Sustainable Biomass Production in Agroforestry Systems

William Schroeder[1], Chris Stefner[1], Garth Inoye[1], Ian Pickering[2] and Henry de Gooijer[1]

Agriculture and Agri-Food Canada, Agri-Environment Services Branch, Agroforestry Development Centre, Indian Head[1], Melfort[2], Saskatchewan

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Abstract

Research conducted in 2007 through 2009 on the occasional biomass harvest from willow rings could provide balanced co-existence between agriculture and wetlands. This would provide biomass feedstock while preserving the wetland for future generations. The focus of the research will be on the sustainable production of biomass in agroforestry systems. The goals of this research project are to determine the impact of biomass harvest on re-growth of willow rings; evaluate the feasibility of mechanical harvest using a bio-baler; determine the biomass yield and production costs; and quantify fuel characteristics of harvested willow. Results have shown that the bio-baler tested can efficiently harvest biomass from willow rings at a rate of 6.5 tonnes/hour. The re-growth of the willows was rapid and was not impacted by the harvest. There are thousands of hectares of wetlands and surrounding willow rings available on the Canadian landscape for harvesting at a reasonable cost of production. The willow ring biomass harvested is suitable for small scale heating systems. Additional research will be conducted on the utilization of the biomass harvested from willow rings as a bioenergy source to supply a biomass boiler for heating purposes at the Agriculture and Agri-Food Canada (AAFC) Agroforestry Development Centre (ADC) in Indian Head, Saskatchewan. This research will include the economics and environmental aspects and will consider the life cycle analysis.

Introduction

Agroforestry is an integrated and intensive agricultural production system that includes trees and shrubs as an essential component to achieve environmental, economic and social goals. In other words, trees are not incidental to the farm operation, but rather contribute to improved productivity, yield, profitability and sustainability. Willow rings are abundant and occur naturally in the Canadian landscape and can be an integral part of an agroforestry system (Fig. 1). The benefits of the willows is not always apparent and in fact it is easier to see the downside of a wetland and its components rather than looking at the potential advantages. Harvesting willow rings can produce woody biomass that can be used as fuel for heating as well as provide an opportunity to rejuvenate mature willow stands. Thus, there are economic and environmental benefits of the occasional harvest or coppice of willow rings. Willows have the ability to regenerate on their own after coppice, which is a key component of the sustainable biomass production in an agroforestry system.

Figure 1. Typical landscape showing willow rings.

Objectives

The objectives of this research was to determine short and long term impacts of coppicing on environmental function of willow rings; evaluate the feasibility of mechanical harvest of willow from typical willow rings in the aspen parkland; determine biomass yield potential of willow rings; and to quantify the fuel characteristics of harvested willows. The methodology used to accomplish the objectives for this project was that natural willow rings were selected for biomass removal in fall 2007 and 2009. The willow biomass yield was determined in both years and the willow re-growth was measured in 2008. The fuel characteristics of the harvested biomass was also determined.

Harvest technology was developed as a result of a partnership with AAFC and Laval University and produced the first bio-baler prototype in 2006. This machine did not withstand the rigor of harvesting woody biomass and the third generation WB-55 bio-baler was eventually introduced, which had improved harvest capacity, reliability and ruggedness (Fig. 2). The WB-55 bio-baler is manufactured and distributed by Anderson Group in Chesterville, Quebec and has a 1.7 kg hammer with a cutting width of 225 cm hinged on a rotor turning at 2200 rpm. This baler weighs 6000 kg and requires a 180 hp tractor for operation.

Figure 2. The 2006 bio-baler prototype and the 2009 WB-55 bio-baler.

The 2009 harvest was completed in November using the WB-55 bio-baler and includes the total area occupied by five separate willow rings totaling 1.83 ha. The yield from the 1.83 hectares harvested was 19.2 tonnes of dry matter (DM) per hectare.

Table 1: Harvest Capacity and Yield of the 2009 Willow Ring Harvest.

Total area harvested (ha)	1.83
Total biomass harvested (tonnes DM)	35.1
Willow ring yield (tonnes DM/ha)	19.2
Total bales harvested	143
Mean bale fresh weight (kg)	341
Moisture content (%)	28.0
Bio-baler capacity (bales harvested/hour)	24

The low moisture content of 28 percent was attributed to harvesting over mature willow rings that contained a significant amount dead wood. Typical moisture content from harvested willows would be approximately 40 to 50 percent. The bales harvested per hour include travel time between willow rings as a result the harvest rate of bales per hour is lower that it would be in a plantation setting. The estimated cost of production of the biomass from willow rings was $50.00 per tonne DM. This cost is based on equipment rental rates from the 2008-2009 custom and rental rate guide developed by Saskatchewan Ministry of Agriculture.

Following the mechanical harvest the willow stems were typically splintered because of the rough cutting edge of the shredder hammers. To look at the impact of the mechanical harvest on willow regeneration, five nested 1 m^2 monitoring sites were randomly selected and staked in the harvested area. The two treatments applied at each nest were: willows harvested with bio-baler, stems not pruned and willows manually pruned to have a clean cut (Fig. 3).

Figure 3. Shredding action of bio-baler resulted in splintered stumps compared to the clean cut from hand pruning.

During the growing season the number of shoots that developed were counted in each 1 m^2 plot. At the end of the growing season biomass was harvested from each plot and total dry weight determined for each willow species present. There was no significant difference between the two treatments (Fig. 4).

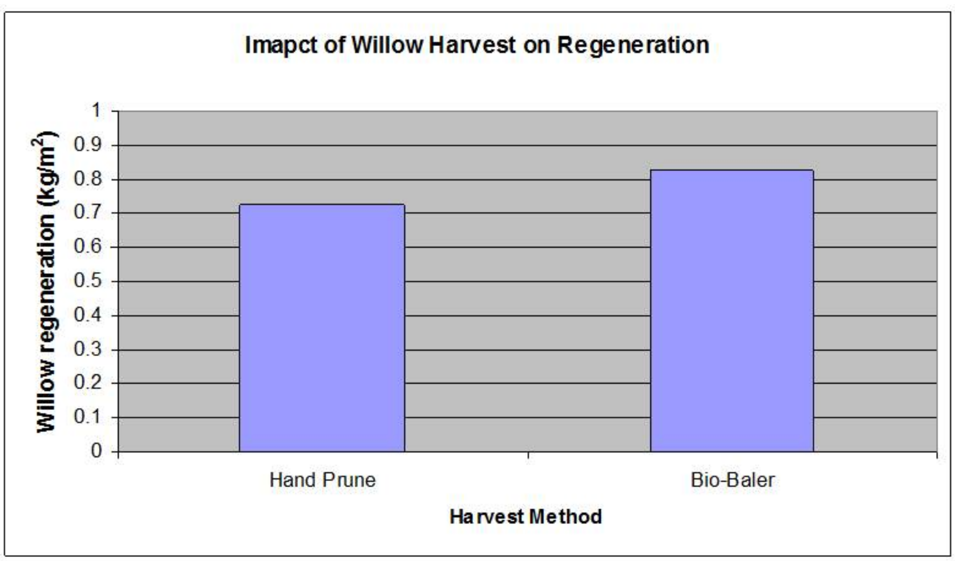

Figure 4. The impact of the willow harvest comparing the bio-baler to hand pruning.

The utilization of the harvested willow ring biomass was also considered and combustion seemed obvious. There is already an established technology in Europe and North America with respect to using woody biomass as a fuel source for bio-boilers. The willow bales would need to be processed or chipped prior to combustion, which could be done with a round bale tub grinder. Bales are an ideal storage method as the biomass naturally dries while stacked compared to fresh chips which need to be dried artificially or mechanically. The modern chip burners have the capability to operate at greater than 80 percent efficiency. There is a transport distance limitation due to the low bulk density of chips and therefore the energy balance is maximized if the fuel is used as close to its production site as possible.

In terms of fuel characteristics of willow biomass, the ash content is approximately 1.65 percent and the calorific value is 19.6 gigajules per dry tonne. Three round bales make up one dry tonne of willow biomass, which is the equivalent of 400 litres of heating fuel (Fig. 5).

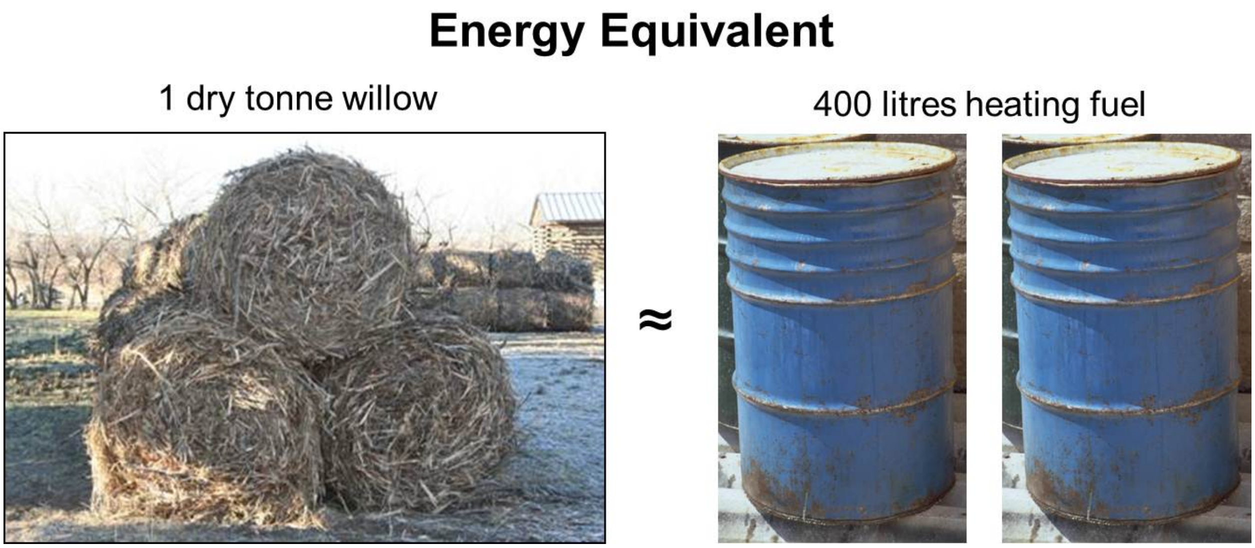

Figure 5. Comparing the energy of willow biomass to heating fuel.

Conclusions

The re-growth of the willows was not impacted by the harvest and was rapid. The bio-baler was able to efficiently harvest at a rate of approximately 6.5 tonnes/hour and provided an opportunity to rejuvenate over mature willow rings. The management of willow rings in agricultural fields requires a balance between wildlife habitat, renewal of the natural woody vegetation, protection of the natural water control function of the marshes and profitable agricultural production. There is a significant prospect to take advantage of wetlands for biomass production (15-20 tonne DM/ha). There are thousands of hectares of wetlands available for harvest and the biomass produced is well suited to small scale heating.

The Next Steps

As mentioned earlier combustion of the biomass produced from willow rings is an ideal utilization method. To that end, staff from the ADC Research Unit will be focusing their efforts on completing the cycle of sustainable biomass production in agroforestry systems. In doing so, a three year pilot project is underway to determine the efficiency, feasibility and economics of heating with woody biomass.

The harvested bales are stored outside in order to reduce the moisture content to approximately 18 per cent at which time the bales are chipped using a haybuster tub grinder (Fig. 6 & 7).

Figure 6. Willow bales stored at the ADC in Indian Head, SK.

Figure 7. Processing the willow bales using a haybuster tub grinder.

In February of 2012, the ADC set up and commissioned a 300 kw KOB Pyrot fully automated combustion burner that uses wood chips as fuel to heat the biomass boiler system (Fig 8). This unit has one million btu's of heating power and will be used to heat the greenhouse, lab space and part of the administration building at the ADC. The previous natural gas boilers will kept on line as a back-up heating supply.

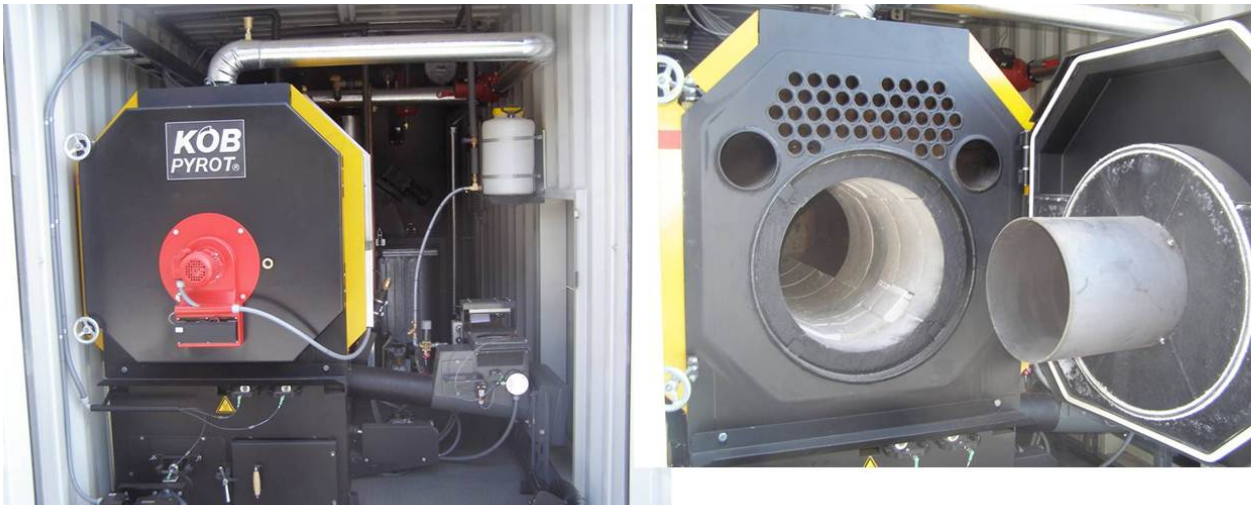

Figure 8. The KOB Pyrot combustion biomass boiler located at the ADC in Indian Head, SK.

In the first month of operation, the biomass heating system has been providing adequate heat to the greenhouse, lab and administration building (Fig. 9).

Figure 9. The biomass heating system in operation at the ADC in Indian Head, SK.

The system has been operating at approximately 94 percent efficient and there has been a significant reduction in natural gas use. Monitoring equipment as well as records from the operation and maintenance of the biomass boiler unit will provide data on the efficiency of the boiler, the emissions, the amount of fuel needed and the savings with respect to natural gas. This information will form the next phase of the research that the ADC will conduct over the next three years on the sustainable biomass production in agroforestry systems.