	2000	PRE	50	25	19 f	36 b
Excel Super	670	POST	100	80	0 m	7 d
Frontier	1100	PRE	70	40	12 h	40 b
Dual II Magnum	1250	PRE	85	20	4 kl	12 cd
Hoe-Grass	2800	POST	95	95	0 m	5 d
Pursuit	210	PRE	5	0	23 e	45 ab
Pursuit	315	PRE	15	5	11 h	40 b
Plateau	290	POST	60	50	15 g	26 c
Plateau	580	POST	90	85	5 jk	14 c
Accent + agral	33 + 0.2%	POST	70	40	8 i	24 c
Elim + agral	60 + 0.2%	POST	90	45	2 lm	10 d
Ultim + agral	67 + 0.2%	POST	85	50	2 lm	10 d
Beacon + agral 90	33 + 0.2%	POST	100	80	0 m	6 d

Summit + agral 90	350 + 0.2%	POST	95	80	0 m	10 d
Basagran Forte	1750	POST	0	0	25 d	48 ab
Laddok	2000	POST	0	0	43 a	56 a
Distinct + agral 90 + 28% UAN	286 + 0.25% + 1.25 L/ha	POST	0	0	32 c	45 ab

The 2 WAT rating was similar to the 1 WAT rating for crop tolerance

* 0 = no damage and 100 = completely killed

□ Average height in plot

§ Means followed by the same letter within a column are not significantly different ($p<0.05$) according to the Duncan's Multiple range test.

Table 2.2.4. Effect of selected pre-emergence and post emergence herbicides on switchgrass cultivar 'Sunburst' on crop density, weed control and cost of treatment

		Application Timing	*Crop Density (October 14)*	*Weed Control (September 3)*		*Cost of Treatment*
				*Visual (0-100)**		
Treatment	*Rate (g or mL of product/ha)*		*plants/m²*	*BLW¶*	*GRW*	*$/ha*
Weedy Check			22 c §	0	0	n/a
Weed-free			51 a	100	100	n/a
Achieve + Turbocharge	250 + 0.5%	POST	26 bc	0	80	6.00
Atrazine 480	1000	PRE	39 b	93	10	12.00

Atrazine 480	2000	PRE	43 ab	95	10	23.00
Excel Super	670	POST	10 de	0	93	34.00
Frontier	1100	PRE	30 b	77	95	44.00
Dual II Magnum	1250	PRE	42 ab	60	90	42.00
Hoe-Grass	2800	POST	5 e	0	92	59.50
Pursuit	210	PRE	47a	83	90	39.50
Pursuit	315	PRE	34 b	88	93	59.50
Plateau	290	POST	14 cd	90	90	n/a
Plateau	580	POST	5 e	97	100	n/a
Accent + agral	33 + 0.2%	POST	22 c	20	85	64.00
Elim + agral	60 + 0.2%	POST	24 bc	60	90	42.50
Ultim + agral	67 + 0.2%	POST	16 c	65	92	59.50
Beacon + agral 90	33 + 0.2%	POST	12 d	75	85	n/a
Summit + agral 90	350 + 0.2%	POST	9 de	83	90	n/a
Basagran Forte	1750	POST	46 a	90	0	39.00
Laddok	2000	POST	55 a	95	10	29.00
Distinct + agral 90 + 28% UAN	286 + 0.25% + 1.25 L/ha	POST	48 a	95	75	28.50

§ Means followed by the same letter within a column are not significantly different ($p<0.05$) according to the Duncan's Multiple range test.

* 0 = no control and 100 = complete control (no weeds visible or all weeds brown and dead)

¶ BLW = broadleaf weeds (redroot pigweed, lamb's quarters and stinkweed); GRW = annual grass weeds (yellow and green foxtails and barnyard grass

2.2.3. Discussion

Weed pressure in the untreated check plots in both trials severely suppressed switchgrass establishment as indicated by crop height four weeks after treatment and in comparison with the weed-free check. In Experiment 1, Sunburst was suppressed by all treatments except Atrazine + oil at the low rate and Distinct. Cave-in-Rock was not as sensitive as Sunburst to the high rate of Atrazine + oil. Some initial stunting and purpling occurred due to the Pursuit treatments for both cultivars. However, most plants in plots treated with 210 ml/ha of Pursuit are growing out of the initial damage. Cave-in-Rock appears to be more tolerant to Pursuit than Sunburst. Although Plateau provided good weed control, it also severely damaged the switchgrass and especially at the high rate. In 2000, the trial will include an even lower rate of Plateau. Distinct appeared to be the safest herbicide for both cultivars in this experiment. Plants in plots treated with Distinct were as tall and vigorous as plants in the weed-free check plots.

The most promising treatments in Experiment 2 are Laddok, Distinct, Basagran Forte and the low rate of Atrazine applied pre-emergence. As in Experiment 1, switchgrass plants are growing out of the stunting and discolouration due to the Pursuit treatments. Again, Plateau effectively controlled weeds in the plots but hurt the crop. The sulfonyl urea herbicides Beacon, Summit, Accent, Elim and Ultim severely impeded switchgrass establishment. Plants that did survive are small and sparse.

A well established stand is defined as a population of 10-32 plants/m^2. In plots treated with Plateau, Excel Super, Beacon, Summit and Hoe-Grass, switchgrass was poorly established. Crop injury was highest in these plots.

For crop safety, the most promising treatments are Distinct, Laddok, Basagran Forte and the low rates of Pursuit and of atrazine. For broad spectrum weed control and good crop tolerance, the best choices in 1999 were Pursuit at the low rate and Distinct. However, Distinct only suppresses grasses. Therefore, if annual grasses are the dominant weed, it would not be as effective as Pursuit. On the other hand, if lamb's quarters was the dominant weed, Pursuit would not be as effective. Herbicide choices must be based on the weed species present. If broadleaf weeds are the main problem, Laddok or Basagran Forte will provide excellent control without any injury to the switchgrass. It is difficult to achieve good control of annual grasses without compromising crop safety. In 1999, the best grass weed control with the least injury was obtained with Pursuit at 210 mL/ha.

There were few significant difference between Cave-in-Rock and Sunburst cultivars. Overall, Cave-in-Rock appeared to tolerate Pursuit better than Sunburst but Sunburst was more tolerant of atrazine. For both crop tolerance and broad spectrum weed control, the low rate of Pursuit was the best compromise. When broadleaf weeds dominate, the low rate of atrazine and oil or the Distinct treatment would be the best options.

It is important to remember that these results and their interpretation are based on one year of data from one site, therefore, they must be viewed with caution.

2.2.4. Summary of Plans for 2000

1. Evaluate crop stand and yield from 1999 trials

2. Apply treatments to switchgrass stand established in August 1999

3. Set up new trials as follows:

a. Repeat trials of 1999 with at least two varieties of switchgrass and at two other locations.

a. Establish trial that will be sprayed at different stages of switchgrass to evaluate effects of crop stage on tolerance
b. Establish trial for evaluation of additional herbicide products at recommended timings at half and full label rates according to availability and new information in the literature e.g. Will include Lontrel, 2,4-D, atrazine + quinclorac (Facet/ Paramount),
a. Based on final results from 1999 trials, select most promising herbicides to use in a trial to evaluate effects of tank mixes or sequential applications for broad spectrum weed control and crop tolerance
b. Based on final results from 1999 trials, select most promising herbicides and determine minimum rate that would be effective on weeds but safest for crop

1. Attempt to seed into clean areas to reduce effects of weed competition on crop productivity and growth; I.e. Want to test crop tolerance only because, with few exceptions, the weed control ability of each chemical is already documented

2. Apply for minor use registration for most promising products and combination

3.0 MARKETING STUDY

One of the main objectives of this project is to ultimately develop improved switchgrass varieties which are best suited to the growing conditions of eastern Ontario. Ideally, these materials will have a low cost of production and will produce a high quantity and quality of usable material for Ontario processing industries. The marketing study performed in this phase will:

- Identify the key players in switchgrass breeding in North America, study their financial and breeding approaches;
- Assess the current market opportunities for switchgrass to identify potential partners who have a vested interest in switchgrass improvement (farming communities, processors, seed companies, and public sector organizations);
- Assess factors which can contribute to private sector involvement in breeding programs;
- Assess various options for the development of switchgrass breeding in Ontario.

3.1. Status of Switchgrass Breeding in North America

Switchgrass has been used in North America for more than 50 years for; soil conservation purposes, as a fodder and as an ornamental crop (Elberson et al., 1999). Research on the crop has been conducted in the United States since the 1930's which has generated valuable information, and many different varieties for soil conservation and for fodder purposes (Elberson et al., 1999).

Switchgrass assessment for biofuel production was initiated in the late 1980's in the United States, and in the early 1990's in Canada. The U.S. program is managed by the U.S.

Department of Energy (USDOE) through its Biofuels Feedstock Development Program (BFDP). Research in Canada has been mostly conducted 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.

In recent years, in the United States, the research program has focused on four main areas (McLaughlin et al., 1997):

- **Yield Evaluation and Management:** Focus areas included variety trials, seed dormancy, influences of harvest timing and frequency on switchgrass yields and quality, and initiation of licensing procedures for increasing the range of use of herbicides for weed control during establishment of switchgrass.
- **Genetics and Physiology:** The program included a centralized nursery established at Oklahoma State University. Over 100 combinations of known and wild accessions of switchgrass were used for genetic, phenological, and physiological characterization.
- **Breeding:** Breeding characteristics of switchgrass were better defined through experiments estimating levels of self-compatibility and hybridization potential within and among ploidy types and ecotypes. Three cycles of breeding were completed in 1997, the evaluation of initial grains under field conditions was conducted.
- **Biotechnology:** Efforts to develop rapid propagation techniques for producing switchgrass from tissue culture were initiated to provide tools for accelerated breeding, screening, and genetic transformation of switchgrass. Propagation of fully developed inflorescences directly from node cultures has been achieved, as has production of transgenic material using a DNA Particle Inflow Gun.

The program involves several institutions and field locations across the United States. Plant breeding is being performed in Nebraska, Wisconsin, Georgia, Oklahoma and South Dakota. Tissue Culture and physiology research are based in Tennessee. Scale-up areas have been established in Iowa, Texas, and Tennessee. Field trials (including those performed in collaboration with the USDA Natural Resource Conservation Service (USDA/NRCS)) are in place in most regions of the central and eastern United States.

The annual USDOE budget for switchgrass development was approximately US$ 670,000 over fiscal years 1996 and 1997 (Table 3.1), or slightly more than 1 million Canadian dollars. This level of effort was spread over 8 main projects. The breeding projects were mostly located in southeastern and southcentral United States. However, programs have recently been developed in more northerly areas, including South Dakota and Wisconsin. The typical breeding program receives approximately $ US 80,000/yr and is based at a University where an existing program on warm season grasses is already present. The university additionally provides approximately 25% of a professor’s time to lead the program, as well as in-kind overhead support. These costs represent an additional contribution of approximately $US 40,000/yr for a total of $US120,000. This is similar to the cost estimated by Vogel et al. (1989), who estimated it takes a minimum of $US100,000/yr to maintain a grass breeding program.

Table 3.1. USDOE Sponsored Switchgrass Evaluation and Improvement Projects FY 1996 and 1997

BREEDING PROJECTS	**FY 1996**	**FY 1997**
• Genetic Improvement of Switchgrass for Agronomic and Biomass Fuel Production Traits (NE)	115,000	115,000
• Selection and Breeding of New Switchgrass (*Panicum virgatum*) Varieties for Increased Biomass Production	82,700	72,200

(OK)		
• Bioenergy Crop Breeding and Production Research in the Southeast (GA)	78,000	78,000
AGRONOMIC / PHYSIOLOGY STUDIES		
• Development of Optimal Establishment and Cultural Practices for Switchgrass as an Energy Crop (AL)	84,500	85,000
• Productivity Research of Switchgrass (*Panicum virgatum*) as a Biofuels Crop (TN)	80,000	75,000
• Development of i*n vitro* Culture Systems for Switchgrass (*Panicum virgatum)* (TN)	64,000	64,000
• Switchgrass as a Biofuels Crop for the Upper Southeast: Variety Trials and Cultural Improvements (VA)	75,500	65,200
• Switchgrass Cultivars and Cultural Methods for Biomass Production in the South Central United States (TX)	84,500	132,000
TOTAL	**US$664,200**	**US$686,400**

United States Department of Energy - Office of Fuels Development. 1997.

The breeding investment with perennial grasses can take a long time to bear dividends. Vogel et al. (1989) estimated it takes a minimum of 10 years to develop a new cultivar. Perennial grasses take somewhat longer than most crops to develop, due to the fact that they are perennials, therefore early selection is not recommended (Taliaferro et al., 1999). The return on investment is thus relatively slow as it is not realized until the improved cultivar is released and used. The steps in forage grass breeding are outlined in Figure 3.1

Germplasm Collection

↓

Evaluation

↓

Enhancement

↓

Breeding

↓

Production Testing

↓

Cultivar Increase and Release

↓

Utilization

Figure 3.1 Steps in the Development and Release of a Forage Cultivar (Vogel et al., 1989)

In eastern Canada, performance testing of switchgrass varieties was begun in 1992 by REAP-Canada. Currently, four performance trials of switchgrass are underway testing existing cultivars and advanced breeding materials from the University of Nebraska, University of Oklahoma and REAP-Canada. Two site locations are in Ontario at the College d'Alfred, of the University of Guelph (which are included in this report). The other two performance trials are in Quebec; at the Macdonald Campus of McGill University in Ste Anne de Bellevue, Quebec (45 km from the Ontario border), and a smaller trial located in Pintendre, 15 km east of Quebec City. The latter site has a similar climate to the Arnprior- Renfrew area of Eastern Ontario.

A breeding program was initiated in 1992 by REAP-Canada to evaluate switchgrass breeding systems. Two space-plant nurseries, of 1000 plants each, were established in Tavistock, Ontario. Restricted phenotypic selection was used at a 20% selection pressure. This resulted in two germplasms being developed which are under assessment in Europe and North America as REAP 921 (population originally derived from "Summer") and as REAP 922 ("Sunburst" origin). These germplasms were developed with the objective improve productivity and quality for various applications, including as a feedstock for the pulp and paper industry.

The following review was performed to assess strategies for improving switchgrass, with particular reference to the pulp and paper industry. In general, many of the quality improvements (such as low ash content) for pulp and paper would also improve switchgrass for bioenergy applications. However, specific breeding objectives may be required for each market application if quality objectives are not similar.

3.2. Overview of Switchgrass Breeding for a Specific Application: Pulp and Paper Production *(In collaboration with Dr. N. A. Tinker, Agriculture Canada, Ottawa)*

Switchgrass (*Panicum virgatum* L.) shows potential as a productive, renewable pulp source. However, genetic improvement of switchgrass has been directed primarily toward development of varieties for forage or biomass. For pulp production, the ideal switchgrass variety might have: 1. high stem and leaf sheath /leaf ratio, 2. long fibres, 3. high cellulose content, and 4. low lignin and ash content. This review assesses the feasibility of meeting these objectives in terms of the characteristics and genetic variability of switchgrass. This review is concluded with general recommendations for a breeding initiative, directed towards developing switchgrass varieties suited for pulp production.

3.2.1. Characteristics

Switchgrass is a perennial, sexually reproducing grass species. Plants also spread clonally by rhizomes, filling vacant space and forming complex intra-clonal competitive patterns (Harntnett, 1993). Clonal reproduction maintains plant density in perennial stands, and provides breeders with a method to propagate and evaluate individual genotypes. Switchgrass shows a range of ploidy levels, with 2n = 23 (tetraploid) and 2n = 72 (octaploid) being the most common (McMillan and Weiler, 1959). Higher ploidy level may be associated with greater photosynthetic capacity (Warner *et al*, 1987), but variation in ploidy level may have contributed toward species adaptation (McMillan and Weiler, 1959). Switchgrass biotypes have been classified as green versus blue-green (Eberhart and Newal, 1959) or upland versus lowland (Porter, 1966).

3.2.2. Potential for genetic improvement

Use of switchgrass for pulp is a new opportunity, hence genetic variability for pulping quality *per se* has not been studied. Studies indicate that switchgrass stems show superior pulp quality and yields to leaves with leaf sheaths being of generally intermediate value (Radiotis et al.1986). Since percent leafiness and number of culms have been shown to be highly heritable (Newall and Eberhart, 1961), superior pulping quality might be achieved through selection for increased stem fraction.

Quality attributes studied in relation to forage and biomass production can be used to evaluate other possibilities for improving pulp quality. Holocellulose (hemicellulose + cellulose) yield per unit area has shown substantial genetic variability, although genetic effects were dependent on environment (Hopkins *et al*, 1995). For forage use, increased hemicellulose can give improved digestibility, while for pulping, cellulose is the most desirable fraction. Genetic studies and breeding results have consistently shown that switchgrass digestibility can be genetically increased: either through decreased cell wall proportion (Vogel *et al*, 1984) or through increased monosaccharide content (Godshalk *et al*, 1988). It is reasonable to assume that changes in the opposite direction (increased wall content and reduced monosaccharide content) could also be achieved, and that this would lead to better pulping quality. Genetic variability for lignin content has not been demonstrated, and variability in fibre length has not been extensively studied in switchgrass. Variability in fibre length has been identified to be present in wheat straw (Jacobs et al., 1998) and is likely present in switchgrass. Another important trait to be considered in switchgrass is the ash content. A high ash content of the feedstock is undesirable as it interferes with chemical recovery in boilers; a high silica content wears out equipment and high ash content leads to lower pulp yields. Increasing the stem:leaf fraction of switchgrass will lead to lower ash contents in perennial grasses as leaves have higher ash contents (Samson and Mehdi, 1998). Variability may exist between switchgrass varieties in their ability to block silica entry into the plant at the root level, as occurs in dicotyledons. However, silica is recognized to play an important role in plants for mechanical strength (Majumder et al., 1985).

In the development of superior switchgrass varieties, agronomic factors would also need to be considered. Traits, such as height and maturity, have shown high heritability (Talbert *et al*, 1983), while biomass yield generally shows low heritability. There appears to be good potential to select for winter hardiness (Hope and McElroy, 1990). Susceptibility to insects or disease has not been extensively studied.

Recurrent restricted phenotypic selection (RRPS) is a breeding method that has shown excellent results for improving perennial forage grasses (Burton, 1982). Recurrent restricted phenotypic selection is effective for achieving rapid genetic improvement in characters that cannot be measured prior to mating. Simpler methods of phenotypic selection can be used to improve characters that can be measured accurately on single plants prior to mating. Recurrent restricted phenotypic selection could be initiated for a program using populations derived from the most adapted varieties. Traits related to pulping quality would be measured on single plants at maturity. Selected plants would be intercrossed in a greenhouse during the winter, and the second cycle would be initiated the following spring. Development of a first variety would commence as soon as suitable improvements were made. Experience with RRPS has indicated that substantial gains could be made within a few years (Burton, 1982), however evaluation and registration of a variety could take up to an additional three years.

Concurrent studies should be conducted to investigate heritability of pulping-related traits, and to study the relation between pulping quality and single plant characters. These studies would involve a random set of diverse genotypes (single plants) propagated clonally into stands large enough to pulp. Characters measured on single plants could be physical (e.g. stem breaking resistance), chemical (e.g. detergent fractionation), or visual (e.g. microscopy). In particular, characters that could be measured prior to mating should be examined. Knowledge of the relationship between single plant characters and pulp quality would be invaluable for designing future breeding strategies.

3.2.3. Types of varieties

Current options for switchgrass varieties include open pollinated, synthetics, or first generation chance hybrids. Open pollinated varieties may show unpredictable genetic drift, which could be a disadvantage for varieties that incorporate important quality characters. Many successful switchgrass varieties have been synthetics, produced from mixtures of elite breeding lines. Synthetics allow the breeder some degree of control over the use of a variety, and ensure some degree of predictable performance. First generation chance hybrids are composed of seed from random matings among a small set of inbred lies. These varieties have the same advantages as synthetics, but may show greater uniformity and more hybrid vigor. Production of first generation chance hybrids would depend on the ability to produce a set of inbred lines that flower simultaneously. Mike Casler, at the University of Wisconsin, has used this system in orchardgrass and believes the system to be successful in switchgrass as well (Casler, 1999). Production of true single-cross hybrids is probably not an option in switchgrass unless useful types of male sterility are discovered.

3.2.4. Genetic mapping: a useful intermediate strategy

Linkage maps of genetic markers, once restricted to the most important crop species, are not practical in minor species. There are two reasons for this: 1. new and inexpensive marker technologies are now available, and 2. maps from model species, such as rice and barley, provide "framework" markers for use in other species. A pragmatic mapping strategy in switchgrass would be to develop a map using a framework of "RFLP" markers from other species, refining the map as necessary using random type markers such as "RAPDs" and

"AFLPs".

Maps of molecular markers provide many new opportunities for cultivar development, 1. Genes affecting "difficult traits" can be mapped relative to genetic markers, and selection can be practiced based on linked markers. This strategy is called "marker assisted selection". 2. Maps can assist with the introgression of new traits from exotic "donor" parents into adapted varieties by "natural" breeding methods (i.e. sexual mating, not genetic transformation). 3. Maps can help to elucidate the chromosome behavior of a species, leading to a better understanding of processes and potential uses for polyploidy. 4. Maps can show locations of genes with known function, allowing comparison to other species. 5. Maps provide a ready source of markers that can be used in cultivar characterization and identification.

3.2.5. Potential long term strategies

Genetic transformation has only recently been successful in model grass species such as maize and rice. Eventually, opportunities may exist to introduce special traits (such as herbicide resistance) into lesser-studied grass species, but it is not currently an option until it has become routine in other grass species. Also, there is such limited experience in breeding switchgrass and understanding what factors are contributing to productivity improvements, that investing large sums of funds in genetic engineering approaches may bear little dividend, compared to conventional breeding and physiology studies. In the interim, genetic mapping can provide information about the locations that affect key traits, such as fibre length. This might lead to testable hypotheses about biochemical processes involved. Ultimately, this could provide opportunities for more advanced types of genetic manipulation.

Another potential area for investigation is apomixis, the production of asexual seed that is genetically identical to the parent. Apomixis occurs in several grass species, and may exist at low frequencies in other grass species, such as switchgrass. Molecular markers could be used to conduct large-scale screenings to search for apomictic strains of switchgrass. If identified, apomixis would be an ideal system for the development of true-breeding varieties.

3.2.6 Conclusion

A switchgrass breeding initiative to develop varieties suited for the pulp and paper industry would have immediate, intermediate, as well as long-term objectives. An immediate objective would be to commence phenotypic selection for traits perceived to be associated with pulping quality. Concurrent studies would evaluate the heritability of these traits, and assess their relationship to pulping quality. Development and evaluation of a variety would commence as soon as progress was made. Intermediate objectives would be to construct a linkage map of molecular markers, and to locate genes affecting pulping quality. Long term objectives might include more advanced forms of genetic manipulation, such as the discovery and use of apomixis.

3.3. Identifying Opportunities for Private Sector Involvement in Switchgrass Breeding

Establishing a comprehensive switchgrass breeding program in Ontario will require raising a substantial annual budget, along with the involvement of several partners. The current US program is entirely government-driven. The potential of developing a program that will provide financial arrangements conducive to encouraging private sector involvement is examined here. A first scenario examined an industry funded program. A second scenario is a government funded program, similar to that in the United States. As we enter the new millennium, perennial biomass feedstocks, such a switchgrass, will become increasingly important as a renewable raw material for fueling a sustainable economy. Investment and support from both industry and government will likely be required to fully respond to this challenge.

3.3.1 Scale of the Program

The breeding program would require an annual budget of $150,000 including the hiring of a breeder ($70,000-$85,000), facilities, test plots, and related expenses, such as administrative services. Furthermore, an additional budget may be required for each specific industrial application, ranging from $30,000-50,000/yr. The involvement of industrial and public partners could allow the breeding development to be carried out without capital investments: the contributions will be used to pay for current expenditures. The ideal center for the breeding program would be close to the major centre of utilization. In Ontario, Eastern Ontario would be a potential program centre, as it represents a relatively large underutilized land base in the province. Performance trials could be subsequently conducted at all the major provincial research stations to ensure the adaptability of the material to the various regions of the province. These performance trials could also assess germplasm being developed from US DOE programs, primarily from the Midwest and Great Lakes regions.

3.3.2 Identifying Industry Opportunities and Partners for Switchgrass Improvement in Ontario

It is a necessary first step to identify which industries stand to gain from switchgrass development and who could help support switchgrass improvement. Potential partners are likely large industrial companies operating in Canada that could become large switchgrass consumers within the foreseeable future. Each industrial partner could then make contributions in the following respects:

- A financial contribution to the joint venture which will be deductible for tax purposes as outlined in section 3.3.3
- A technological contribution in the form of industrial trial runs

Potential partners could also include farmers who would be interested in growing switchgrass, or the forage seed industry. The main potential private sector partners would be biomass consuming industries in the bioenergy or agri-fibre industries. There may also be possible interest from the mushroom industry.

The potential bioenergy industry users are mainly the ethanol and fuel pellet industry. In the ethanol industry, there are several potential partners including Iogen Corporation, Petro Canada and Commercial Alcohol's. This latter company is currently the largest player in Ontario's ethanol industry. They recently opened a large corn ethanol facility in Chatham, Ontario, and are planning to open another similar facility in Quebec. Iogen Corporation, an enzyme manufacturer, and Petro Canada have a joint venture ethanol project in the Ottawa region. Their plant is the world's first cellulosic ethanol demonstration plant to use agricultural feedstocks, it is scheduled to open in spring 2000. This facility is a 25 million dollar demonstration plant that requires approximately 300 tonnes of fibre per week (which will include corn stalks, switchgrass and oat hulls) and will produce approximately 5 million litres of ethanol per year. If the cellulosic ethanol technology proves successful, this project could lead to the construction of large ethanol plants in the order of 150-200 million litres in size, requiring approximately 10,000 tonnes of fibre per week or 350,000 tonnes of fibre per year. The cellulosic ethanol industry could also attract investment from other oil companies and large agricultural corporations such as Cargill.

It remains to be determined if Ontario can compete with Western Canada (or other regions of North America) in terms of low cost biomass production for ethanol production. The declining beef industry in Southern and Eastern Ontario suggests Ontario may not be a low cost leader in Canada for forage production. Ethanol, like beef, is a highly transportable commodity and the ethanol plants will first be built where the lowest cost feedstock is available. For the cellulosic ethanol industry to be competitive with gasoline, biomass needs to be procured in the $35-$45 range (P. Foody Sr., 1999 pers. comm.). In this respect, Western Canada may be a more competitive region to start the industry. In the US, an agricultural sector model (POLYSIS) has been developed which evaluates the price, quantity and location of energy crop production and the potential effects of large scale energy production on traditional crops. This model indicates that the Southeastern US states and North Central Great plains are the areas with the greatest potential production of low cost switchgrass (M. Walsh, 1999 pers. comm.). In Eastern Canada, the full economic cost of fall harvested switchgrass has been estimated to be $57-$71/tonne (Girouard et al., 1999). This suggests the material (unless major cost reductions can be achieved) may be too expensive for use in new commercial-scale plants in Ontario. However, it may be possible that existing grain ethanol plants could be switched to biomass ethanol if the investment in the plant has already been made in Ontario. The establishment of 300 acres of switchgrass in Eastern Ontario in 1999 for the Iogen/Petro-Canada cellulosic ethanol demonstration plant should provide valuable data for assessing the real commercial cost of growing switchgrass in eastern Ontario.

A more promising biomass energy market could be the production of switchgrass biomass fuel pellets in Ontario for domestic and export sales. Currently, approximately 100,000 tonnes of wood pellets are being exported to Scandinavia from Canada. An economic analysis by REAP-Canada indicates that switchgrass could be an attractive pellet fuel. Production costs of switchgrass fuel pellets have been estimated to be $89-$121 for bagged switchgrass pellets while bagged wood pellets have a production cost of $124/tonne (Samson et al., 1999). Bulk handling of switchgrass fuel pellets for delivery in rural areas would reduce costs by a further $19/tonne. Switchgrass appears competitive with wood residues for fuel pellets and is an attractive low greenhouse gas emitting fuel compared to heating with oil, propane or electricity (from coal) in Ontario. There are no major corporations in the pellet fuel industry at this time able to support breeding work. Shell Oil formerly had a subsidiary, known as BioShell, which produced wood pellets. There is good potential that some of the major oil companies will take an interest in pellet biofuels in the future. It is difficult to predict how large the pellet fuel industry could become. The current North American pellet industry produces approximately 1.2 million tonnes per year and is based almost exclusively on wood residues. New high efficiency gasifier pellet stoves are now available to successfully burn moderately high ash fuels, such as switchgrass (Samson et al. 1999). This could greatly expand the market in North America and Europe. The pellet industry has the potential for pay farmers the full economic cost of growing switchgrass in Ontario. Furthermore, it may provide opportunities for farmers to participate in biofuel pellet cooperatives as the investment in a pellet plant could be well within the grasp of a group of 25 potential farmer investors.

The pulp and paper industry represents a large potential consumer of switchgrass in Ontario. Ontario has the distinct advantage of having a large industry already developed. Research trials have proven switchgrass to be a suitable hardwood (e.g. poplars) substitute for pulp and paper manufacturing and has similar pulp yields (Radiotis et al., 1986). In Ontario, hardwood is being procured at approximately $80-100 tonne (Fox et al., 1998). This represents a relatively high value market price for switchgrass growers if pulp mills could be converted to process switchgrass. An economic assessment of switchgrass as a pulp source indicated if 20% were used as a substitute for hardwood furnish in pulp and paper manufacturing in Eastern Ontario, 380,000 tonnes of switchgrass would be required by the pulp an paper industry by the year 2005 (Fox et al., 1998). This would represent about 40,000 ha of switchgrass production. If the quality of switchgrass for pulping could be improved (by creating varieties with a high stem plus leaf sheath: leaf ratio) such that switchgrass pulp yields were enhanced, it would reduce switchgrass procurement costs. For example, given switchgrass is procured at $70/tonne and a 47% pulp yield is obtained in a Kraft pulping process, if this was increased to a 50% pulp yield from a higher cellulose feedstock, it would reduce procurement needs from 213 tonne/day to 200 tonne/day for a mill that produces 100 tonne/day of switchgrass pulp. This would result in a net saving to the mill of $910/day, or $330,215/yr. If a pulping industry can be developed using switchgrass in Ontario, it appears a program dedicated to yield and quality improvement of switchgrass is justifiable by an individual mill if these gains could be realized in quality alone. The most likely potential partner, in the pulp and paper industry, would be Domtar Incorporated, which operates mills in Eastern, Central and Southern Ontario. Domtar Inc. has provided strong research support for switchgrass development as an agri-fibre source and has been involved in supporting hybrid poplar work in Ontario.

Some of the other potential markets for switchgrass that could help spur interest in breeding is the use of switchgrass as a source of livestock bedding and as a substrate for growing mushrooms. REAP Canada is currently selling 100 tonne/yr of switchgrass produced at approximately $55/oven dried tonne (odt) to farmers for livestock bedding. This market is quite large in Eastern Ontario and Quebec, as spring cereal acreage is in decline and the trend is towards short straw cereal varieties. The mushroom industry is perhaps the most interesting early market opportunity for switchgrass producers in Ontario. The industry is located throughout the province and a good potential also exists for export of switchgrass into nearby states and Quebec. Currently, winter wheat is a preferred feedstock for mushroom cultivation because it has a relatively long straw, which is hollow in nature. These characteristics provide for well-aerated compost with good structure. Switchgrass appears to have similar traits to winter wheat straw. Winter wheat straw is being supplied to one mushroom plant in Eastern Ontario at $99/odt, while higher prices are being obtained for material delivered to Quebec and the Eastern United States. It is difficult to assess how much fibre could be provided to this market from Ontario switchgrass producers, as the use of the material is only in its infancy at this time. Nonetheless, there could be a significant economic gain realized by mushroom producers if a lower cost feedstock could be developed for the industry. For example, a moderately sized modern mushroom plant requires approximately 60 tonne/day of fibre. Assuming material could be delivered for $20/tonne less than current fibres used, the mushroom company would save $1,200/day, or approximately $420,000/yr.

Once farmers realized the economic benefits from a diversity of markets, a marketing system could be organized, so that it may be possible for farmers to contribute to a check off system for switchgrass plant improvement. This approach is increasingly being used to fund corn, soybean and wheat breeding programs in Ontario, and is an important funding source for breeding funds in the western provinces.

A final potential supporter of switchgrass breeding in Canada could be one of the major forage seed houses in Ontario. The largest forage seedhouses in Ontario are Pickseed and OSECO, their main interest in switchgrass would be for seed sales. Assuming that the crop covered one million acres in Ontario, and that the average length of stand was eight years, it could generate annual sales of one million pounds of seed (assuming a seeding rate of 8 lbs/acre). Currently switchgrass seed sells for approximately $4 per lb, which would provide annual sales of $4 million/yr. However, this level of acreage of switchgrass in Ontario is not on the short-term horizon. It is probable that the return on investment for seed sales of switchgrass will be a weak driving force, compared with the potential benefits for processing industries from improved quality and reduced costs of switchgrass production. Processing industries would benefit most if they could keep seed cost low for switchgrass producers. This would minimize production costs for farmers and reduce risks to planting switchgrass.

3.3.3. Scenario A: Industry Funded Breeding (*In collaboration with Patrick Girouard, Consultant, Vaudreuil, Qc.)*

The review of marketing opportunities in Ontario indicates that several industries could benefit from switchgrass improvement in the province in the short-term. The fiscal incentives available to these industries have been identified below.

In view of the uncertainties with respect to the use of switchgrass and the scientific methodology suggested, the technical phases of the development will qualify under the Canadian SR&ED (Scientific Research and Experimental Development) tax credit program.

In order to allow partners to minimize the cost of their investment in the program, a joint venture could obtain the status of a prescribed research center for Ontario and Federal tax purposes. This status would allow partners who have a direct interest in switchgrass (for industrial or agricultural purposes) to take advantage of the following benefits:

- A 20% Ontario Business Research Institute (OBRI) tax credit which would be fully refundable to the individual partners; for smaller Ontario corporations (i.e. net income of less than $200,000), the credit will be 30%, taking into account the Ontario Innovation Tax Credit (OITC);
- A 20% federal tax credit which could be used to offset Federal taxes otherwise payable; for smaller corporations (i.e. net income of less than $200,000), the credit will be 35% and will be fully refundable;
- Provided the switchgrass program is incremental to other R&D conducted in Ontario by the partner, each partner will be able to reduce its Ontario taxable income by 37.5% (or 52.5% in the case of a small company) of its actual contribution to the program. This deduction is equivalent to over 4% of the gross cost of the contribution.

An example of the after-tax cost of a contribution to a joint venture by a partner would be as follows:

	Industrial	**Small**
Contribution	10,000	10,000

OBRI tax credit	2,000	3,000
Federal Tax Credits	1,600	2,450
	3,600	5,450
	6,400	4,550
Ontario Superallowance	400	400
Tax deduction (36% / 21%)	2,300	1,350
	2,700	1,750
Net Cost	3,700	2,800

Thus, if a research program costs 150,000/yr and eight to ten years are required for variety development, it would require 1.2-1.5 million dollars prior to any return on investment. Using the tax credits available to industrial and small businesses this would represent a net cost to investors of $440,000-$555,000 for larger industrial supporters, or $336,000-$420,000 for smaller industry investors.

In reviewing this market opportunity, the likelihood of an entirely industry funded program is relatively small at this time, given that there is no significant commercial use of switchgrass established in the province. It is probable that industries would be more interested to support switchgrass breeding once large industrial markets are established. Publicly funded support will be required to start the breeding initiative (as has been the case in the US). Nonetheless, if several industry partners could share the cost of a program it would facilitate an earlier industry participation in switchgrass breeding in Ontario.

3.3.4 Scenario B: Publicly Funded Breeding Program

The most viable way to start a breeding program in Ontario would be to develop a cooperative venture with northern US breeders and with federally or provincially funded grass breeders. Preliminary discussions with US Department of Energy management and contractors have indicated a willingness to form partnerships. The most logical cooperating partner for REAP-Canada would be Dr. Mike Casler at the University of Wisconsin. Dr. Casler is a dedicated forage grass breeder with significant experience in cool season grass breeding. He is developing a large US Department of Energy switchgrass plant material improvement program, for the Great Lakes region. The germplasm he is basing his program development on would be in a similar maturity range, as that required for most of southern and eastern Ontario. The program is based in Madison, Wisconsin (which has a growing season similar to the warmer zones of Southern and Eastern Ontario) and includes performance testing for more northerly locations in Wisconsin and surrounding states. Rainfall however is slightly lower than in most of the Ontario region.

Another possible partnership, is with the Institut de Recherche et de Developpement en Agroenvironment (IRDA), based in St Hyacinthe, Quebec. The institute is funded by the Ministry of Agriculture, Ministry of Environment, and the Quebec farmers union (The Union des Producteurs Agricole (UPA)). The IRDA was established to help create more environmentally friendly farming practices in the province. The program director, expressed interest in bioenergy crop development. IRDA plant breeder, Marcel Levesque, made a subsequent visit to REAP-Canada's breeding nurseries and performance trials, in September 1999. The IRDA has expressed an interest in cooperating in plant material improvement in this region. Marcel

Levesque's labour can be covered by existing program support from IRDA, provided the project is approved by the joint panel of IRDA. The University of Guelph is another potential partner. Dr. Steve Boley has a mandate which includes perennial grass breeding. The University of Guelph first started supporting switchgrass performance testing in collaboration with REAP-Canada at the College d'Alfred, of the University of Guelph, in 1997. The program is anticipated to expand to each of the provincial agricultural colleges, in Ontario, in the year 2000. The performance testing of switchgrass represents a relatively low investment cost and can assist farmers in identifying promising materials to enable a relatively rapid scale-up of switchgrass production.

3.3.5 Marketing Summary

The possibility of establishing a private sector led switchgrass breeding program appears to have much potential. However, further market development of switchgrass needs to take place before this can be realized. In Ontario, the initiation of a breeding program must begin with a government-funded program. This could be done in collaboration with US or Quebec based breeders, to keep costs at a minimum, should full funding not be available. Industry participation would likely follow once switchgrass has established itself as a commercial crop in Ontario. Research tax incentives have been described which will help facilitate this process. The pulp and paper industry and large mushroom producing companies are among the most promising potential switchgrass supporters. The ethanol industry appears a less probable candidate, unless forecast prices for switchgrass in Ontario are reduced. Switchgrass as a biomass feedstock for pellet production appears quite promising as well. However, unlike the pulp and paper and ethanol industries, the pellet industry has no large major corporate players at this time with the financial base for supporting such a long-term investment. The forage seed houses are not prone to support the crop, because of the long duration of its stand length and relatively low seed investment by the farmer on a per area basis. Switchgrass plant improvement in Ontario will conceivably only be able to be seriously developed through public support at this time. Climate change mitigation provides an excellent rationale for the government supporting of this activity. As well, switchgrass plant improvement has significant potential to create rural economic stimulation and job opportunities, particularly in marginal farming areas.

It is relatively remarkable that switchgrass is being commercialized in Ontario at present with minimal research investment to date. This attests to the plants commercial potential, farmer friendliness and adaptation to the growing conditions of the province. The leading switchgrass variety in eastern Canada, Cave-in-Rock, was developed simply from an increase of seed collected from a prairie in Southern Illinois. This native species of Ontario has much potential for future improvements in quality and yield, for its various market applications. The future use of switchgrass for mushroom cultivation, livestock bedding, fuel pellets, ethanol and pulp and paper industry would undoubtedly be accelerated through an aggressive plant improvement program involving province-wide performance testing and an Ontario based plant breeding program. REAP-Canada is ideally positioned to help coordinate this activity, as the organization has 8 years of research experience with warm season grasses in Ontario, as well as a growing network of partnerships with industry, research scientists and farmers interested in realizing the opportunities of switchgrass.

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Home Page