
Harvesting natural willow rings with a bio-baler around Saskatchewan prairie marshes

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Savoie, P., F. Lavoie, L. D'Amours, W. Schroeder and J. Kort. 2010. **Harvesting natural willow rings with a bio-baler around Saskatchewan prairie marshes.** *Canadian Biosystems Engineering/Le génie des biosystèmes au Canada*. 52: 2.1–2.5. Several grass and woody crops grow naturally around potholes, marshes and sloughs across the Canadian Prairies. This vegetation serves as a valuable habitat for wildlife, but can become invasive on agricultural land and a source of wild fires. This paper presents an innovative harvesting method that can rejuvenate the vegetation, while providing a useful biomass. The prototype, based on a modified round baler and called a “bio-baler”, was used in Saskatchewan to harvest natural willow rings around marshes. It cut, shredded and baled the woody crop in a single pass. Harvest rates averaged 3.5 and 6.6 t/h [fresh weight (FW)] on two sites of different brush density [11 and 43 t/ha of dry matter (DM), respectively]. Round bales were typically 1.22 m wide by 1.35 m diameter; they weighed on average 251 and 347 kg F at each site (density of 144 and 199 kg FW/m³). Moisture content of harvested crop averaged 41%. The bio-baler recovered 62% of biomass (7 and 27 t DM/ha, respectively). The technology could be used to manage naturally growing woody shrubs, while collecting a currently neglected source of biomass. **Key words:** harvest, woody crop, brush, shrub, bale, biomass.

Plusieurs plantes herbagères et arbustives croissent naturellement dans les milieux humides des Prairies canadiennes. Cette végétation est un habitat favorable pour la faune mais elle peut envahir les terres agricoles et être la source des feux de broussailles. L'article présente une nouvelle méthode de récolter et de rajeunir cette végétation tout en fournissant une biomasse utile. Le prototype est une presse à balles rondes modifiée qui a été utilisée en Saskatchewan pour récolter des saules naturels en bordure de marais. Il coupait, broyait et formait des balles rondes de branches en un seul passage. La capacité de récolte moyenne était de 3,5 et 6,6 t/h (masse fraîche – MF) sur deux sites à rendement différent (11 et 43 t/ha de matière sèche – MS, respectivement). Les balles avaient des dimensions moyennes de 1,22 m de largeur et de 1,35 m de diamètre; elles pesaient en moyenne 251 et 347 kg de MF sur chaque site (masse volumique de 144 et 199 kg MF/m³). La teneur en eau moyenne était de 41%. La récolteuse a récupéré 62% de la biomasse originale (7 et 27 t MS/ha). Cette technique permettrait de contrôler la masse de broussailles au champ tout en récupérant une biomasse présentement peu valorisée. **Mots clés:** récolte, plantes arbustives, broussailles, buissons, balle, biomasse.

INTRODUCTION

Wetlands in the Canadian prairies play an important ecological role in plant and wildlife diversity (Huel 2000). However, the development of agriculture in the twentieth century included drainage and the loss of considerable wetland area. For example, according to Gilmour (2004), 71% of wetland area around Minnedosa, MB, disappeared between 1928 and 1982. Current management practices suggest maintaining the marshes (also called potholes or sloughs) and the surrounding natural vegetation (Stolte 2002). As the willow rings grow around these marshes, they sometimes become invasive to nearby agricultural land, can be a source for brush fires and are sometimes intentionally burned (Rowe 1990). A more balanced coexistence between agriculture and wetlands could include occasional harvest of the willow rings. This biomass could be used for combustion or other useful applications while preserving the wetland for future generations.

Limited commercial technology is available to harvest small woody crops either in natural stands or in plantations. The main machine currently used to harvest short-rotation woody crops in plantations is a modified self-propelled (SP) forage harvester with a rotary saw header (Spinelli et al. 2009). The rotary horizontal saws cut the stems, which are then fed into a chopper. The woody stems are transformed into chips, between 25 and 50 mm long, which must be carried out from the field immediately in trailers, requiring typically two to four additional tractors at harvest time. These SP willow harvester-chippers are industrial machines with high rates [average of 35 green t/h according to Spinelli et al. (2009)]; they require a large capital outlay, usually greater than \$500,000 per unit.

An experimental alternative was developed by Lavoie et al. (2008) to harvest cultivated willow. Based on a modified agricultural round baler, the machine cuts, shreds and compacts the woody stems into a round bale; it is called hereafter a “bio-baler”. The original bio-baler included a 1.97-m-wide four-saw-blade horizontal cutter, a 1.55-m-wide horizontal rotor shredder and a 1.22-m-wide agricultural baler. It could harvest one or two willow rows

at a time with continuous cutting and baling rates of 8 to 12 t FW/h. Typical stem diameter was between 25 and 50 mm at a cutting height of about 100 mm above the ground. Stem length was typically 4 to 5 m. In 2006, more than 90 bales were harvested, with a bale diameter ranging from 1.0 to 1.5 m and a density between 220 and 300 kg FW/m³. The prototype was built at a cost of about \$70,000, making such a machine more accessible to small land owners than the SP willow harvester-chipper. In addition, the round bale format is well suited for natural aeration resulting in less storage loss than chips (Garstang et al. 2002). Most farms are also well equipped to handle round bales.

The prototype demonstrated the feasibility of cutting, shredding and baling long-stem cultivated woody crops in a single pass. The saw blades were chosen to achieve a neat and clean cut of stubble in order to minimize stump splintering, maintain plant health and favour rapid re-growth of plantations. However, in natural brush stands, the ground is often not level and can be scattered with rocks; such conditions make it difficult to maintain sharpness of horizontal saw blades. The header was further modified to make it suitable to remove natural stands growing on uneven and rocky terrain.

The objective of this paper is to briefly describe header modifications, to report an original application for the removal of natural woody crops in the Saskatchewan prairie and to determine the productivity of the bio-baler on willow rings.

METHODS

Modified header to harvest shrubs

A new header was designed and adapted to the original baler. The original saw blades and shredder in front of the baler were replaced by a 2.30 m wide rotor and 20 flail hammers with a cutting edge attached to a 200 mm diameter rotor. Each flail cutter had a mass of 1.7 kg; it extended to a length of 150 mm beyond the rotor surface. The rotor turned at 2200 rpm and the peripheral speed of flails was 58 m/s. Figures 1 and 2 illustrate schematically the original header and the new header. The new header and the full prototype are described in more detail by Savoie et al. (2009).

Experimental site

Two sites of natural willow rings were identified in Indian Head, Saskatchewan. Figure 3 shows an aerial photography of site 1, which is located at latitude 50.4674°N and longitude 103.7098°W. The soil is an Oxbow loam covered mainly by a mix of two natural willows, *Salix bebbiana* Sarg. and *S. petiolaris* Sm. Site 2 is located at latitude 50.5074°N and longitude 103.7043°W; its soil is an Oxbow clay loam covered predominantly by *S. bebbiana*.

Prior to harvest, the number of stems per unit area was estimated at each site over five random transects. Stems were counted on each transect 1 m wide by a distance from the outer edge to the inner edge of the ring (about 5 m for site 1 and 3 m for site 2). Stem diameter was measured with a caliper at waist height (1 m above the ground); this



Fig. 1. Original four-saw cutter head developed to harvest willow plantations on level land.

height was a compromise between diameter measured at breast height (1.37 m) typical for large trees (Burns and Honkala 1990) and diameter measured at the base (0.1 m above the ground) when stems are pre-cut (Labrecque and Teodorescu 2003).

The willow rings were cut at about 100 mm above the ground and baled with the prototype bio-baler developed and described by Savoie et al. (2009) using the shredder cutter head (Fig. 2). The prototype was operated by a Case International 7110 tractor (97 kW). The time to harvest each bale was clocked (± 1 s) to estimate harvest rate; the

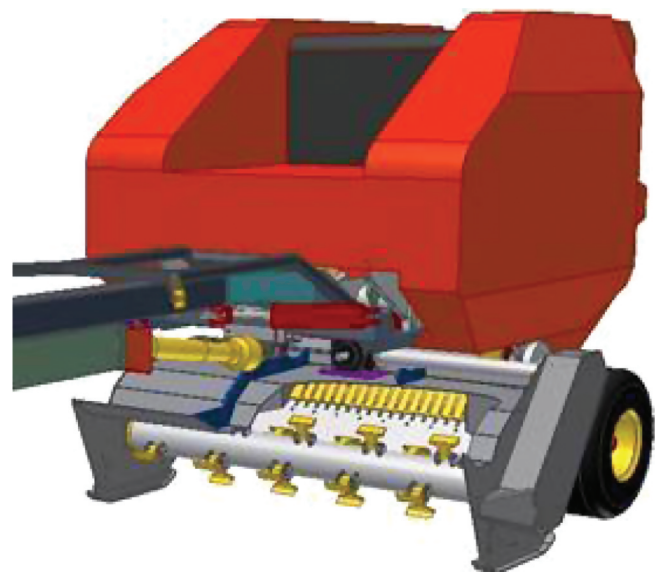


Fig. 2. Second shredder cutter head developed to harvest natural vegetation (such as willow rings) on rough terrain.



Fig. 3. Aerial photograph of willow ring at site 1 in Indian Head, SK.

time to wrap bales, travel without harvesting or idle was not included in harvest time.

Bale mass and loss measurements

Each bale was weighed on a platform scale (1000 kg full range; precision ± 0.2 kg). During harvest, samples of about 300 g of freshly cut willow corresponding to each bale were collected. They were placed in a drying oven at 103°C for at least 72 h, until constant weight was measured, to estimate moisture content. The method is similar to measuring moisture in forages (American Society of Agricultural and Biological Engineers 2006), but it requires more time (typically 24 h for forages) because of the slow diffusion of moisture from woody crops.

The bale chamber of the prototype produced round bales of 1.22 m width and variable diameter. The diameter was set at 1.35 m. The willow ring at site 1 was harvested on October 24, 2007. Site 2 was harvested the following day.

After harvest, five 1-m² plots were selected randomly at each site to estimate loss. All residual woody material on each plot was collected in a bag, weighed and oven dried. The DM loss was estimated by excluding the highest and the lowest values collected, and averaging the other values. The estimated loss was extrapolated to total harvested surface and added to harvested yield to estimate total yield. The harvested area on each site was measured by taking several GPS coordinate measurements and calculating the surface covered by the prototype bio-baler. Recovered biomass was the ratio of harvested yield over total estimated yield.

RESULTS and DISCUSSION

Figure 4 shows standing willow stems prior to harvest. Pre-harvest characteristics are reported in Table 1. Stems were more mature on site 1 as reflected by the larger average diameter measured at waist height (17 mm) than



Fig. 4. Stools of natural willow (*Salix bebbiana*) before harvesting.

on site 2 (12 mm). Stems were also taller on site 1 (5.3 m) than on site 2 (2.9 m). Stem density was similar on both sites (14 to 15 stems/m²). The width of the willow ring is the distance from the outer edge to the inner edge; it averaged 4.8 m for site 1 and 3.0 m for site 2. An estimate of pre-harvest yield was not done because of the large variability in willow density around the ring. In addition, there were large quantities of aquatic plants (*Typha latifolia*), sedges (*Carex* sp.) and grasses (*Beckmannia syzigachne*, *Agropyron repens*) interspersed with the willow especially on site 2 near the inner edge of the marsh.

Figure 5 shows the residual stems after harvest. The stems were typically splintered because of the rough cutting edge of shredder hammers. This is not a problem in natural brush stands which usually regrow vigorously after cutting. However, in plantations where regular regrowth is expected, a sharp and clean cut is preferred. For this reason, the original saw-blade cutter (Fig. 1; Lavoie et al. 2008) may be more appropriate in plantations. Figure 6 shows the operation of the bio-baler in an actual willow ring (site 1).

Table 1. Pre-harvest characteristics of willow rings at two sites in Indian Head, SK.

| Variable | Site 1 | Site 2 |
|---|--------|--------|
| Average stem diameter at 1 m height (mm) | 16.7 | 11.8 |
| Standard deviation of stem diameter (mm) | 9.0 | 6.8 |
| Average height of stems (m) ¹ | 5.3 | 2.9 |
| Total transect area sampled (m ²) | 24.1 | 14.8 |
| Number of stems | 344 | 225 |
| Stems/m ² | 14.3 | 15.2 |
| Average width of ring (m) | 4.8 | 3.0 |

¹Height of stems was measured three times on site 1 and five times on site 2.



Fig. 5. Splintered stems after passage of bio-baler using the shredder cutter head.

Table 2 reports the harvested quantities, the rate of harvest, the moisture content at the time of harvest and the dry matter (DM) recovered. Bales were heavier at site 1 (347 kg) than at site 2 (251 kg). This is explained in a large part by the abundant herbaceous biomass (aquatic plants, sedges and grass) on site 2, which was mixed with the willow and reduced total bale weight. Bale density was 28% less at site 2 than at site 1 because of the grass. The proportion of grass versus woody crop was not measured, but could be assessed in future trials to validate the observation of lower density in the presence of more herbaceous crop. Harvest capacity was greater at site 1 (6.6 t/h) than at site 2 (3.5 t/h). The total quantity of biomass harvested was greater at site 1 (1858 kg DM) than at site 2 (864 kg DM).

Biomass from willow rings could be used as a renewable combustible fuel. Natural willow has been reported to have a calorific value of 19.6 MJ/kg DM (Schroeder et al. 2009). This value is theoretically reduced to 15.1 MJ/kg at 20% moisture and 10.8 MJ/kg at 40% moisture, typical of harvest conditions. However, willow bales are expected to lose some moisture during storage because of natural ventilation which would improve the heat value.

After harvesting with the bio-baler, residual willow particles and branches left on the ground were hand



Fig. 6. Bio-baler harvesting a willow ring.

collected on five random plots of 1 m² at each site. Table 3 reports the estimated non-recovered biomass (or loss). The sum of the recovered biomass (harvested bales) and the non-recovered biomass (loss estimated by sampling) represent the total yield: 43 t DM/ha on site 1 and 11 t DM/ha on site 2. At both sites, the percentage of recovery was similar and averaged 62%. Consequently, 38% of the biomass was left on the ground. This organic matter can have several environmental benefits such as moisture retention, a natural soil nutrient after decomposition and wildlife habitat protection. However, this loss is currently not well controlled. Future engineering development of the bio-baler are expected to improve stem cutting and mass flow inside the bale chamber so the percentage of biomass recovery and the percentage left on the ground are adjusted more precisely to desired levels.

The harvest capacity of the bio-baler was less in natural willow rings (4 to 7 t/h) than values reported previously in willow plantations (8 to 12 t/h, Lavoie et al. 2008). This is partially explained by the rougher terrain of natural vegetation. Harvest capacity is also related to yield, as presented by results from willow rings. At site 1, harvest capacity was 7 t/h in an area yielding 43 t DM/ha whereas at site 2, harvest capacity was 4 t/h and yield was 11 t DM/ha. The bio-baler had to travel more to fill the bale chamber. Similar results have been observed in poplar

Table 2. Bale density, field capacity and harvested biomass from the willow rings.

| Variable | Site 1 | | Site 2 | |
|---------------------------------------|------------------|--------------------|------------------|--------------------|
| | Average or total | Standard deviation | Average or total | Standard deviation |
| Harvested area (m ²) | 690 | | 1280 | |
| Number of bales harvested | 9 | | 6 | |
| Wet mass per bale (kg) | 346.6 | 23.5 | 251.2 | 20.9 |
| Wet bale density (kg/m ³) | 198.5 | 13.4 | 143.8 | 12.0 |
| Harvest time per bale (s) | 189 | 52 | 256 | 87 |
| Capacity (t wet/h) | 6.61 | 1.82 | 3.53 | 1.25 |
| Moisture content (%) | 40.4 | 1.7 | 42.7 | 2.1 |
| Biomass harvested (kg DM) | 1858 | | 864 | |
| Yield recovery (t DM/ha) | 26.9 | | 6.7 | |

Table 3. Estimation of harvest loss and biomass recovery.

| Variable | Site 1 | | Site 2 | |
|-----------------------------------|------------------|--------------------|------------------|--------------------|
| | Average or total | Standard deviation | Average or total | Standard deviation |
| Loss measured (g/m ²) | 2640 | 286 | 710 | 226 |
| Moisture content (%) | 40.5 | 1.1 | 39.6 | 3.3 |
| Yield loss (t DM/ha) | 15.7 | | 4.3 | |
| Estimated total yield (t DM/ha) | 42.6 | | 11.0 | |
| Percentage recovery (%) | 63.2 | | 61.2 | |

plantations harvested with SP forage harvesters, where higher yields generally resulted in higher capacity and lower operating costs (Spinelli et al. 2009).

The prototype was designed with a heavy frame and robust components to work in rough conditions. A commercial version was further reinforced, and weighs 6070 kg (Anderson Group 2010). This large weight may limit operation on wetlands. Harvest during the dry season and selection of large tires may increase the number of available working days of the bio-baler.

CONCLUSION

An experimental bio-baler successfully cut and baled natural willow in a single operation. Willow rings were cleared with a recovery of 62% of the original biomass. Harvest rate was between 4 and 7 t/h (fresh weight). The bio-baler could improve land management in areas where natural shrubs slowly invade agricultural fields.

The management of willow rings in prairie 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. The prototype bio-baler is a new tool which can potentially improve the overall management of these ecosystems.

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