Research and Development of Fibre Crops in Cool Season Regions of Canada

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Abstract

Both annual and perennial agri-fibre crops are being developed in Canada as fibre crop species. Annual crops are primarily being targeted as crops for higher value land and smaller, but higher value markets. Research studies on hemp and flax examine the adaptation of European varieties to Canadian growing conditions, and investigate cultural practices and their impact on fibre quality. Additionally, increasing acreage of short-statured grain hemp varieties may provide a by-product for some fibre applications.

Perennial grasses are being developed for marginal lands and larger, but generally lower value, fibre and energy market applications. The main grass under biomass development is switchgrass. In the wetter and cooler regions of Canada, other more chilling tolerant C_4 grasses such as prairie cordgrass have potential as an alternative species to reed canary grass. The main advantages of C_4 grasses over C_3 grasses are their lower silica and nutrient contents, high water use efficiency, and their ability to be harvested more easily using the delayed harvesting system.

Fibre markets for perennial grasses currently include their use for livestock bedding, "straw bale" housing, and as a compost substrate for mushroom production. Promising future markets include the pulp and paper and composite industries as well as energy industries. Commercial plantings of switchgrass were made in 1999 for a demonstration cellulosic ethanol plant. Processing of switchgrass as a pelletized feedstock has a strong net energy balance and appears a promising means to use the material for space heating or composite applications.

Keywords: fibre crops, hemp, flax, switchgrass, reed canarygrass, markets

Introduction

There is a growing interest in Canada in the development of agricultural sources of fibre for non-food markets such as pulp and paper, fiberboard, composites and biofuels. Food-related opportunities include their use as a horticultural mulch, for livestock bedding applications, and as a compost substrate for mushroom production. Many factors suggest Canada could become an important producer of agri-fibres in the cooler temperate zones of the world. It has a large agricultural land base, an excellent transportation infrastructure, is a relatively low cost commodity producer and has a strong research and production infrastructure from its wood based fibre industries. This overview will emphasize opportunities for perennial fibre crops as: 1) Canadian production experience is limited with annual fibre crops in comparison to other cool, temperate regions and 2) larger opportunities for agri-fibre utilization in industrial applications are likely to be realized from perennial fibre crops such as switchgrass and reed canarygrass that have a lower cost of production and are more widely adapted to marginal farm land than annual crops.

Annual Fibre Crops:

Hemp (*Cannabis sativa*) is a dedicated annual fibre crop that appears to be well suited to Canada's climatic conditions. Recent legislative changes by the Canadian government have made it possible for farmers to once again grow this crop. Most production research to re-develop the crop has been addressing the suitability of European fibre hemp varieties, seeding dates and rates, and time and method of harvest. The overall goal is to optimize fibre quality and yield of the various products while minimizing harvesting costs and easing harvesting problems. Recently there has been increased effort to introduce and develop some shorter statured dual grain and fibre hemp varieties, which may produce a more economical fibre for use as a co-product in industrial applications. The 1999 growing season in Canada saw a sharp increase in hemp production with 12,500 hectares planted. However, the hemp industry is experiencing some growing pains as one of the main processors of the production from this acreage recently went bankrupt. As a result, the land area planted to hemp in the year 2000 is expected to be reduced to about 6000-8000 ha. Despite this set back to the Canadian industry, a plant-breeding program has been initiated in southern Ontario to develop hemp varieties specifically adapted to this region. The main target markets for hemp are non-woven fibre applications (such as a reinforcing agent for manufacturing automobile panels) and seed for various food products.

Fibre flax (*Linum usitatissimum* L.) production in Canada was virtually eliminated in the period following World War II, due to the loss of government financial assistance, competition from newly developed synthetic fibres, and technological advancements promoting the adoption of various other natural fibres. Although currently most popular in Western Europe, where production systems have benefited from investment in breeding programs, government subsidies, and technological advances, fibre flax is being re-established in Canadian markets for woven applications. Canada appears to be an ideal location for fibre flax production because of its abundance of land, advanced production systems of other crops, an agricultural history that includes fibre flax, and the development of technologies that enable the blending of different types of fibres. Since most of the cultivation of fibre flax has been based in Western Europe, an expanded research effort is required to successfully re-introduce the crop into eastern Canada. Preliminary research conducted on the adaptability of modern European cultivars to eastern Canadian growing conditions suggests that most fibre flax varieties grown in eastern Canada have very high biomass production relative to those grown in Western Europe (Couture, 1999). However, since the sole Canadian fibre flax plant recently went bankrupt, the most significant challenge facing the re-introduction of the crop into Canada may be restoring the confidence of farmers. Fortunately, the plant is now under new ownership and 500-600 ha will be planted in the year 2000, with production of 3000 ha anticipated by 2003.

Perennial Grasses as Biomass Crops

Fast growing perennial grasses are ideal candidates for fibre production as they have lower maintenance costs and are more efficient at collecting solar radiation during the growing season than annual crops. Perennial grasses are also better adapted to marginal soils, which have low opportunity costs for agricultural production. Grasses are categorized into two broad groups, cool and warm season, based on their photosynthetic cycle. Cool season grasses utilize the C_3 metabolic pathway and are most common in wet regions with cool night time temperatures. Reed canarygrass is perhaps the most promising perennial grass crop in these wet cool regions for biomass applications. In zones with somewhat higher temperatures, warm season (C_4) grasses such as switchgrass (*Panicum virgatum*) and miscanthus (*Miscanthus sinensis*), which have moderate chilling tolerance, may be more productive. C_4 plants use only one half as much water per tonne of biomass produced, which contributes to their higher yield potential than C_3 species such as reed canarygrass. In North America, miscanthus has not been extensively evaluated as there are concerns about the species escaping into natural areas, and more productive native C_4 grasses are available. Nonetheless, more chilling tolerant C_4 grasses will likely need to be developed for more northerly areas. Presently, the main areas of switchgrass production are confined to those regions suitable for silage maize production. Other native C_4 grasses are better adapted than switchgrass to cooler regions and to more extreme soil moisture conditions. Prairie cordgrass (*Spartina pectinata*) and prairie sandreed (*Calamovilfa longifolia*) are most likely the two highest priority native C_4 grasses to be developed. Prairie sandreed is better adapted to the drier (> 40cm annual precipitation) and cooler prairie regions of western Canada. Performance data on unimproved stands of prairie sandreed in western Canada (Stumberg *et al.*, 1998) and the U.S. Great Plains (Jacobson *et al.*, 1986) indicate that the species has good potential if seedling vigor problems can be overcome. Prairie cordgrass has more significant seed establishment problems than prairie sandreed. However, prairie cordgrass has greater yield potential than switchgrass in wetter, cooler environments as it has a longer period of leaf area duration (Madakadze *et al.,* 1998). Big bluestem (*Andropogon gerardii*) is another potential biomass species. It has a similar native range to switchgrass, but has a higher stem to leaf ratio, and merits further investigation as a fibre crop.

Perennial Grasses for Fibre Utilization

The main advantage of perennial grasses is that they can produce more fibre per hectare than hardwood trees in most of North America and they can be harvested each and every year. In eastern Canada, annual yields from 6 to 13 oven dry tonnes (ODT) $ha^{-1}yr^{-1}$ (depending on the harvesting regime) can be achieved with current switchgrass cultivars. Fall harvested reed canarygrass usually produces between 7-12 ODT $ha^{-1}yr^{-1}$ and its productivity is frequently moisture limited. Perennial grasses cannot replace softwood fibre, but usually have better pulping properties than cereal straws. For pulp and paper production, the preferred harvest period at present for both reed canarygrass and switchgrass is the spring harvest. According to this technique, the crops are not cut in the fall but rather left in the field to overwinter and are harvested in early spring prior to spring regrowth (Hemming *et al.,*1994). With the delayed harvesting system, translocation and leaching of nutrients to the soil recycles nutrients for the next growing season. This reduces the ash content of the feedstock, which subsequently minimizes black liquor treatment problems in the pulp mills.

The Silica Issue and its Impacts on Agri-fibre Utilization

Silica is the main quality barrier preventing perennial grasses and straw from being more widely utilized in both the pulp and paper industry and the energy sector. Silica, which is the single largest component of ash in perennial grasses, varies greatly in quantity between species. In the pulp and paper industry, silica-rich feedstocks complicate the recycling of chemicals from recovery boilers, and increase maintenance costs while shortening the lifespan of machinery.

Developing lower ash feedstocks will facilitate the entry of agri-fibres such as perennial grasses into the pulp and paper industry.

There are two principle ways in which silica comes into contact with biomass feedstocks: i) through surface deposition by soil contamination, and ii) internally through water uptake by passive water flow and/or metabolic processes (Samson and Mehdi, 1998). In perennial grasses, the major mechanism of silica entry is through the uptake of monosilicic acid in water. Crop residues, such as corn and straw, are generally higher in silica than dedicated feedstocks, as these residues are more exposed to wind erosion during the production cycle, and to soil contamination during harvesting.

The main difference in silica contents between perennial grass species is often related to the photosynthetic mechanism of the grass, and to the amount of water being transpired by the plant. As warm season (C_4) grasses, on average, use half as much water as C_3 grasses per tonne of biomass produced (Black, 1971), the decreased water usage reduces the uptake of monosilicic acid resulting in a lower ash content of the plant. This effect was demonstrated in an analysis of various feedstocks collected by REAP-Canada for analysis by the pulp and paper industry (Table 1). The C_3 species (reed canary grass and phragmites) were found to have more than twice as much ash content as the C_4 species (prairie cordgrass, switchgrass, big bluestem, prairie sandreed, and miscanthus). Wheat straw was found to have a higher ash content than other C_3 species because it was also grown on a clay soil (to be discussed), and the residue is prone to silica deposition during the production and harvesting processes.

Table 1. Ash Content of Wheat Straw and Overwintered Perennial Grasses

Prairie cordgrass *(Spartina pectinata)*	C_4 perennial	1.6%
Switchgrass *(Panicum virgatum)*	C_4 perennial	1.7%
Big bluestem *(Andropogon gerardii)*	C_4 perennial	1.8%
Prairie sandreed *(Calamovilfa longifolia)*	C_4 perennial	1.9%
Miscanthus *(Miscanthus sinensis)*	C_4 perennial	2.0%
Reed canarygrass *(Phalaris arundinacea)*	C_3 perennial	6.3%
Phragmites *(Phragmites communis)*	C_3 perennial	7.5%
Wheat straw	C_3 annual	11.1%

Adapted from Radiotis *et al.*, 1996

Within species, the water use efficiency will fluctuate depending on the region in which the crops are grown, and on the soil type. Water use per tonne of biomass produced is highest in regions which have a low rainfall to evaporation ratio, and where biomass crops are grown on marginal soils (Samson and Chen, 1995). A combination of these conditions may explain some of the higher values obtained by a U.S. survey reporting switchgrass ash contents of 2.8%-7.6% (McGlaughlin *et al.*, 1996).

The translocation and deposition of silica in plants is also heavily influenced by the soluble silica levels in the soil, which is present as monosilicic acid; $Si(OH)_4$ (Jones and Handreck, 1967). Clay soils have higher monosilicic acid levels than sandy soils, and therefore produce feedstocks with higher silica levels. A Scandinavian study found silica levels in reed canarygrass to be highly influenced by soil type; reed canarygrass had silica levels of 1.3%, 1.9% and 4.9% on sandy, organic, and clay soils, respectively (Pahkala *et al.*, 1996). In Denmark, high silica contents in wheat straw were strongly correlated to clay soils as well (Sander, 1997). Silica is mainly deposited in the leaves, leaf sheaths and inflorescences of plants. Lanning and Eleuterius (1987) found switchgrass silica contents to be 1.03%, 3.85%, 3.41% and 5.04% in stems, leaf sheaths, leaf blades and inflorescences, respectively, in Kansas prairie stands. Due to the low stem silica content, the overall silica concentration of the grass decreases as the stem content increases.

Commercialization Opportunities for Perennial Grasses in the Pulp and Paper industry

To improve quality for the pulp and paper industry, one of the strategies being developed as a means to increase the stem content is to reduce the leaf content by overwintering. Pulping studies have found that the stem component of grasses, followed by the sheaths and then the leaves, has the highest pulp yield, fibre length, and brightness (Goel *et al.*, 1998). However, with increasing stem content, biomass yields are reduced. Spring harvested switchgrass yields were found to be approximately 24% lower in southwestern Quebec than that of fall harvested switchgrass (Radiotis *et al.*, 1996). Higher losses may be experienced during mild winters. This loss of biomass is due to both the late season translocation of materials to the root system in winter (Parrish and Wolf, 1992), and the physical loss of leaves and seed heads during winter (Radiotis *et al.*, 1996). This lower yield increases the cost of spring-harvested relative to fall-harvested switchgrass by approximately 17% (Girouard *et al.*, 1999b).

Selecting less brittle switchgrass varieties and plants with higher stem to leaf ratios will improve the economics of spring harvesting. However, long term fall harvesting of switchgrass in more northerly regions requires further field testing to evaluate yield sustainability. With additional research in plant breeding, reducing yield and cost differences between fall and spring harvested material is achievable. Fractionation of the stem and leaf components for utilization in agri-fibre and energy markets respectively may expand opportunities for utilization of fall harvested crops for pulp and paper applications. In regions such as eastern Canada, where hardwood chips are generally delivered to pulp mills for $80-$100/ODT, switchgrass provides a cost advantage at the mill gate – an advantage that will grow as wood fibre supplies tighten. The most recent economic analysis of switchgrass production in eastern Canada for use as a spring-harvested crop for pulp utilization estimates costs to be $61 to $81 tonne (Girouard *et al.,* 1999a). Estimates are mostly influenced by achievable yields and land opportunity costs.

By planting switchgrass on marginal land, the farm economy would be strengthened through additional farm receipts. For instance, it has been estimated that adding 15% switchgrass pulp to the fine paper and hardwood market pulp currently produced in eastern Ontario and southwestern Quebec would require less than 5% of the agricultural land base and provide new farm receipts of $20-40 million a year (Fox *et al.,* 1998). Overall, most of the traditional supply problems with using agri-fibre crops are now largely resolved (Table 2). The main barrier to the use of perennial grasses in the pulp and paper industry at present is the low economic return from the pulp and paper industry, which is preventing the major capital investment necessary to utilize the material in the industry.

Table 2.Traditional Supply Barriers to the Use of Agri-Fibres in Canada (Girouard and Samson,2000)

Barrier	Solution
• Infrastructure set to handle wood	Integrate agri-fibre lines into existing mills.
• Security of supply	Emphasize drought tolerant perennial fibre crops instead of residues.
• Low cost fibre does not always translate into low fibre cost pulp	Use higher cellulose content sources like perennial grasses.
• High ash and silica content	Use species with intrinsically lower contents, overwinter material, source material from sandy soils and avoid soil contamination by using perennials.
• Logistics of supply systems/material bulkiness	Grow high yielding crops within a short distance of a mill, use high density square balers and new fabric covered outdoor buildings for on-farm storage; use leading-edge digester technology to reduce the impact of bulkiness on throughput.
• Short fibre length	Blend agri-fibres with wood fibres and improve fibre characteristics through investing in plant breeding

Other Fibre Applications of Perennial Grasses

A number of other smaller fibre applications have been attracting grower and industry interest in switchgrass. There is interest in eastern Canada in switchgrass as a livestock bedding because cereal straw is scarce. As well, switchgrass is proving to be a promising feedstock for compost production for mushroom cultivation. At present, mushroom producing companies in eastern Canada and the north-eastern United States have to transport winter wheat straw over 500 km to supply their needs. Winter wheat is favored because it has a relatively long straw with a hollow structure that produces a well-structured and aerated compost. Commercial trials of mushroom compost from switchgrass have been successful and it appears to be a suitable substitute for winter wheat straw, particularly because it contains fewer weeds. This could be a relatively high value market for switchgrass, as winter wheat straw is being purchased at approximately $100/tonne (Cdn). In the year 2000, several straw bale houses will also be constructed in Quebec using switchgrass. This material is being sold at $120/tonne in small bales. The low nitrogen content and dry nature of spring harvested switchgrass make it less prone to decomposition than cereal straw for this application.

Biomass Energy Applications for Perennial Grasses

Undoubtedly the fibre applications of perennial grasses will also frequently be coupled with their use in the biomass energy industry in the future. As mentioned earlier, high value components such as stems may be fractionated and utilized for fibre, while other lower quality fibre components may be used for energy. Recent biomass energy developments in Canada are having an impact on the commercialization of perennial grass biomass crops and could help improve their economics for use as fibre crops. The first of these developments has been the construction of a cellulose-derived ethanol production demonstration facility that will use agricultural feedstocks for its supply, including cereal straw, corn stalks and switchgrass. Approximately 125 ha of switchgrass were planted in the spring of 1999 in Ontario's Ottawa valley for this plant. The project is a joint venture between Iogen Corporation, a Canadian enzyme manufacturer, and Petro Canada, one of Canada's largest oil companies. The plant is a $25 million investment and it will use approximately 60 tonnes of biomass per day when it begins operation in August 2000. If the technology proves successful, larger facilities will be built to operate at capacities in the order of 1000 tonnes/day.

A second emerging biomass energy market opportunity is that of densified biomass fuels. Presently, approximately 100,000 tonnes of pelletized wood residues are being exported annually into Scandinavia from Canada. This may also create market opportunities for perennial grasses. The use of perennial grasses for pelletizing purposes has been facilitated by the recent development of new, close-coupled gasifier, pellet stove technology (http://www.pelletstove.com.)/. It has burned switchgrass fuel pellets with a combustion efficiency of 82-84% (Samson *et al*., 2000). An economic analysis found switchgrass to be a promising feedstock for pellet production as it required minimal drying inputs and had a higher throughput potential than wood (Table 3). The pellets could have market applications for both energy and composite applications.

Table 3. Summary of Preliminary Pellet Production Costs (Cdn$/tonne)

	Wood Industry Survey	Switchgrass	Short Rotation Willow
Feedstock	$ 34.35	$46-$68	$58-$85
Drying	$11.93	$0	$15.00

Direct Pelleting Costs	$59.00	$25.26-39.33	$39.33-$50.57
Bagging	$19.25	$19.25	$19.25
Total cost	$124.53	$93.51-$129.58	$131.58-$169.82

Feedstock cost for short rotation willow and switchgrass based on Girouard *et al*., 1999b, for $U.S. divide by 1.5.

Production rates based on 30 lbs/hp for wood residues, 45-70 lbs/hp for switchgrass and 35-45 lbs/hp for short rotation willow.

Energy Costs Associated with Switchgrass Pellet Production

An analysis of the energy costs associated with switchgrass fuel pelleting is important in identifying the greenhouse gas offset potential of the technology. The energy costs associated with switchgrass production and delivery to a large industrial user have been estimated to be approximately 0.91 GJ/tonne for an 8 tonne/ha yield (Girouard *et al.*, 1999b). In the case of pellet production, the hauling distance would be reduced from an average of 60 km to 20 km, as the pellet conversion facility is much smaller than a pulp and paper industry. This reduces the energy cost to 0.79GJ/tonne and creates an energy output to input ratio for the crop (assuming an energy content of the crop to be 18.5 GJ/tonne) of 23:1 (Samson *et al.*, 2000). This high level of energy output to input compares favourably to grain production, which is typically in the 4-6:1 range.

Additional energy is required for pre-processing, pelletizing, marketing and delivery of switchgrass for use as a pelletized product. The energy costs associated with switchgrass fuel pellet production is estimated to be 1.27 GJ/tonne (Table 4). Surprisingly, production and delivery of switchgrass represents 62% of the energy required in the entire switchgrass fuel pellet production chain from field to delivery to the consumer. This is largely due to the energy associated with fertilizer use and application which represents 36% of the total energy cost. Nonetheless the net energy output to input ratio is 14.6:1 (assuming an energy content of 18.5GJ/tonne in the feedstock). Considering that this material can be used quite conveniently as a substitute for fuel oil heating, it appears an excellent strategy to maximize the energy output from a hectare of land. By comparison, the energy balance of switchgrass fuel pellet production appears to be in the order of 3 –4 times higher than cellulosic ethanol (Bull *et al.,* 1992), and about ten times higher than corn ethanol (Shapouri *et al*., 1995). It is evident that fuel pellet production from switchgrass is an efficient land use strategy to displace oil use compared to alternative cropping and energy end use applications which have much less favourable energy production and energy output to input ratios. As well, it bodes well for switchgrass pellets to be a sustainable feedstock to replace plastics in composite applications.

Table 4. Energy Associated with Switchgrass Pellets

Activity	GJ/tonne
Switchgrass establishment	0.028
Switchgrass fertilization and application	0.460
Switchgrass harvesting	0.231
Switchgrass transportation	0.072
Pellet mill construction	0.043
Pellet mill operation	0.244
Management, sales and billing	0.027
Delivery of pellets	0.166
Total input energy	1.271
Total output energy	18.50
Energy output/input ratio	14.6

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