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Economic Assessment of Short-Rotation Forestry and Switchgrass Plantations for Energy Production in Central Canada

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Abstract

Along with agricultural and forest residues, dedicated energy plantations could help to meet Canada's energy needs. Resource Efficient Agricultural Production (REAP)-Canada, together with McGill University, is involved in an on-farm participatory research program in central Canada. The purpose of the program is to determine which factors are limiting biomass productivity and cost-effectiveness for various biomass crops. Two main crops are being investigated: willow trees *(Salix spp.)* grown under a short-rotation forestry (SRF) system and switchgrass *(Panicum virgatum),* a perennial grass. This paper reports estimates of the cost of growing both crops in central Canada, based on quasi-commercial size plots, along with advantages and disadvantages of each crop as an energy source.

Although no long-term field-scale yield data are at present available in central Canada to estimate production costs, significant information is available from climatically similar regions. If annual yields between 7 and 11 odMg (oven-dried megagrams) are representative of what can be achieved under rainfed conditions, the research indicates that SRF willow can be grown on marginal land in central Canada for $63-$95/odMg.

Switchgrass, a native, C_4 perennial prairie grass, is recognized as a species that performs well on marginal sites. This is a major advantage over other biomass crops since most of the land available for biomass production in central Canada is lower quality land. First-year establishment costs of switchgrass are approximately one-quarter those of SRF willow. As well, assuming that both switchgrass and SRF willow yield 10 odMg/ (ha-yr), the total cost of production for switchgrass is estimated to be 30%-40% less than for SRF willow.

The energy sector represents a promising market for biomass, but other markets, such as papermaking, need to be investigated if the full potential of these new crops is to be achieved.

Résumé

Les plantations énergétiques, conjointement à l'utilisation des résidus agricoles et forestiers, pourraient aider le Canada à faire face à ses besoins en énergie. Resource Efficient Agricultural Production (REAP) Canada, en collaboration avec l'Université McGill, participe à un programme de recherche à la ferme dans le Canada central. Le but du programme est de déterminer quels facteurs limitent la productivité et la rentabilité de diverses cultures de biomasse. On étudie deux ressources principales, soit les saules *(Salix* spp.) cultivés selon un système de sylviculture à courte révolution (SCR) et le panic érigé *(Panicum virgatum),* une herbacée pérenne des Prairies de type C4. Ce rapport présente des estimations des coûts de ces deux cultures dans des parcelles de taille quasi-commerciale au Canada central, ainsi que les avantages et désavantages de chacune comme source d'énergie.

Bien que l'on ne dispose pas actuellement de données de rendement au champ à long terme pour l'évaluation des coûts de production au Canada central, on peut utiliser des quantités considérables de données de régions climatiquement semblables. Selon les études, sur la base de rendements compris entre 7 et 11 tonnes de matières sèches dans des conditions pluviales, on pourrait cultiver des saules (obtenus par SCR) sur les terres marginales du Canada central pour 63 à 95 $ la tonne (matières sèches).

On a établi que le panic érigé donne un bon rendement sur les terres marginales, ce qui constitue un important avantage par rapport aux autres cultures de biomasse, étant donné que la plus grande partie des terres disponibles pour la production de biomasse au Canada central sont des terres de qualité inférieure. Les coûts de l'établissement du panic érigé, la première année, sont d'environ le quart de ceux du saule SCR. De même, en supposant une production de panic érigé et de saule SCR équivalant à 10 t/ha de matières sèches par année, on estime que le coût total de la production du panic érigé est de 30 à 40 % inférieur à celui du saule SCR.

Le secteur de l'énergie représente un marché prometteur pour la biomasse, mais il faut étudier d'autres marchés, comme celui de la papeterie, pour obtenir le maximum de ces nouvelles cultures.

Introduction

Along with agricultural and forest residues, dedicated energy plantations could help to meet Canada's energy needs. Resource Efficient Agricultural Production (REAP)-Canada, together with McGill University, is involved in an on-farm participatory research program in central Canada. The purpose of the program is to determine the productivity and cost-effectiveness of various biomass crops using commercial farming methods. Two main crops are being investigated: willow trees (Salix spp.), a C_3 crop, grown under a short-rotation forestry (SRF) system, and switchgrass (Panicum virgatum), a C_4 perennial grass that performs well on marginal sites. This paper reports estimates of the cost of growing both crops in central Canada, based on quasi-commercial size plots, along with advantages and disadvantages of each crop as an energy source.

Methods

Beginning in 1993, 15 ha of biomass plantations were established in the provinces of Quebec and Ontario. An interesting feature of these plots is that woody and herbaceous crops are being evaluated and compared on the same site, based on practices that farmers would be expected to perform (Table 1).

Table 1. Sequence of cropping practices observed during the first 4 years of SRF willow and switchgrass monoculture plantations.

	SRF Willow	Switchgrass
Plantation Life	Approximately 20 years	5-15 years
Harvest Cycle	Every 3-4 years	Annual

Time of harvest	Late fall/early winter	Fall (Sept.-Oct.) or spring (May)
First year activities		
Spray with broad spectrum herbicide (fall preceding planting)	Yes	Yes
Plough, disc, harrow	Yes	Yes
Planting	12500 cuttings per ha; 4.23¢ per cutting	Seed @ $7.00/kg; 6 kg/ha
Herbicides	Grass herbicide	Broadleaf herbicide
Mechanical weeding	Yes	No
Harvest	No	Yes (round bales)
Second- year activities		
Fertilizer	200-20-53 kg/ha[a]	50-10-0 kg/ha
Herbicide	If necessary (grass herbicide)	No
Harvest	No	Yes
Third-year activities		
Fertilizer	If possible	50-10-0 kg/ha
Harvest	No	Yes
Fourth-year activities		
Fertilizer	If possible	50-10-0 kg/ha
Harvest	Yes	Yes

[a] Due to tree height, fertilizer application was assumed to have occurred only during the second year of a cycle Nonetheless, fertilization every year, or every other year, is probably a better strategy when possible. For the purpose of the study, nitrogen rate was estimated based on a trade-off between tree requirements over a 4-year cycle and environmental concerns.

The economics of SRF willows and switchgrass was investigated for harvest cycles of 4 years and I year, respectively. Estimates for establishment and other preharvest costs were obtained from REAP-Canada quasi-commercial plots (3 sites of 5 ha). Harvesting costs were estimated entirely from secondary data. Transportation costs for a 40-km haul were also included in the analysis.

A biomass final supply price was determined using a budgeting approach and was developed on a Microsoft Excel spreadsheet. Full cost budgeting was used; that is, all cash and non-cash costs were considered, including a return to the farmer's land, labor, and management. The final supply price represents the market revenue necessary to cover all these costs. Annual land rent was estimated as 5% of the land purchase value; labor was charged at $10/hour; and management was estimated as 3% of the purchase value of land and equipment. The analysis did not include government subsidies and tried to provide a fair return to farmers for the use of marginal farm land.

Results and Discussion

Establishment Costs

Total establishment costs per hectare were estimated at $976 (Fig. 1) and $220 (Fig. 2) for SRF willow and switchgrass, respectively. Thus during the first year, a farmer must invest approximately 4 times more money to establish SRF willow than switchgrass. Nonetheless, when establishment costs are amortized over the plantation life, the cost differential narrows due to the longer life cycle assumed for the tree plantations. For instance, if a stand of SRF willow is assumed to have a life cycle of 20 years and a stand of switchgrass 10 years, annual establishment costs are $78 and $28 per hectare, respectively, using a 5% real rate of interest. The main factors making SRF establishment more expensive are cutting and planting costs: $528 and $288 per hectare, respectively, compared with $42 for switchgrass seed and $25 for its planting.

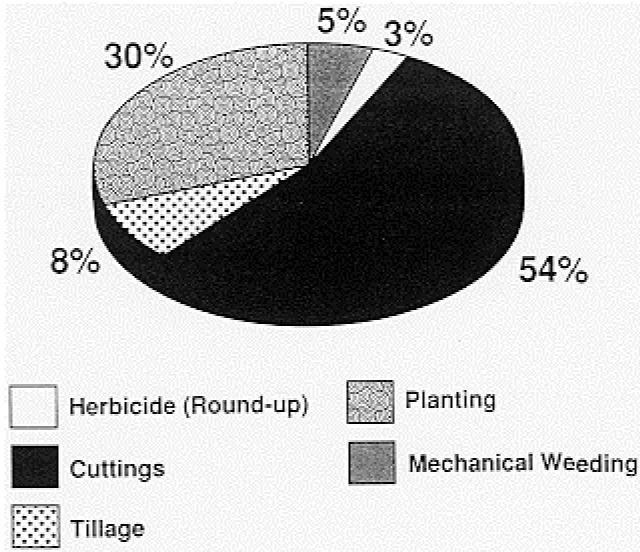

Figure 1. Breakdown of establishment costs for 1 ha of SRF. Total cost is $976

Final Supply Price

Final supply prices of the biomass, for a range of yield and including delivery to a processing plant, are presented in Figure 3. On an equivalent yield basis, switchgrass biomass Was estimated to be on average 37% less expensive to grow than SRF willow biomass. Given current cultivars, we believe that the switchgrass yield range in central Canada should be in the order of 8-12 odMg (oven-dried megagrams)/ha. For this yield range, switchgrass biomass could be produced for between $38 and $51/odMg. For SRF monoculture plantations, Samson et al. (1994), after a literature review of yields obtained in large unirrigated experimental sites in Europe and North America, suggest that SRF monoculture plantations under rainfed conditions will likely not produce more than 7-11 odMg/(ha - yr) in central Canada, a moderate rainfall, temperate region. Based on this range, SRF willow biomass was estimated to be produced for $63-$95/odMg.

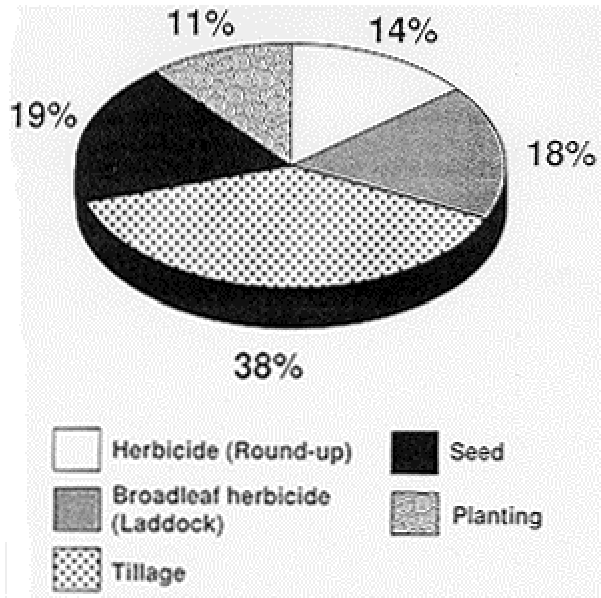

Figure 2. Breakdown of establishment costs for 1 ha of switchgrass. Total cost is $220.

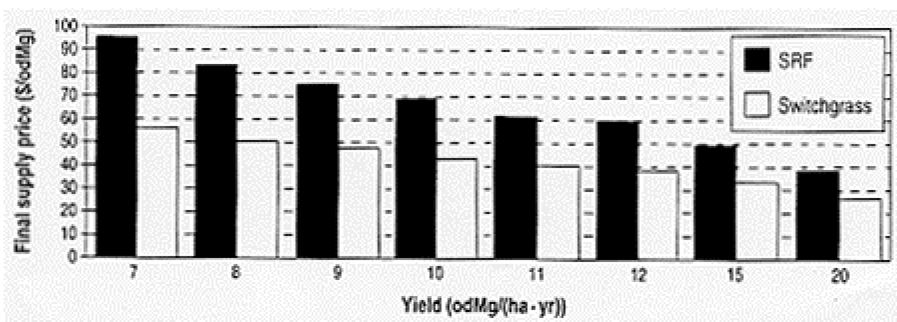

Figure 3. Final supply price of SRF willow and switchgrass grown in monoculture plantations in eastern Canada. **Note:** Harvest costs are assumed constant per hectare, whatever the yield achieved.

For both crops, harvest and transportation of the biomass represent approximately 50% of the total cost (Figs. 4 and 5). Improvements in harvesting technology and in transportation logistics thus have the potential to substantially reduce biomass production costs. Costs related to managing the plantatiions and leasing the land were estimated to be of equal importance to transportation. Establishment costs, which in the case of SRF are substantial, do not represent a major share of final cost since they are spread over the life of the plantation. Although a significant reduction in establishment costs will mitigate the cash-requirement problem in the first year, it will likely not reduce total biomass costs as much as decreases in harvesting and transportation will.

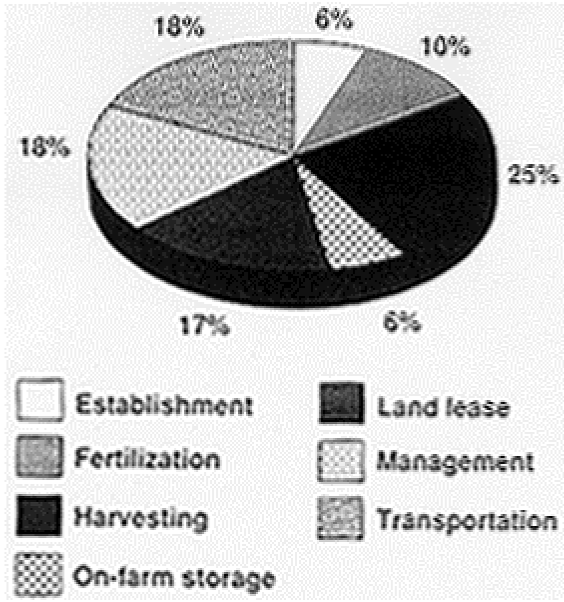

Figure 4. Cost breakdown for 1 ha of switchgrass. Total cost is $433 (10-year life span 10 odMg/(ha-yr)). Adapted from Tayara (1995).

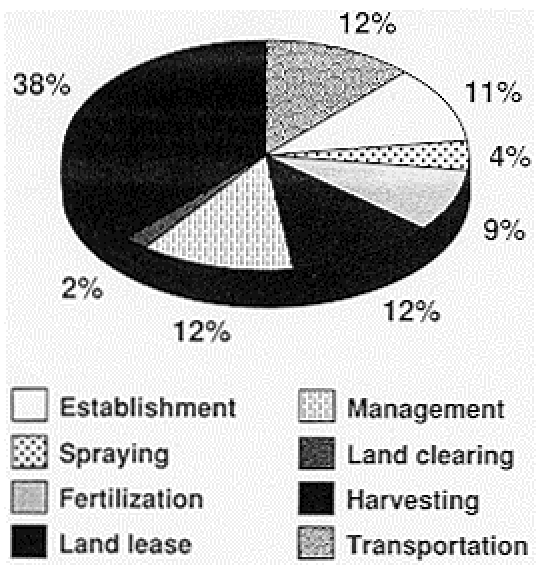

Figure 5. Cost breakdown for 1 ha of SRF willow. Total cost is $2746 (4-year harvest cycle; 10 odMg/(ha-yr)). Adapted from Girouard (1995).

The relationship between yield, land quality, and cost needs more research. Yield is a major cost driver in both SRF willow and switchgrass plantations, as is (to a lesser extent) land cost. In the absence of direct subsidies, it is very likely that energy crops will only attract low quality land. Although land cost will be minimized on marginal land, yields will also be lower, and the net effect may be an increase in the average cost per tonne of the biomass compared with using better quality land. The net effect will likely be different for different crops.

The specific relationship existing between yield and harvesting costs also needs to be better defined. Most studies in the past, including this one, have assumed that harvesting costs per unit area are constant, regardless of yield. More recent studies, for example Walsh (1995), have increased harvesting costs after a given yield level is achieved. The main impact of this change in methodology will be that production costs will not drop as fast while yield is increasing, leading to a new lowest cost solution. The real issue is to define where biomass can be produced at the lowest cost ($/tonne), not to maximize yield at any cost.

Energy Market Opportunities

The attractiveness of switchgrass and SRF willow in monoculture plantations for potential energy markets can be summarized as follows:

Alcohol fuel production - Lower production costs and ease of use for farmer (no need for farmers to purchase new equipment) suggest that switchgrass is more promising than SRF willow for ethanol production. At present, an unsubsidized ethanol producer can pay no more than $30/odMg for the biomass and be profitable, which is only $8/odMg lower than the low end of the final supply price range established in this study. Improvements in production and processing economics, as well as implementation of economic instruments to limit greenhouse gas emissions could make ethanol produced from this crop a viable non-subzidized transportation energy option in the medium run.

Electricity generation - Based on conversations with energy experts, the cost of fossil fuels (natural gas, coal and heavy fuel oil) in central Canada for electricity production ranges between $2.50 and $4.00/GJ (gigajoule). In comparison, switchgrass and SRF willows could be delivered for between $2.17 and $2.91IGJ[1] and $3.2 and $4.82 /GJ[2], respectively. Thus, purely on a cost basis, switchgrass has potential for electricity generation; but differences in risk, conversion efficiency, and capital and maintenance costs associated with power plants using biomass versus fossil fuels must be estimated before making a final statement. If reductions in carbon dioxide emissions were credited to. the use of biomass, or if gasification technology would prove efficient on the scale of a commercial power plant, biomass feedstocks would become more competitive. Cogeneration (heat and power production) will probably be the entry point for biomass crops in the electricity-generation market, due to higher conversion efficiency obtained in these plants. Another opportunity may be co-firing with coal in existing boilers.

[1] Switchgrass biomass selling for $38-5I/odMg; 17.5 GJ/odMg.

[2]SRF biomass selling for $63-95/odMg; 19.5 GJ/odMg.

Heat production - Biomass combustion systems have to compete primarily with three conventional energy sources: heating oil, natural gas, and electricity. Based on Statistics Canada/ Natural Resources Canada (1994), these three forms of energy were delivered to household consumers for $5.33- $22.83/GJ (Table 2).

SRF willow and switchgrass biomass would easily compete with conventional energy sources but for the higher initial capital cost of biomass-based heating systems. The larger initial capital investment often makes biomass a less attractive energy option, although in some cases it is the most cost-effective over the life span of the biomass combustion unit. The use of the biomass crops on-site would further reduce biomass cost by 12% to 18% (Table 2).

Table 2. Cost of energy from residential-delivered conventional sources versus from biomass energy crops.

	Retail price[a] ($/GJ)		
	Quebec		**Ontario**
Heating oil (#2)[b]	9.27		9.29
Natural gas[c]	7.14		5.33
Electricity[b,d]	16.61		22.83
SRF Willows		3.20-4.82	
SRF Willows (on-site use)[e,f]		2.82-4.46	
Switchgrass[e]		2.17-2.91	
Switchgrass (on-site use)[e,f]		1.71-2.46	

[a]Heating oil, natural gas, electricity: average price for 1989 to 1993. Source: Statistics Canada/Natural Resources Canada (1994).

[b]Prices include provincial and federal sales tax.

[c]Implicit price: these prices have been derived by dividing gas utility revenue by the sales volume for a given month. Since metering and billing practices differ between utilities these implied prices must be used with caution. Prices exclude taxes.

[d]Residential rates for monthly consumption of 1000 kW-h.

[e]Does not account for the effect of moisture on conversion efficiency.

[f]Does not include costs related to a 40-km haul.

A potential entry point for biomass combustion systems is to replace propane heating systems on farm complexes. For instance, a greenhouse owner in eastern Ontario is now converting from propane to woodchips (from forest residues) as a heating source to benefit from substantial fuel cost savings. Propane costs 25¢/L (approximately $9.79/GJ) and the owner anticipates reductions in his annual fuel bill of approximately two-thirds (or $12 000). With savings such as these, the payback period of the combustion unit will be fairly short (probably in the order of 3 years). SRF willow and switchgrass -biomass would also seem to be a promising fuel option in this case. Some greenhouse owners in the Maritimes are also moving away from propane to woodchips (Flann 1994). Research undertaken by REAP-Canada, with support from the Eastern Ontario Model Forest, will provide data to construct a more detailed picture of the potential of biomass heating systems in central Canada.

Conclusions

Based on the research conducted by REAP-Canada during the last 3 years, switchgrass appears to be a more promising biomass crop than SRF willows due to lower production costs, better adaptation to marginal sites (except poorly drained soils), and farmer acceptance (no need for farmers to purchase new equipment). In the short term, the most viable energy markets for biomass crops in central Canada appear to be, in order, heat production, ethanol production, and electricity generation. Accordingly, as long as biomass crops will not be entitled to. direct production subsidies, as conventional cash crops, the greatest potential for biomass crops will remain on land unused by conventional agriculture.

A way to commercialize the SRF willow concept would be to use these plantations as biofilters to reduce the problem of urban sewage sludge disposal. Irrigation of SRF willow plantations with sewage sludge would provide nutrients to the trees at minimal cost as well as moisture to boost tree growth above levels that could be obtained under rainfed conditions. The biomass so produced could be used to heat municipal buildings, schools, and other structures. Another potential way to commercialize the SRF concept would be as an on-farm heat source since there would be an elimination of transportation costs. In this case, the trees could be grown in monoculture plantations or in a windbreak system, which would also protect cash crops on the farm.

Finally, with the expected growth in the world demand for paper and paper products in the coming years, Canadian papermills are looking for new sources of fiber. The potential of SRF willow and non-wood biomass should be considered because, among other things, they could be grown near the mills (cost advantage over the natural forest) and would be more responsive to changes in industrial fiber needs (because of shorter harvest cycles and higher productivities than the natural forest). In fact, papermaking may offer the best commercial implementation opportunities for biomass crops in the short- and mediumterms. From this perspective, the aim of future research should be to develop biomass-supply systems for a variety of industrial markets, not only for energy production.

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