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Ellerslie Short-Rotation Woody Crops Technical Development Site, Edmonton, Alberta

A Compendium of Operational Research

Tim Keddy[1], Derek Sidders[1] and Carmela Arevalo[2]
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[2] BC Ministry of Forests, Lands and Natural Resource Operations

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The Canadian Wood Fibre Centre brings together forest sector researchers to develop solutions for the Canadian forest sector's wood fibre related industries in an environmentally responsible manner. Its mission is to create innovative knowledge to expand the economic opportunities for the forest sector to benefit from Canadian wood fibre. Part of the Canadian Wood Fibre Centre's mandate is to work closely with FPInnovations and other stakeholders in the development and uptake of end-user relevant wood fibre research.

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Abstract

The Ellerslie Short Rotation Woody Crops (SRWC) Technical Development Site provided a unique opportunity to evaluate (from establishment to end-user) growth and yield, physical and chemical characterization, carbon sequestration, and economics associated with high-yield afforestation (hybrid poplar and aspen). It also helped with the evaluation of concentrated afforestation (willow and hybrid poplar) plantations in Canada. The 101 operational research trials established from 2002 to 2019 provided the infrastructure and research data to evaluate carbon sequestration potential and for the creation of knowledge transfer products, including SRWC establishment and management protocols, peer-reviewed publications, and educational tours.

Full rotation growth and yield and harvesting productivity analysis identified that High Yield Afforestation plantations resulted in positive return of investment. The 15-year growth of the Forest 2020 Plantation Demonstration and Assessment Initiative plantation averaged 14.12 m^3 ha^{-1} yr^{1}, which resulted in an average net increase of 21.4 tonnes of CO_2 eq per hectare per year. Post harvest sampling identified that 42.42% of the sequestered carbon remained on-site in the form of increased soil carbon (13.59%), residues (4.44%), litter (8.49%) and stumps and roots (15.89%), following the harvesting of logs for pulp (47.91%) and processing of roadside residues (9.67%) for woody biomass.

The development and validation of SRWC establishment and management protocols, clonal suitability and afforestation site suitability models resulting from the operational research at Ellerslie provide a suite of tools for the implementation of a large scale afforestation program in Canada.

Background Information

The Ellerslie Short Rotation Woody Crops (SRWC) Technical Development Site (Figure 1) in Edmonton, Alberta, was established in 2002 by the Canadian Forest Service. The 18-ha site (Figure 2), leased from the University of Alberta, was the first of over 150 Technical Development sites (1,950 ha of afforestation and 37 ha of concentrated biomass plantations) established and monitored by the CWFC in various geo-climatic zones across Canada. The site was established to assess the biophysical and economic potential of the development of renewable and sustainable fast growing, highly productive woody biomass plantations for bioenergy and bio-products. The Ellerslie Technical Development Site is the basis for many SRWC protocols being used in woody biomass and remediation programs. Canada-wide efforts were linked through government initiatives. These initiatives include NRCAN's Forest 2020 Plantation Development and Assessment Initiative, Canadian Biomass Innovation Network (CBIN), Energy Technology Initiative (eco-ETI) and Clean Energy Fund (CEF). Over the last two decades, preliminary SRWC system designs and management regimes have been established and tested at the Ellerslie Site and demonstrated across a broad network of Canadian sites to evaluate site/species suitability.

Figure 1. Soil landscape polygon number 14356 of the agricultural region of Alberta soil inventory database where the Ellerslie SRWC Technical Development Site is located (marked in green).

Figure 2. Ellerslie Short-Rotation Wood Crops Technical Development Site, Edmonton, Alberta. First established in 2002 and harvested in 2018. High-yield afforestation plantations are indicated in yellow, concentrated biomass plantations in white, understory species in dash-lined blocks and stool beds in blue.

For this report, the authors identify Short Rotation Woody Crops (SRWC), also referred to as Wood Energy Crops (WEC), Short Rotation Intensive Culture (SRIC) or Purpose Grown Woody Crops, as a "silvicultural approach to establishing and managing fast growing plantations on previously cleared lands." SRWC are established as a means of rapidly producing fibre for use in the wood products industry. They are also used for energy and require appropriate site selection and preparation, suitable clonal planting stock, and intensive management to achieve high yields (8x native yields) over short rotations (3 to 20 years). For the purpose of clarity, the authors define the three most common types of SRWC plantations as high yield afforestation, mixedwood afforestation and concentrated woody biomass plantations.

High yield afforestation plantations (Figure 3) are grid style plantations of 1100 to 1600 stems per hectare of bio-geo-climatically suitable hybrid poplar and clonal aspen. They are designed to produce largely single stem, large diameter (25 cm +) trees in a single 12 to 20-year rotation. The plantations produce woody feedstocks with a high whitewood to bark ratio. These feedstocks can be used for carbon sequestration and to produce conventional forest products such as lumber, veneer and pulp, and woody biomass for energy production. They can also be used in the production of wood pellets, mulch and bio-char. In addition, high yield afforestation plantations, specifically those with hybrid poplar, are excellent "phytoremediators" that can take up harmful waste products from the soils and lock them away in their woody stems (https://www.treehugger.com/the-hybrid-poplar-1343352).

Mixedwood afforestation plantations (Figure 4) are adaptations of high yield afforestation plantations established to mimic naturally occurring mixedwood forests. By planting tolerant conifer seedlings to high yield afforestation plantations, in addition to increasing the production of woody feedstocks and product options associated with the high yield afforestation plantations, the plantations have the potential for long-term (60 to 90 years) carbon sequestration and creating uniformly spaced, large diameter conifer forests.

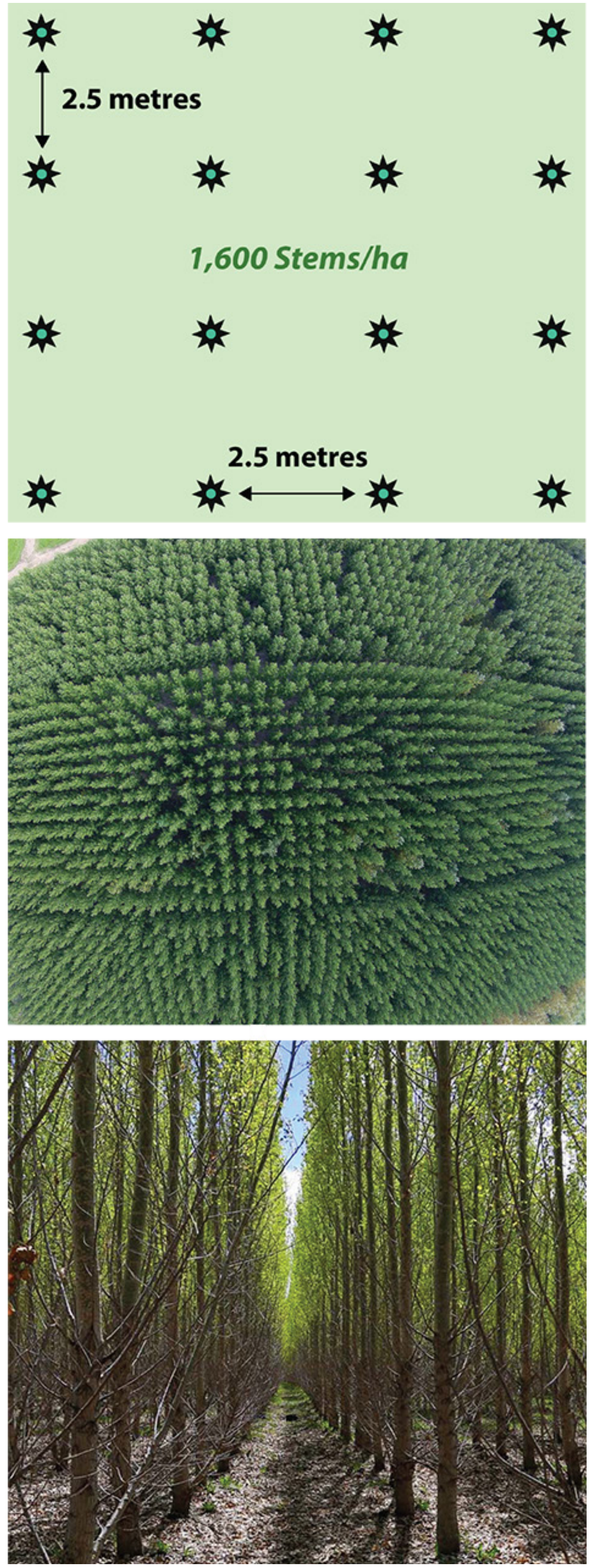


Figure 3. High yield afforestation examples at Ellerslie SRWC Technical Development Site.

Figure 4. Mixedwood afforestation examples at Ellerslie SRWC Technical Development Site.

Concentrated biomass plantations (Figure 5) are bed style plantations of 9000 to 16,000 stems per hectare of willow, hybrid poplar and clonal aspen designed to produce small diameter (< 10 cm) stems in multiple (up to seven) 3-year rotations. The plantations produce woody feedstocks, with a high bark to whitewood ratio that can be used to produce woody biomass for energy production or for use in the production of wood pellets, mulch and bio-char. These biomass crops can also be grown for phytoremediation purposes where plants utilize municipal effluents or biosolids originating from sewage treatment plants; as riparian buffer systems where crops are planted to regulate movement of materials in surface runoff and groundwater whilst providing biomass feedstock for bioenergy.

Figure 5. Concentrated biomass examples at Ellerslie SRWC Technical Development Site.

Site History

Prior to the initiation of the Ellerslie SRWC Technical Development Site in 2002, the area was managed as a portion of the University of Alberta Ellerslie Research Station (Figure 6). The southern portion of the Research Station was home to decades of various agricultural crop research trials. In 2001, Canadian Forest Service staff negotiated an agreement with the University of Alberta to lease a portion of the Ellerslie Research Station to conduct SRWC research.

Figure 6. Historic photo of Ellerslie Research Station. (Supplied by D. Puurveen).

In 2018-19, the site was harvested with funding received as part of the Forest Innovation Program supporting the forest bioeconomy. The objective of the project was to improve the economics and efficiency of logistics for the utilization of woody feedstock. Established and managed from 2002 through 2019 by the CWFC/CFS, the Ellerslie site presented a unique opportunity to evaluate (from establishment to end-user) growth and yield, physical and chemical characterization, carbon sequestration, economics associated with high-yield afforestation (hybrid poplar and aspen), and concentrated afforestation (willow and hybrid poplar) plantations in Canada.

The following summary outlines the operational research and demonstrations conducted at the Ellerslie SRWC Technical Development Site over its 18-year history.

Site Conditions

The site (53°24’39.93”N, 113°32’29.91”W) is located 694 metres above sea level with a mean annual (1981-2010) temperature of 2.6 °C and mean annual precipitation 446 mm (Figure 7), of which 24% falls as snow (Canada Environment and Climate Change 2017).

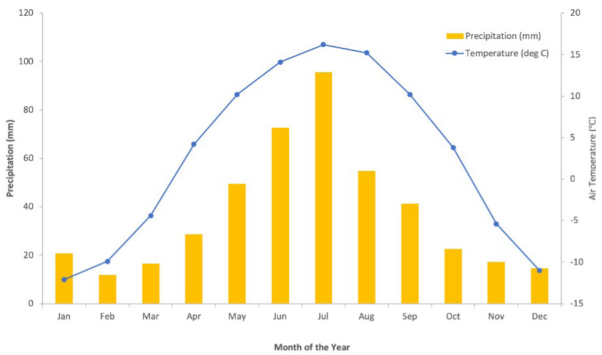


Figure 7. Historical (1981–2010) precipitation and air temperature at the Edmonton International Airport Weather Station which is approximately 11 km away from the Ellerslie SRWC Technical Demonstration Site.

Soil is classified as an Orthic Dark Gray Chernozem on very fine textured materials (not till) over medium textured till to an Eluviated Black Chernozem on fine textured water-laid sediments (Alberta Agriculture and Forestry 2018). It is undulating, with low relief landform and a limiting slope of 2%. Canada Land Inventory for agriculture classified the area as Site Class 1. These sites are generally described as having level to nearly level, deep, well drained soils. They are also known to be imperfectly drained and have good nutrient and water holding capacity. These types of sites can be managed and cropped without difficulty. Under good management they are moderately high to high in productivity for the full range of common field crops (Agriculture and Agri-Food Canada 2016). Pre-planting soil surveys performed specifically at Ellerslie showed the area as having a silty-clay-loam soil texture that drained moderately well, a pH of 6.4, EC of 0.7 and soil C pre-establishment of 78 Mg C ha^{-1}.

Operational Protocol Development Overview

A large portion of the operational research conducted during the early years of the Ellerslie SRWC Technical Development Site was focused on the development and testing of establishment regimes and protocols for SRWC. Proper site preparation is vital to the success of growing any type of agricultural crop. This is also true for the establishment of trees or shrubs on agricultural land since proper site preparation directly impacts the growth and achievable volume of planted trees. Initially, the focus was based on adapting proven technology and methodologies from the forest industry to create enhanced microsites for the planted material.

In 2002, a 3-phase site preparation tool developed by Technology Development Group of Specialists (Technology Development Group) of the Canadian Forest Service was assembled and tested. The 3-phase tool used "off-the-shelf" agricultural and silvicultural components. It incorporated a passive agriculture-based ripper shank, a PTO driven Soukone Meri-Crusher horizontal bed mixer and a passive bedding component (Figure 8). The tool, designed to attach to the 3-point hitch of an 80 to 100 hp farm tractor, was used to create a series of parallel, elevated mixed beds with areas between the beds remaining undisturbed.

Although the microsite created was advantageous for the planted material, post treatment assessments of the methodology identified multiple questions and concerns related to the selective nature of the treatment and the ability to conduct subsequent treatments efficiently. The three main concerns for the suitability of this type of site preparation for SRWC were:

1. The operational productivity of preparing larger areas was lower that anticipated, resulting in higher site preparation costs
2. The exposure of latent seed from the disturbed soils and the ability to control vegetation within the beds following the planting of fast-growing deciduous species resulted in higher than anticipated vegetation management costs
3. Reduced rooting potential and long-term growth impacts associated with selective site preparation on agricultural lands

Figure 8. 3-Phase site preparation tool developed and tested by the Canadian Forest Service.

To develop new options for establishing and managing SRWC in Canada, the Technical Development Group spent a considerable amount to effort in discussions and site visits with tree improvement specialists, agrologists and SRWC proponents across Canada and the northern United States (US). Evaluating the wide range of practices and subsequent growth provided the Technology Development Group with the information needed to develop "Made in Canada" establishment and management protocols for SRWC in Canada. The protocols developed for the establishment and management of High Yield Afforestation plantations in Canada involved four major operational activities: 1) Site Selection, 2) Site Preparation, 3) SRWC Design and Planting, and 4) Vegetation Management.

In 2004, the new protocols were implemented at the Ellerslie SRWC Technical Development Site (Ellerslie). These protocols were developed to incorporate broadcast site preparation techniques. This would create a suitable rooting environment with grid-style design for uniform spacing, nutrient utilization and cost effective, aggressive vegetation management components. The same protocols, relatively unchanged, were used for the establishment and management of all SRWC plantations and operational research trials established at Ellerslie post 2003.

Site Preparation

At Ellerslie, three key components to prepare each treatment site were taken into consideration to: 1) ensure a suitable rooting environment; 2) facilitate future treatments and 3) initiate a site vegetation management program. Depending on the status of the planting area (soil texture, structure, drainage, hardpan depth), the schedule for the completion of these three components may have been altered.

Deep Mixing

SRWC plantations require a suitable rooting environment of 25 to 30 cm. Therefore, site preparation plans at Ellerslie involved the use of proper equipment and methodologies that incorporated the goal of deep mixing. As agricultural sites usually have a compacted soil layer or "hardpan" that will inhibit the rooting ability of the seedlings, deep mixing completed using agricultural equipment (Figure 9) is intended to penetrate and destroy this hardpan so that the trees can push their roots deeper into the soil. By extending their roots deeper into the soil, the trees will be better prepared to deal with the effects of periodic climatic events such as drought and flooding.

Since Ellerslie has a history of annual cropping regimes that created a compacted layer at a soil depth of 10 to 15 cm and an established stubble layer, site preparation operations were completed prior to planting, either in the summer or fall prior to the year of planting or the spring of the year of planting. Regardless of the scheduling during the year prior to planting, the goals of the initial treatments for these treatment sites were the same and were achieved through discing. These discs usually had a maximum width of 4.3 m (14 ft), with large 90 cm (36 in) discs and that were equipped with extensive down force capabilities. The sites were disced in multiple directions to ensure a consistent mixing depth of soils. Subsequent passes were completed perpendicular or diagonal to the initial discing treatment. This multiple pass deep mixing treatment created a crudely mixed soil layer 25 to 30 cm in depth. This enhanced the rooting ability of the planted trees.

Figure 9. Example of equipment used for conducting deep mixing treatments.

Shallow Mixing

The completion of the deep mixing treatments commonly leaves the site uneven, which limits the ability and speed of equipment to travel. It also limits the consistency of subsequent treatments. To deal with these site inconsistencies and to create a finer soil mixture in the top 10 to 15 cm, a shallow discing was completed as a levelling treatment using field discs, shallow cultivators, or harrows (Figure 10). The levelling treatment was completed prior to planting to combine the shallow mixing and pre-planting vegetation management treatments. This was done to reduce costs and ensure that all vegetation was incorporated into the soils prior to planting. The treatment resulted in a consistent and level site ready for the start of site layout and planting operations.

Figure 10. Example of equipment used for conducting shallow mixing treatments.

Site Design and Planting

Designing a suitable site design for SRWC plantations creates the framework for all subsequent operations. It is important to realize that failure to incorporate all facets of plantation management into the site design could potentially create problems and delays throughout the life of the plantation. Site designs and layouts at Ellerslie incorporated the following components:

1) good access;

Good access means incorporating adequate buffers around the perimeter of each treatment site to allow for easy access to portions of the plantations for the purpose of planting, managing and conducting harvest operations.

2) suitable buffers;

Suitable buffers were required to allow equipment to move unhindered around the perimeter of the planted blocks. Along the headlands of each planting block a buffer of 15 m was installed to allow for the positioning and turning of equipment during the completion of operations. Along the sides of the planted area adjacent to the outside beds, a buffer of 10 m was required to allow for the turning of equipment during management operations.

3) multiple species/clones each in individual species/clone block plantings.

To reduce the risks associated with outbreaks of insects, disease and/or pests, Ellerslie incorporated multiple species or clones. Because various clones grow differently, it was important to manage each clone individually based on their growing traits. To facilitate clonal management, each clone was planted individually in a block with the overall site design incorporating buffers between clones.

Planting Operations

Establishing afforestation plantations is an expensive endeavour. The largest portion of these costs is the planting stock and the planting itself. Due to this high cost, it is paramount the planting operations be well designed and carefully implemented. The implementation process can be divided into 3 separate operations: 1) planting design and site marking; 2) stock types and preparation; and 3) planting methodology.

Planting Design and Site Marking

The goal for any plantation design is to ensure an even distribution of stems over the entire area so that each tree can take advantage of the site resources equally. The design must also take operational factors into consideration. For example, the design must incorporate access to equipment for management operations and harvesting operations. At Ellerslie, high yield afforestation plantations were mechanically marked at a spacing of 2.5 m x 2.5 m (1600 stems per hectare) to ensure uniform spacing and rooted hybrid poplar seedlings were manually planted at designated locations (Figure 11).

Figure 11. High yield afforestation establishment protocol overview.

The uniform spacing between rows and between trees within rows allows for multi-directional management operations while enabling the trees to share site resources equally. Consistent spacing is vital. Care must be taken to ensure that all trees are planted in a parallel manner with consistent spacing. This ensures that the subsequent management treatments do not result in the damage or destruction of the planted stems. To accomplish this uniformity on the sites, it is recommended that the sites be “mechanically marked” prior to the initiation of any planting operations.

Site marking is completed so that the planting crews are aware of where the trees are to be planted. By pre-marking the site, the planting operations can be completed in a timely manner without interruptions.

At Ellerslie, marking was completed using a tractor equipped with a specially designed marker or an adapted cultivator/harrow where only required tines enter the soil. For high-yield afforestation trials, the entire site was marked using a two-stage process. The initial stage of the process was completed by operating in a north-south direction, creating parallel marks in the soil at the desired spacing. The second stage of the process was completed by operating in an east-west direction, also creating parallel marks in the soil at the desired spacing. This two-stage system created a grid pattern (Figure 12) over the entire site with the desired planting spots being identified where the marks intersected.

Figure 12. Example of a mechanical marking grid pattern created for high yield afforestation trials.

In 2005, as the interest around the potential of developing a renewable woody biomass feedstock option without the 12 to 20-year lag time associated with high yield afforestation, the Technology Development Group began operational research in concentrated biomass at Ellerslie. Site preparation protocols were consistent with the high yield afforestation plantations. To evaluate the various options associated with establishment designs for concentrated biomass plantations, trials were established between 2005 and 2007 to evaluate the operational characteristics associated with establishing and managing single row, 2 and 3 row bed concentrated biomass designs (Figure 13). Design layouts were completed either through manual or mechanical marking methods depending on the trial size and equipment availability.

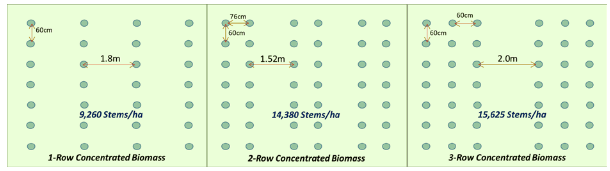


Figure 13. Concentrated biomass designs evaluated at Ellerslie SRWC Technical Demonstration Site.

Stock Types and Preparation

SRWC operational research trials at Ellerslie were established using various types of unrooted (25 cm cuttings and 2 to 3 m whips) and rooted (bareroot and container seedlings) planting material.

Unrooted planting material (cuttings and whips) used for SRWC plantations was obtained using vegetative propagation techniques. This involved harvesting the 1-year old growth from pre-established stoolbeds and processing the harvested material to the desired lengths (Figure 14). The harvesting of vegetative propagation material was completed between following bud set the year before planting and the thawing of soils during the year of planting (November to March). These materials were kept frozen until planting operations were confirmed to start. Prior to planting, the cuttings were conditioned (soaked at room temperature) to ensure they were fully hydrated and ready to grow once planted. Depending on the clone, cuttings were soaked between 24 to 48 hours prior to planting.

Figure 14. Example of unrooted cuttings (25 cm) resulting from vegetative propagation.

Bareroot and container seedlings (Figure 15) used for SRWC operational research trials at Ellerslie were grown at the Canadian Forest Service greenhouse at the Northern Forestry Centre (NoFC) in Edmonton or purchased from proven service suppliers across Canada and the US. Bareroot seedlings were grown in outdoor, shallow rooting nursery beds from small (15 cm) hybrid poplar cuttings or small hybrid aspen transplants. Container seedlings were grown in nursery greenhouses from small (10 cm) hybrid poplar cuttings, aspen root cuttings or hybrid aspen and conifer seeds. These seedlings were grown for a full growing season. They were then harvested in the fall and stored in their frozen state at a temperature of -3 to -5 °C over the winter in preparation for spring planting. Rooted seedlings, although costlier, were used for high yield afforestation trials because they were hardier than cuttings and more capable of withstanding post-planting drought conditions. This reduced the risks of mortality associated with using this stock type for establishing afforestation plantations.

Figure 15. Example of bareroot (Left) and container (Right) rooted planting material.

In preparation for planting, the trees were taken from the freezer and stored in a shaded location with a constant temperature between 3 to 8 °C for three days. This allowed the seedlings to thaw slowly.

Operational research trials conducted in the lab at NoFC identified that hybrid poplar container seedlings require a minimum of 28 days in freezer storage at -3 to -5 °C prior to thawing for consistent seedling dormancy. Once thawed, the root portions of the bareroot seedlings were immersed in water at ambient temperature, for 12 to 18 hours prior to planting. The container seedlings were watered to ensure that the roots were kept moist and free from drought stress, in a shaded location in close proximity to the planting site.

Planting Methodology

Planting operations at Ellerslie were completed early on in the spring, once the soil conditions were acceptable. Activities were coordinated to take advantage of the relatively short window of opportunity to complete planting. For unrooted cuttings, soil temperatures were required to reach 12 °C at 15 cm depth before planting operations were initiated. For all high yield plantations, manual planting was required to ensure proper planting location (Figure 16). When soil conditions were met, 25 cm cuttings were planted with a minimum of 20 cm in the soil and 3 to 5 cm remaining above the ground, with the top bud of the cutting being just above or level with the top of the soil. Cuttings were planted by first creating a suitable opening with a shovel or dibble. Then the cutting was placed at the proper depth and the soil was lightly compacted around the cutting to ensure no air pockets were present below the surface. Extra care was taken during planting operations to ensure the cuttings were not “pushed” into the soil. This “pushing” into the soil can damage the tender buds and bark of the cutting, resulting in mortality.

Figure 16. Manual planting of high yield afforestation operational research trials.

For concentrated biomass in energy plantations, the 25 cm cuttings were also planted. However, mechanical planting was employed on a number of operational research trials to ensure productivity (ability to plant in excess of 5000 cuttings per hour). Reduction of planting costs for the operations was achieved. At Ellerslie, the CWFC tested and operationally employed a Nursery Stock Transplanter (Mechanical Transplanter, Michigan, US) to establish concentrated biomass plantations using 1-row, 2-row and 3-row designs (Figure 17). The Mechanical Transplanter was designed to transplant small seedlings for fruit and vegetable production. It consisted of independent transplanters attached to a drawbar which was then attached via a 3-point hitch to a minimum 50 hp tractor. For the CWFC operations, a three-row transplanter configuration was used to plant 25 cm willow and hybrid poplar cuttings in parallel rows at the desired spacing, approximately 60 cm between trees within the rows. The transplanters used for the operational trials were equipped with deep, 25 cm planting shoes to facilitate the planting of long cuttings. A short-term operational trial conducted at Ellerslie identified that unrooted planted material required planting operations to be completed prior to the second week of July to allow for proper root development and ensure over-winter survival.

Figure 17. Mechanical transplanter configurations for 1, 2 and 3 row bed designs for the concentrated biomass plantation establishment.

For manual planting of rooted planting material, soil temperatures of 8 to 10 °C at 15 cm depth were required before planting operations could begin. When soil conditions were met, seedlings were planted at a depth with a minimum of 2 to 3 cm and a maximum of 5 to 7 cm of soil on top of the container and all roots. The tree seedlings were planted by creating a suitable opening with a shovel. Then the rooted portion of the tree was placed vertically in the hole at the required depth and the soil was lightly compacted atop the roots or container.

Planting operations were stopped once soil temperatures reached 20 °C at a depth of 15 cm. This gave a relatively short window of opportunity to complete planting. Therefore, it was vital that the planting operations were well coordinated.

Vegetation Management

Site preparation treatments completed on agricultural lands increase the risk of exposing latent seeds to resources needed to germinate. Consequently, a flush of competing vegetation following planting activities must be dealt with in an aggressive manner. Proper vegetation management of SRWC plantations and operational research trials is vital to the success and collection of relevant data. Operational research trials were conducted at Ellerslie to evaluate chemical, mechanical and manual post-planting vegetation management treatments.

During the 2002-03 operating seasons at Ellersie, chemical vegetation management options were used to manage post-planting competing vegetation. Operational trials were established using shrouded, zero drift implements, such as the Enviromist (Figure 18), to reduce the risk of mortality to the planted material. Glyphosate applications were initially used on an as-needed basis. This practice had limited success in controlling all competing vegetation species. This resulted in the adoption of mechanical vegetation treatments on an as-needed basis to augment the chemical treatments. In addition to contact-based herbicides, operational pre-emergent herbicide trials were also conducted. The application of pre-emergent herbicides immediately followed planting to control competing vegetation. This practice also had limited success in controlling all competing vegetation species and resulted in the adoption of mechanical vegetation treatments.

Figure 18. Enviromist shrouded herbicide sprayer.

The limited success, cost prohibitive nature of chemical vegetation management treatments, and the requirement of mechanical vegetation management treatments to adequately control competing vegetation prompted the Technical Development Group to create a cost effective, mechanical vegetation management only protocol for SRWC plantations.

Starting in 2004, all operational trials (including previously established trials) at Ellerslie included a mechanical vegetation management component. The objective of mechanical vegetation management treatments at Ellerslie was to ensure that competing vegetation was dealt with in a timely manner starting 10-14 days following planting and continuing until the first frost in the fall of each year. Equipment used at Ellerslie for high yield afforestation plantations consisted of small tractors (30 to 40 hp) equipped with either passive (shallow cultivator or rotary harrow) or PTO-driven (rotary harrow or tiller) attachments (Figure 19). To ensure that the treatments minimized damage to establishing root systems, all equipment was configured to ensure a maximum disturbance depth limited to 3 to 7 cm. This treatment was usually required 4 to 5 times during the first two or three years of the plantation. It was then reduced to 2 to 3 times per year for the next 3 years or until the site reached crown closure. The grid style layout of afforestation plantations permitted vegetation management operations to be completed in multiple directions.

Figure 19. High yield afforestation mechanical vegetation management equipment.

As with afforestation plantations, mechanical vegetation management operations for concentrated biomass plantations usually began within 10 to 14 days following planting and continued on an "as needed" basis until the first frost in the fall. As concentrated biomass plantations grew, the need for vegetation management treatments varied between the multi-row beds and the area separating the beds. Equipment used at Ellerslie for concentrated biomass plantations consisted of small tractors (30 to 40 hp) equipped with PTO-driven (rotary harrow or tiller) attachments for between the beds and a multi-row tilling attachment for between the rows within the beds (Figure 20). The use of "off-the-shelf" attachments for conducting vegetation management treatments was pre-designed by the Technical Development Group to ensure that the operations tested and proven could be easily adopted by SRWC end users. As the beds began to crown close (occurred usually during the second growing season), the vegetation management treatments required for these areas were reduced and most of the treatments were limited to areas between the beds.

Figure 20. Concentrated biomass mechanical vegetation management equipment.

In the beginning of concentrated biomass operational research trials in 2005–06, a lot of effort (time and financial resources), was used in removing the remaining competing vegetation growing between trees within rows of the concentrated biomass beds. This required delicate management and was limited to manual applications. These applications may have included hand-weeding, hoeing or manual tilling with a small garden tiller. These applications were very time consuming and expensive. The benefits were not easily identifiable. Following the 2006 operating season, these treatments were not used at Ellerslie and they were deemed not feasible on larger plantations.

Species and Clones Planted at Ellerslie

In Canada, afforestation and concentrated biomass plantations consist of various hybrids and clones of poplar, aspen or willow. Depending on location, climate and site characteristics, vegetation requirements may also vary. To identify the best performing selections for Ellerslie, the Technology Development Group tested 19 hybrid poplars, 17 improved aspen clones and 32 willow cultivars (Appendix I). They also tested 3 understory softwood tree species, including white spruce (*picea glauca* (Moench) Voss.), black spruce (*picea mariana*) and douglas fir (*pseudotsuga menziesii* var. *menziesii*).

Treatment Trials Established

Since 2002, a variety of treatment trials were established at Ellerslie to test different operational opportunities (Figure 21). These research trials ranged from inter-planting mixedwood species with and under afforestation plantations, testing unrooted hybrid poplar whips as an alternative planting stock, to experimenting on management and vegetation intensities on various clonal trials. Appendix III outlines the 101 various high-yield afforestation and concentrated biomass plantation trials conducted at Ellerslie, their year of establishment and corresponding location.

Figure 21. Ellerslie Short-Rotation Wood Crops Technical Development Site, Edmonton, Alberta. First established in 2002 and harvested in 2018. High-yield afforestation plantations are indicated in yellow, concentrated biomass plantations in white, understory species in dash-lined blocks and stool beds in blue. See Appendix I for corresponding hybrids and clones tested; Appendices II and III for corresponding operational research trials and Figure 61 for the lay-out of the SUNY willow clonal trial (Block No. 69) established on site.

High Yield Afforestation Plantation Assessments

Sampling procedures for the high yield afforestation operational research sites at Ellerslie followed the guidelines established under the Measuring and Monitoring Protocols for Afforestation designed under the Feasibility Assessment of Afforestation for Carbon Sequestration (FAACS) Initiative (Hall et al., 2004). This procedure used a systematic pattern to install circular 100 m^2 plots (5.64 m radius) in clusters comprising of one centre plot. A cluster of plots were then evenly distributed from the central plot, in cardinal directions at 50 m intervals, centre to centre. The total number of plots was based on the size and shape of the stratified field or plantation block. Figure 22 identifies the plot locations sampled in the high yield afforestation strata at Ellerslie. Centre plots were predetermined points located close to the centre of the plantation block, tied-in with a distance and bearing from a physical feature on the site. As per protocol instructions, the Centre Plot was identified as the actual planted tree location closest to the centre of the stratified field or plantation block. All additional plots contained in the cluster used the actual tree planted location closest to the 50 m interval as the plot centres.

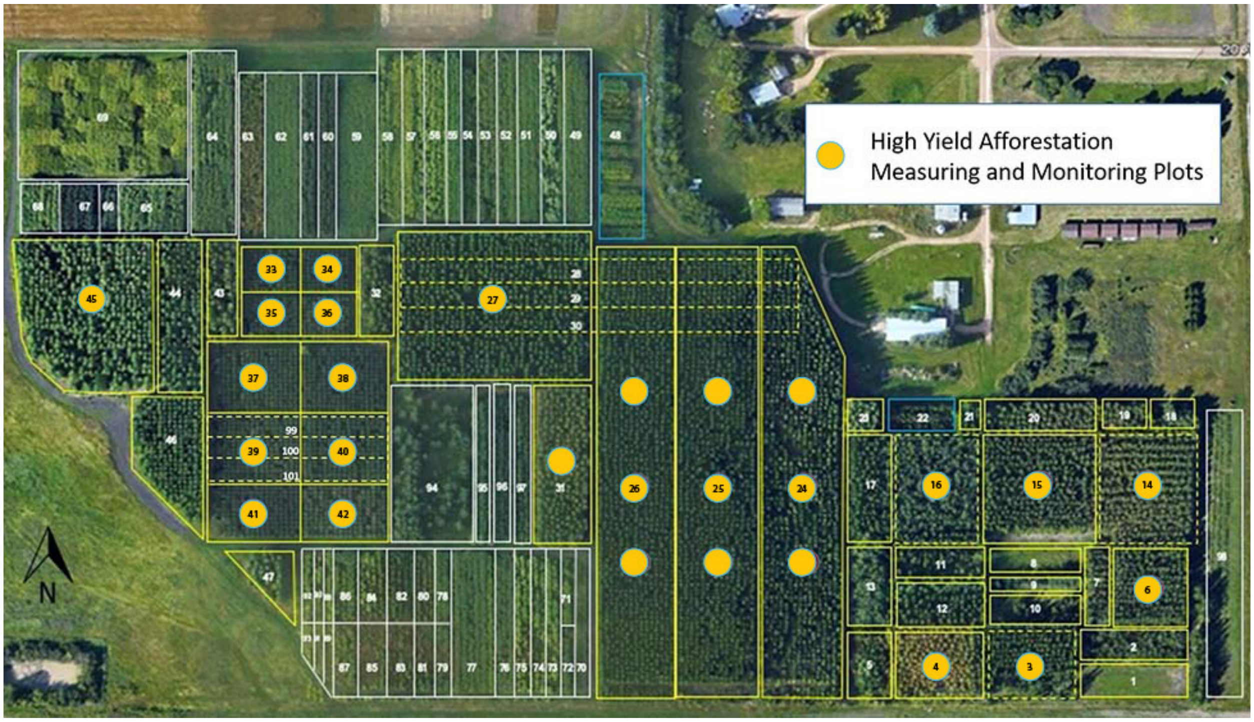


Figure 22. High yield afforestation sampling plots established at Ellerslie SRWC Technical Development Site.

Parameters and Calculations

Trees within sampling plots were assessed for various parameters. At every assessment period, living and dead/unhealthy trees within the plots were assessed for health. They were measured for total height and root collar diameter (RCD) or diameter at breast height (DBH). On selected years and plantation blocks, soil samples were also obtained to determine soil conditions and track ecosystem carbon changes over time. Sampling data was then used to calculate for various performance parameters using the equations outlined in Appendix IV.

Periodic monitoring of the high-yield afforestation sites was completed with the main objective of evaluating the clonal suitability and growth and yield potential of various hybrid poplar and aspen clones. The clones were intended for use in a national afforestation program for augmenting woody biomass supply and carbon sequestration. The secondary goals included developing site suitability indices for developing and validating growth models, validating, dispelling and refining establishment and management protocols, and evaluating physical and chemical woody biomass characteristics. Figure 22 showcases the growth trajectories realized by each of the high yield afforestation trials in relation to the Site Suitability Index (SSI) or estimated hybrid poplar growth trajectory for the Ellerslie SRWC Technical Development Site (Joss et al., 2008). For trials established in 2002, the 16-year DBH growth was largest in the Green Giant clone with an average of 17.4 cm. The height growth and volume growth was largest in the Walker clone at 18.5 m and 258.95 m^{3-ha}, respectively. For trials established in 2004, the 14-year DBH growth was largest in the Assiniboine clone, with an average of 15.5 cm. The height growth was largest in the Walker clone at 19.0 m and volume growth was largest in the Assiniboine clone at 268.32 m^{3-ha}. For trials established in 2005, the 13-year DBH growth was largest in the Brooks 1 clone with an average of 13.9 cm. The height growth and volume growth was largest in the Northwest clone at 17.1 m and 209.06 m^{3-ha}, respectively.

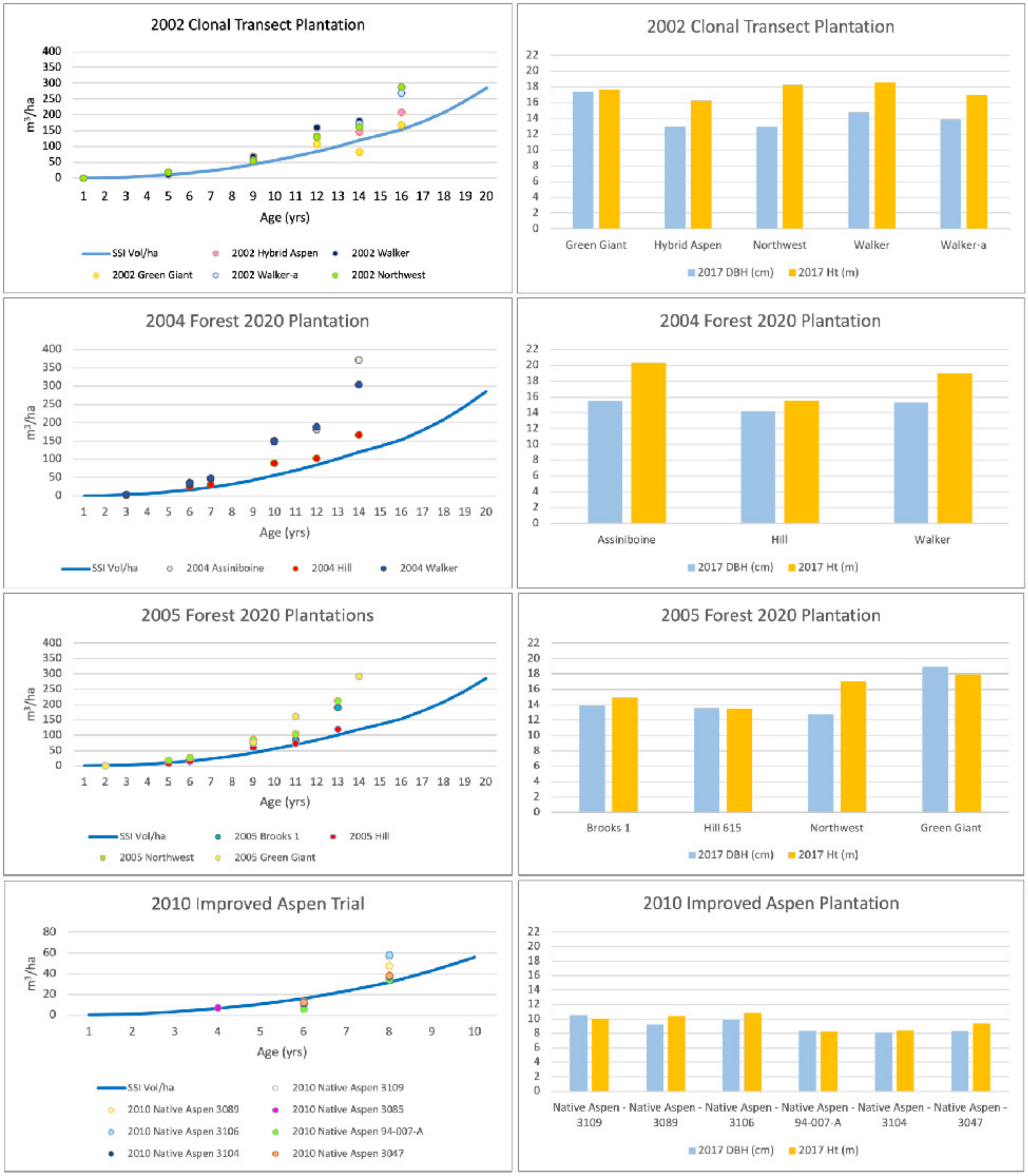
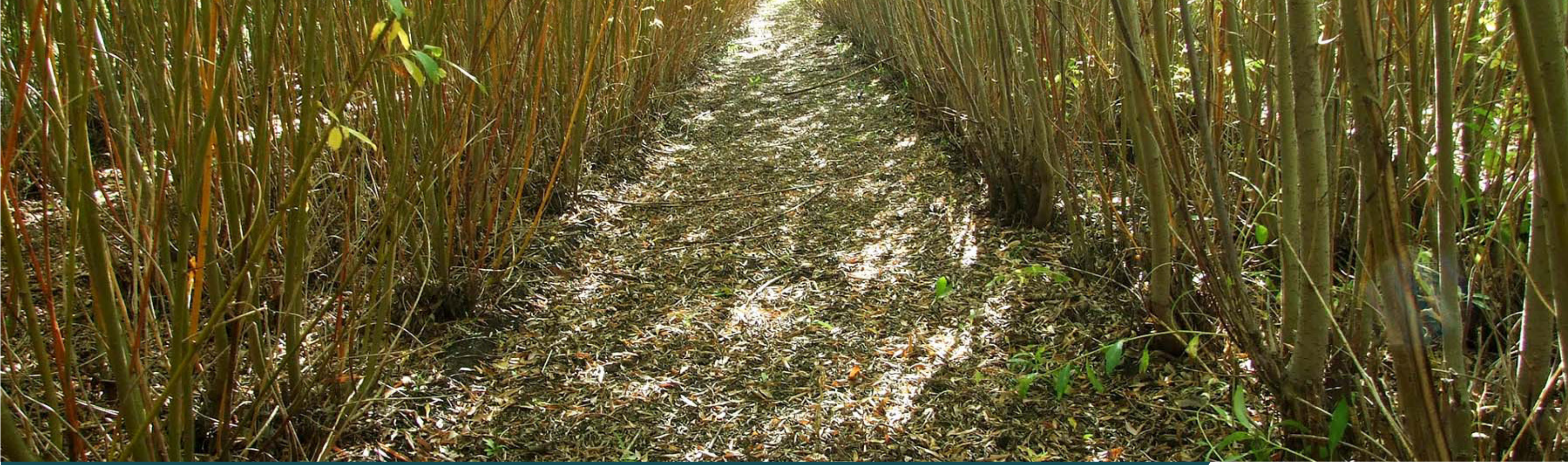


Figure 23. Sampling plot growth & yield summaries of high yield afforestation trials established at Ellerslie SRWC Technical Development Site.

A summary table in Appendix V presents data for the high yield afforestation plantation blocks that were monitored to develop growth and yield trajectories.

The table represents a history of assessments by establishment year, species/clone and measurement year.



Concentrated Biomass Plantation Assessments

Sampling procedures for the concentrated biomass plantations are numerous. Many SRWC groups have developed procedures that relate to estimating above ground biomass potential. The Technical Development Group tested a variety of sampling options at Ellerslie, validating the results of the actual harvested volumes utilized on an operational scale. Operationally comparing sampling results of area-based plot, transect sampling and allometric equation methods quickly identified that there was inconsistency of sampling estimates. There was also an over-estimation of actual harvest volumes for concentrated biomass plantations. The high costs of sampling at a scale needed to accurately estimate the true obtainable volumes for concentrated biomass plantations with a 3-year rotation were identified as unrealistic and not economically feasible. For the operational concentrated biomass plantations at Ellerslie, the Technical Development Group opted for a full-rotation sampling system that incorporated pro-rating the sampling estimates, based on the actual full-trial rotational harvested volumes.

For the SUNY Clonal Trial, Operational Research Site 69, a pre-designed sampling protocol was followed. This protocol consisted of periodic sampling of various parameters incorporating an area-based buffered sampling plot system of 18 planted stems within the gross plot area at a sampling intensity greater that 23% (Figure 24).

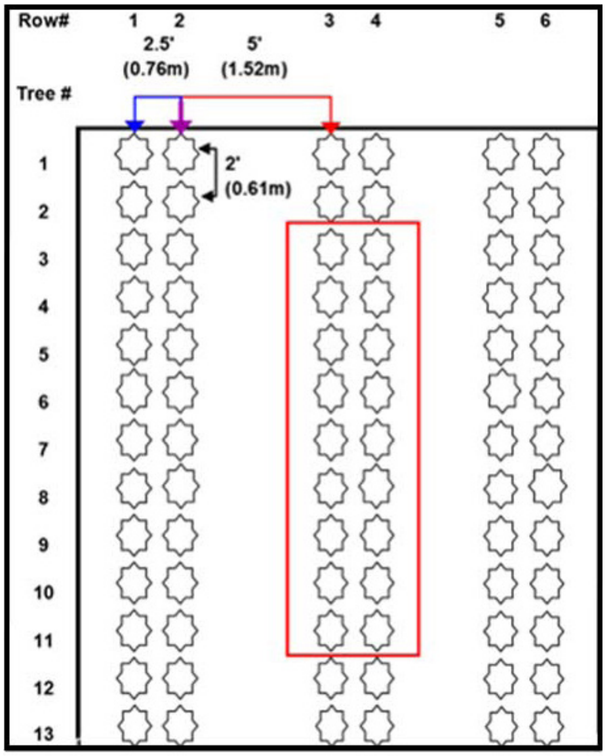


Figure 24. Sampling plot design for the SUNY Clonal Trial established at Ellerslie SRWC Technical Development Site.

Parameters and Calculations

Parameters sampled for the SUNY Clonal Trial included survival, maximum height, coppice stem counts, winter dieback and stem damage until 2012, at which time the detailed monitoring was discontinued. Data was forwarded to SUNY for comparison with other sites established. Harvest volume data was collected until 2018. Parameters sampled for other concentrated biomass operational research sites included survival, maximum height, wet and oven dried (OD) harvest weights, post harvest residues, average mass per live planted spot, moisture contents of samples at time of sample weighing and rotational mass per hectare per year. It should be noted that as the operational trials matured, the sites were used to evaluate a series of sub-trials as operational questions arose. The sites were also used to supply vegetative propagation material for other research trials established across Canada.

Sampling data was then used to calculate for various performance parameters using the equations outlined in Appendix VI. Periodic monitoring of the concentrated biomass sites was completed with the main objective of evaluating the clonal suitability and growth and yield potential of various Salix and hybrid poplar clones for use in a national SRWC program for augmenting woody biomass supply. The secondary goals included developing site suitability indices for developing and validating growth models, evaluating sampling protocols, validating, dispelling and refining establishment and management protocols, and evaluating physical and chemical woody biomass characteristics.

Figure 25 presents data for SUNY Clonal Trial that was monitored as part of the larger, international trials. This trial had sites in Canada and the United States designed to evaluate growth and yield trajectories and clonal suitability (Volk et al., 2011). For the 13-year period that the trial was active at Ellerslie, Salix clone 94001 had the greatest yield, averaging 8.63 oven dried tonnes (ODT) $^{-ha-yr}$. The average of all clones included in the trial being 4.17 ODT^{-ha-yr}. A history of assessments and data summaries by year and clone for the trial is included in Appendix VII.

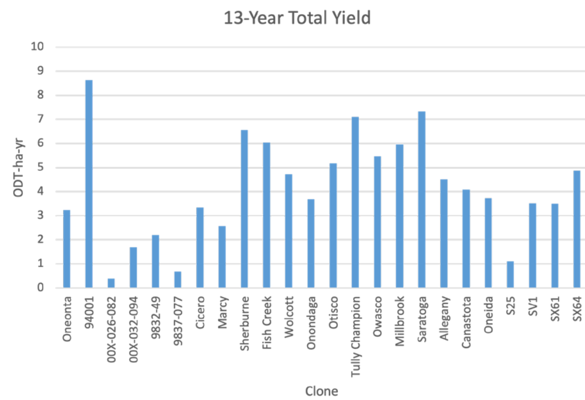


Figure 25. Average yields (ODT) of SUNY Willow Clonal Trial at Ellerslie SRWC Technical Development Site.

In 2007, the Technical Development Group partnered with Agriculture and Agri-Food Canada (AAFC) to operationally test a prototype woody biomass harvester at Ellerslie and other concentrated biomass SRWC sites in western Canada. Operational data collected for the developmental assessment included pre-harvest assessments, harvesting summaries and post-harvest residue sampling of a subset of concentrated biomass trials at Ellerslie. Table 1 summarizes the 2007–08 sampling completed as part of this operational trial.

Table 1. Concentrated biomass assessment summary completed in 2007-08 at Ellerslie Short-Rotation Woody Crops Technical Development Site.

Map Legend Number	Clone	Root System Age	Coppice Status	Above Ground Growth Age (Yrs)	2007 Mean Max Ht (m)	2007-08 Harvest Wet Wt/ha (Tonnes)	2007-08 Harvest Residues/Ha (Tonnes)
53	Acute Willow	3-Yr Root Systems	Not Coppiced	3	1.47	0.52	Not Sampled
52	Alpha	3-Yr Root Systems	Not Coppiced	3	2.02	1.59	Not Sampled
55	Charlie	3-Yr Root Systems	Not Coppiced	3	2.08	2.72	Not Sampled
51	Hotel	3-Yr Root Systems	Not Coppiced	3	1.94	3.24	1.08
49	India (1 Yr)	3-Yr Root Systems	Coppiced	1	Not Sampled	7.33	2.26
49	India (2 Yr)	3-Yr Root Systems	Coppiced	2	3.38	9.32	4.20
54	NM-6	3-Yr Root Systems	Not Coppiced	3	2.42	10.00	0.48
50	Pseudo	3-Yr Root Systems	Not Coppiced	3	2.39	1.22	1.86
57	SX-61	2-Yr Root Systems	Not Coppiced	2	1.95	Not Harvested	
57	SX-64	2-Yr Root Systems	Not Coppiced	2	1.78	Not Harvested	
57	SX-67	2-Yr Root Systems	Not Coppiced	2	1.90	Not Harvested	

In 2009 and 2010, operational harvesting and processing trials were completed to evaluate potential mid-supply chain options for woody biomass obtained from concentrated biomass plantations. Area based plots were manually harvested. The harvested material was chipped using a small-scale PTO powered Wallenstein BX32 Chipper. The elasticity of the one and two-year-old India willow made it unattainable to process in this manner and was not included in the trial after testing a small portion of the harvested material. Table 2 summarizes the harvesting and processing operations conducted at Ellerslie in 2009–10.

Table 2. Concentrated biomass harvesting and chipping summary completed at Ellerslie Short-Rotation Woody Crops Technical Development Site (2010–11).

Map Legend Number	Clone	Root System Age	Above Ground Growth Age	Coppice Status	2009–10 Harvest Wet Wt^{-ha} (Tonnes)	2010 Chipping Trial Pre-Chipping Wt (kg)	2010 Chipping Trial Post-Chipping Wt (kg)	2010 Chipping Trial Loss
49	India	5-Yr Root Systems	1	Coppiced	11.00	Not Sampled		
49	India	5-Yr Root Systems	2	Coppiced	28.75	Not Sampled		
49	India	5-Yr Root Systems	3	Coppiced	51.94	398.9	349.8	12.31%
54	NM-6	5-Yr Root Systems	3	Coppiced	Not Sampled	42.2	39.3	6.87%
57	SX-61	4-Yr Root Systems	4	Not Coppiced	6.50	195.1	177.6	8.97%
57	SX-64	4-Yr Root Systems	4	Not Coppiced	5.44	163.4	135.4	17.14%
57	SX-67	4-Yr Root Systems	4	Not Coppiced	8.60	258.0	222.4	13.80%

Operational testing of the prototype woody biomass harvester in 2007 identified the need for several improvements and re-engineering. In 2010, the newly developed Anderson BioBaler, jointly developed and produced with AAFC, was operationally tested at Ellerslie. The BioBaler is based on an agricultural round baler platform. It is reinforced to handle woody crops and modified with a specialized harvesting header that can cut, condition and feed the stems into the bale compression chamber. The BioBaler is suitable for harvesting larger biomass stems (< 13 cm base diameter) efficiently, with the potential to harvest up to 40 bales per hour (Anderson website). Under optimal conditions it can average 10 to 15 bales per hour operationally. The end-product is a round, moderately compacted bale, 122 cm in diameter. Harvesting operations in 2011 were limited to area-based plots. They were manually harvested for growth and yield sampling purposes only. Table 3 summarizes the harvesting data collected at Ellerslie during 2011 and 2012.

Table 3. Harvesting data summary completed at Ellerslie Short-Rotation Woody Crops Technical Development Site (2011 and 2012).

Map Legend Number	Clone	Root System Age	Above Ground Growth Age	Coppice Status	Year Sampled	Harvest Wet Wt^{-ha} (Tonnes)
49	India	7-Yr Root Systems	4	Coppiced	2011-12	76.33
53	Acute	6-Yr Root Systems	3	Coppiced	2010-11	5.75
52	Alpha	6-Yr Root Systems	3	Coppiced	2010-11	5.51
55	Charlie	6-Yr Root Systems	3	Coppiced	2010-11	4.53
54	NM-6	6-Yr Root Systems	3	Coppiced	2010-11	14.86
50	Pseudo	6-Yr Root Systems	3	Coppiced	2010-11	3.58
57	Sx Clones	5-Yr Root Systems	1	Coppiced	2010-11	1.67
59	Hotel 1-Row Design	4-Yr Root System	4	Not Coppiced	2010-11	19.23
62	Hotel 3-Row Design	4-Yr Root System	4	Not Coppiced	2010-11	27.26

In 2012–13, the Technical Development Group evaluated a series of options for estimating woody biomass in concentrated biomass plantations. The research incorporated full population harvesting and weighed data collection of all live planted spots within a 103.68 m^2 plot (54 rows of 3-row bed design) in Bed #4. It also integrated harvesting and mass sampling of 10, 5 m X 3.2 m sub-plots of a 160 m^2 plot (81 rows of 3-row bed design) in Bed #3. Analysis of the data of individual rows in a 3-row design identified that the eastern rows had a survival of 91.36% for Bed #3 and 83.33% for Bed #4. Centre rows had 93.83% for Bed #3 and 83.33% for Bed #4. Western rows had a survival of 93.83% for Bed #3 and 79.63% for Bed #4. Average wet weights for live planted spots for Bed #4 averaged 0.6022 kg per live spot. The western row averaged 0.9256 kg, the centre row averaged 0.4859 kg and the eastern row averaged 0.4122 kg per spot.

The single year's growth on an eight year root system for Bed #3 had a mean maximum height of 2.64 m, survival of 93% and 10.79 wet tonnes per hectare. The single year's growth on an eight year root system for Bed #4 had a mean maximum height of 2.28 m, survival of 82.72% and 7.78 wet tonnes per hectare. Regardless of the plot sampling size or the intensity, the variation of the estimated biomass compared to actual was inconsistent and ranged from +30.28% to -31.09%. This emphasized the variability associated with estimating woody biomass in concentrated biomass plantations through sampling (Figure 26). After considering the high costs associated with concentrated biomass sampling and the short, 3-year rotations, the Technical Development Group opted for a full-rotation sampling system. This system incorporated pro-rating the sampling estimates, which were based on the actual full-trial rotational harvested volumes. Data summaries of the sampling completed in 2012–13 for concentrated biomass operational trials at Ellerslie are included in Appendix VIII.

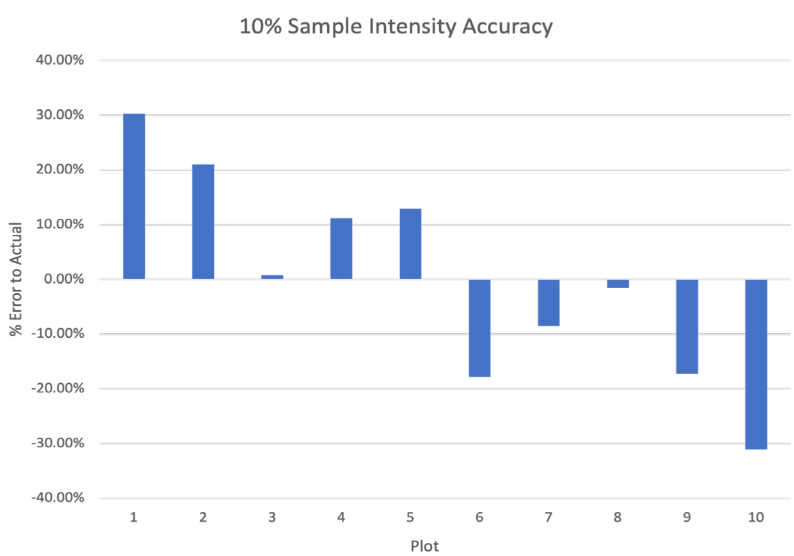


Figure 26. Sampling accuracy of 10% sample intensity of Concentrated Biomass Plantation Trial at Ellerslie SRWC Technical Development Site.

In 2018–19, the final assessment was completed at Ellerslie. As part of the harvesting operations, the concentrated biomass harvesting sites were harvested using the Anderson BioBaler. Due to the size of some of the material, a conventional feller-buncher was required for the beds with larger diameter stems. Table 4 summarizes the 2018–19 harvesting operations for concentrated biomass plantations at Ellerslie.

Table 4. Summary of 2018-19 concentrated biomass harvesting operations at Ellerslie Short-Rotation Woody Crops Technical Development Site.

Map Legend Number	Clone	Harvester	ODKG per Planted Stem	2018 Harvest ODT^{-ha}	Root System Age	Above Ground Growth Age	Rotational ODT^{-ha-yr}
57	SX-67	Anderson BioBaler	1.04	16.29	13	7	2.33
57	SX-64	Anderson BioBaler	0.88	13.77	13	7	1.97
57	SX-61	Anderson BioBaler	0.47	7.28	13	7	1.04
55	Charlie	Anderson BioBaler	0.88	13.69	14	7	1.96
54	NM-6	JD Feller-buncher	5.15	80.40	14	7	11.49
53	Acute	Anderson BioBaler	1.07	16.67	14	7	2.38
52	Alpha	Anderson BioBaler	1.38	21.53	14	7	3.08
49	India-4	JD Feller-buncher	2.65	41.33	14	4	10.33
49	India-5 (Edge Row)	JD Feller-buncher	4.78	74.63	14	5	14.93
49	India-6	JD Feller-buncher	3.63	56.68	14	6	9.45
49	India-7	JD Feller-buncher	4.97	77.70	14	7	11.10
56+58	P-38 (1st Rotation)	JD Feller-buncher	1.72	26.81	7	7	3.83
62	Hotel 3-RowDesign	Anderson BioBaler	2.48	38.82	12	7	5.55
59	Hotel 1-RowDesign	Anderson BioBaler	3.91	36.18	12	7	5.17

Soil Assessments

An important objective of the operational research conducted at Ellerslie was evaluating the potential of SRWC to sequester carbon in a sustainable manner. To evaluate this potential and the impacts of SRWC on site sustainability, several soil assessments were conducted between 2003 and 2019. Tables 5 and 6 summarize the average soil composition and analysis information collected between 2003 and 2010 as part of the sustainability research conducted at Ellerslie. Information for individual samples are included in Appendix IX.

Table 5. Average soil composition of samples collected between 2003 and 2010 at Ellerslie Short-Rotation Woody Crops Technical Development Site.

Map Legend Number	Year	Sand (%)	Clay (%)	Silt (%)	pH	Total Org C (%)
4	2003	22.50	36.00	41.50	6.41	7.99
24	2003	24.33	31.00	44.67	6.36	6.75
15	2005	15.00	33.00	52.00	6.77	6.37
16	2005	25.00	31.00	43.50	6.04	7.05
25	2005	28.17	31.17	40.17	5.88	6.67
27	2005	28.00	32.50	39.00	6.01	8.11
31	2005	30.50	30.00	39.50	6.40	7.40
49	2010	30.00	33.50	36.50	5.69	5.89

Table 6. Soil analysis summary of samples collected between 2003 and 2010 at Ellerslie Short-Rotation Woody Crops Technical Development Site.

Map Legend Number	Year	Ca (mg kg^{-1})	K (mg kg^{-1})	Mg (mg kg^{-1})	Na (mg kg^{-1})	P (mg kg^{-1})	NO_3-N (mg kg^{-1})	NH_4-N (mg kg^{-1})
4	2003	3112.5	207.2	399.5	177.7	8.5	25.3	78.7
15	2005	3093.5	316.0	347.5	208.8	6.4	21.4	26.2
16	2005	2956.5	250.0	342.0	195.5	9.1	27.9	33.7
24	2003	351.2	71.9	163.3	360.0	6.6	29.0	48.1
25	2005	408.0	70.0	143.5	357.5	4.9	65.3	73.5
27	2005	392.5	64.8	127.5	339.5	6.0	104.2	65.9
31	2005	294.0	108.0	145.5	287.5	6.9	150.0	38.9
49	2010	352.5	87.8	119.0	276.0	7.1	351.0	122.0

In 2003, to evaluate long-term impacts on soil carbon of the parallel, elevated mixed beds compared to the undisturbed portions between the beds, a series of soil samples were collected from the 2002 Northwest Hybrid Poplar site. An adjacent field would be later planted to Hill Hybrid Poplar as part of the 2004 Forest 2020 operational research site. Table 7 summarizes the average 2003 data collected as part of this research. Information for individual samples are included in Appendix IX.

In 2004, soil assessments were completed as part of the Forest 2020: Plantation Demonstration and Assessment Initiative. The 2 year, $20 million federal initiative focused on 1) establishing demonstrations of fast-growing tree plantations across Canada to mitigate greenhouse gas emissions and generate more wood fibre, and 2) exploring investment mechanisms to attract funds to establish plantations in the future. To evaluate the potential of SRWC to sequester carbon, above and below ground, the pre-treatment sampling was completed using the measuring and monitoring protocols for afforestation designed under the Feasibility Assessment of Afforestation for Carbon Sequestration (FAACS) Initiative. This procedure was used on all sites afforested as part of the Forest 2020 Initiative in the Prairies in 2004 and 2005. For Ellerslie, pre-treatment carbon for the site was calculated to be 78.46 Mg^{-ha}, consisting of 78.08 Mg^{-ha} soil carbon (Mean Bulk Density=0.91895@ 5.6647 % C) and 0.3765 Mg^{-ha} aboveground biomass (annual cropping stubble). Table 8 summarizes the data collected for pre-treatment calculations at Ellerslie.

Table 7. Summary of average 2003 soil sampling completed at Ellerslie Short-Rotation Woody Crops Technical Development Site.

Map Legend Number	Location	pH $CaCl_2$	E.C. $mmhos^{-cm}$	Total C %
4	Adjacent Field	5.75	0.42	7.7
	Elevated Microsite Beneath Trees	5.96	0.62	8.1
	Elevated Microsite Between Trees	5.97	0.71	8.3
	Undisturbed Microsite Between Rows	5.94	0.62	8.2

Table 8. Summary of pre-treatment Forest 2020 sampling at Ellerslie Short-Rotation Woody Crops Technical Development Site.

Map Legend Number	Year	Plot	0-15cm Bulk Density E ($g.cm^{-3}$)	0-15cm Bulk Density W ($g.cm^{-3}$)	Org.C (%)	In-Org.C (%)	Total C (%)	15-30 cm Bulk Density E ($g.cm^{-3}$)	15-30 cm Bulk Density W ($g.cm^{-3}$)
25	2004	C1	0.963469	1.062245	5.335	0.039	5.374	1.092245	1.054286
	2004	N1	1.034898	0.900408	5.223	0.167	5.390	1.127347	0.835714
	2004	S1	1.053878	0.922245	5.600	0.078	5.678	1.051633	1.037143
	2004	C2	0.766531	0.747959	5.803	0.03	5.833	1.006327	1.041837
	2004	N2	0.833469	1.130204	5.612	0.091	5.703	1.142857	1.039184
	2004	S2	0.870612	0.741429	5.867	0.143	6.010	0.917143	0.945102
	2004	**Site**	**0.920476**	**0.917415**	**5.573**	**0.091**	**5.665**	**1.056259**	**0.992211**

Research conducted during the early stages of the plantation identified that a loss of soil organic carbon occurred post establishment and returned to pre-treatment levels by year-6 (Sun et al., 2015). If aboveground biomass growth was incorporated into the calculations, the ecosystem carbon returned to pre-establishment levels within 3 years (Arevalo et al., 2011). In spring of 2019, soil assessments were completed to determine full rotation carbon impacts of the Forest 2020: Plantation Demonstration and Assessment Initiative site at Ellerslie. The Assiniboine hybrid poplar portion had the highest soil carbon at 94.58 Mg^{-ha}. It was followed by the Walker hybrid poplar portion at 91.05 Mg^{-ha} and the Hill hybrid poplar portion at 85.52 Mg^{-ha}. Table 9 and Figure 27 summarize the full rotation soil data for Ellerslie. Information for individual samples are included in Appendix IX.

Table 9. Full rotation Forest 2020 soil carbon assessments completed at Ellerslie Short-Rotation Woody Crops Technical Development Site.

Map Legend Number	Year	Total Carbon (%)	Total Inorganic Carbon (%)	0-15cm Bulk Density ($g.cm^{-3}$)
24	2019	5.23	0.89	1.0983335
25	2019	5.65	0.84	1.10055575
26	2019	5.86	1.21	1.0316665

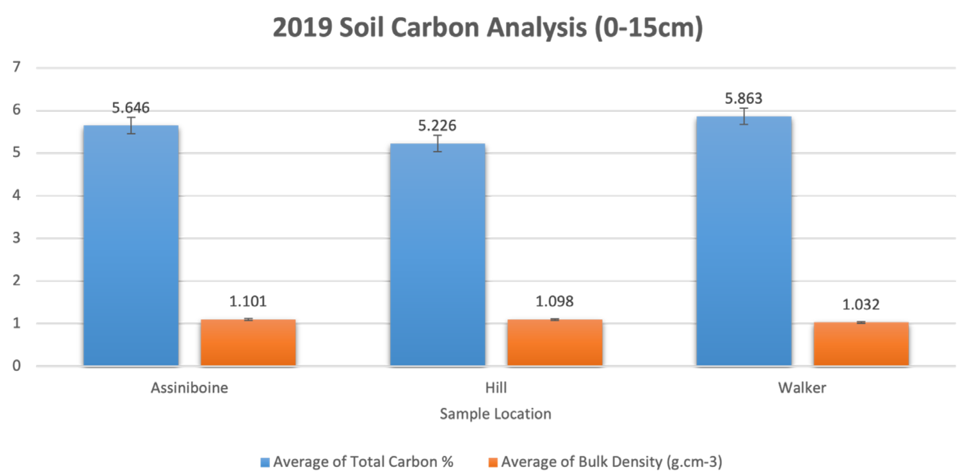


Figure 27. Full rotation Forest 2020 soil carbon assessment summary completed at Ellerslie Short-Rotation Woody Crops Technical Development Site.

Physical and Chemical Wood Fibre Characterization

An integral component of the operational research conducted at Ellerslie involved the evaluation of the physical and chemical properties of SRWC biomass. The Technical Development Group established partnerships with FPInnovations, University of British Columbia and CanmetEnergy Ottawa to conduct various characterization assessments. The majority of the analysis was completed by FPInnovations using the Fibre Quality Analyzer and Silviscan systems. An overview of the methodologies used and supplied by FPInnovations is included in Appendix X. Table 10 summarizes the 2007 physical characterization work completed in conjunction with FPInnovations for 9 Salix clones from Ellerslie and 2 off-site Salix clones.

Table 10. Summary of the physical properties of Salix clones evaluated in 2007 at Ellerslie Short-Rotation Woody Crops Technical Development Site.

Map Legend Number	Clone / Species	Diameter (mm)	Avg Density (kg/m³)	MFA (°)	MOE (GPa)
5	SV1	13.98	499.6	13.63	13.57
5	Viminalis	10.26	417.8	19.65	8.96
49	India	13.22	392.8	19.84	8.88
50	Pseudo	11.84	430.7	16.25	10.82
51	Hotel	8.74	420.4	19.45	8.72
57	SX67	8.70	408.6	18.92	10.47
57	SX64	7.53	398.8	18.50	9.61
57	SX61	10.5	382.5	23.08	7.95
73	Juliet	9.18	363.6	22.09	6.97
N/A	*Salix Discolor*	10.66	389.4	22.43	8.77
N/A	SA 2	13.22	412.3	16.33	10.93

The carbohydrate composition across all samples were fairly consistent, with approximate values of glucan of 40%, xylan of 13%, mannan of 1%, and trace amounts of both arabinan and galactan. The total carbohydrate composition is in good agreement with values observed for other hardwoods. Results of the 2007 chemical characterization is included in Appendix XI.

Discussions with FPInnovations staff following the 2007 Salix analysis identified an inconsistency in the values and the impacts that knots have on the analysis. To evaluate these differences, the Technical Development Group established a project with FPInnovations to evaluate these impacts in various hybrid poplar and Salix clones. Overall, the results of the study compared well to data in the literature and no significant differences between the knots and clear wood chemistry was identified. The physical fibre characteristics, wood densities and calorific values were found to be comparable to published values for samples of this age. More importantly, the results, included in Appendix XI, identified that;

1. there was no evidence of a superior species or clone in the samples evaluated,
2. the practices employed to grow these clones did not adversely affect their wood chemistry, physical or fibre properties, and
3. the most important factor to consider when selecting clones of interest is growth rates.

In 2008, destructive sampling was completed at Ellerslie to collect “cookies” from a variety of hybrid poplar clones and hybrid aspen established in 2002 (Walker, Northwest, Green Giant and Hybrid Aspen) and 2004 (Assiniboine and Walker). Three cookies were collected from each tree; one at the stump, one at DBH or 1.3 m, and one from just below the whorl of year-5 growth. Physical characterization was completed on all samples using SilviScan. The average values for the hybrid poplar and hybrid aspen evaluated were found to be comparable to samples of a similar age presented in the literature and are included in Appendix XI.

The remainder of the material was chipped and chips from each sample were well mixed and air-dried to an average solid content of 93.7%. A significant number of knots were noted after chipping the samples. The knots were quantified in the “accepts” chip fraction by hand-sorting and determining the weight percent of the total mass of chips. The hybrid aspen, Walker and Northwest hybrid poplar chips were then used to create kraft pulp for analysis. Tables 11 and 12 summarize the pulping analysis work conducted in collaboration with FPInnovations in 2008.

Table 11. Summary of kraft pulp characteristics for a target kappa of 17 hybrid poplar and hybrid aspen evaluated in 2008 at Ellerslie Short-Rotation Woody Crops Technical Development Site.

	Hybrid Aspen	Northwest HP	Walker HP	Northern AB Bleached Aspen Pulp
Kappa Number (Test results)	16.670	16.330	17.190	No Data
Screened yield %	47.660	50.410	49.290	No Data
Rejects %	6.160	3.930	4.970	No Data
Fiber Length LWa (mm)	0.734	0.752	0.750	0.730
Coarseness (mg/m)	0.070	0.079	0.070	0.100

Note: Fiber Quality Analyzer (FQA-Hi Resolution) used for Coarseness, Fibre Length, Curl Index and Width.
LWa = Average length weighted.

Table 12. Summarizes the physical properties of the hardwood pulp samples calculated for 300 mL Canadian Standard Freeness (CSF) of hybrid poplar and hybrid aspen evaluated in 2008 at Ellerslie Short-Rotation Woody Crops Technical Development Site.

	Hybrid Aspen	Northwest HP	Walker HP
PFI Mill revs., (x1000)	4.95	7.52	7.03
Air Resistance (s/100mL)	420.00	176.00	245.00
Tensile Index (N.m/g)	93.10	79.50	96.70
Stretch (%)	2.95	4.00	3.77
Tensile Breaking Length (km)	9.49	8.11	9.86
Zerospan Breaking Length (km)	13.10	12.40	13.10
Burst Index (kPa.m^2/g)	7.38	6.33	7.46
Tear Index (4 ply) (mN.m^2/g)	7.18	8.53	8.16
Apparent Sheet Density (kg/m^3)	787.00	774.00	790.00
Surface Roughness (Sheffield units)	20.00	29.00	27.00
Scattering Coefficient (c^2/g)	217.00	191.00	196.00
Opacity (%)	91.00	90.20	91.40

Table 13. Average physical properties summary of wood pellets produced from SRWC in 2009-10 at Ellerslie Short-Rotation Woody Crops Technical Development Site.

Values	Hybrid Poplar	Salix
Heating Value (MJ/kg)	18.4	18.2
Durability (%)	82.6	85.5
Moisture Content (%)	9.2	11.2
Mean Ash Content (%)	1.8	1.9
Mean Bulk Density (kg/m^3)	636.0	629.3
Mean Particle Density (kg/m^3)	1197.5	1169.8

In 2009-10 the Technical Development Group collaborated with the University of British Columbia to produce and evaluate wood pellets created from various hybrid poplar and Salix clones from Ellerslie. The results of the analysis showed no significant differences between the two species. Table 13 summarizes the physical properties and dimensions of the pellets produced from SRWC completed by the University of British Columbia in 2009-10. Information for individual clones are included in Appendix XI.

In 2018, as a component of the full rotation harvesting of Ellerslie, the Technical Development Group completed detailed timing of woody biomass processing of the bales harvested from the concentrated biomass sites by the BioBaler. This was done using a Haybuster 1130 tub grinder (Figure 28) supplied by Agriculture and Agri-Food Canada in Indian Head, SK. The purpose was to create mulch and roadside residue from the high yield afforestation sites using the Pezzolato PTH700 Drum Chipper. The chipper was supplied by Biomass Innovations in Drayton Valley, AB. Samples of the mulched and chipped material produced during these operational research trials were shipped to CanmetEnergy Ottawa for physical and physiochemical analysis. Tables 14 and 15 summarize the physical and physiochemical analysis of the woody biomass produced from SRWC and completed by CanmetEnergy Ottawa in 2018-19.

Figure 28. Woody biomass processing at the Ellerslie SRWC Technical Development Site.

Table 14. Summary of the CanmetEnergy Ottawa physical mulch properties analysis of woody biomass produced in 2018–19 at Ellerslie Short-Rotation Woody Crops Technical Development Site.

Bale Type	Recently Harvested Bales			Stored (< 3Yr) Bales	
Biomass Size	Haybuster 1130 with 1" Screens*	Haybuster 1130 with 2" Screens	Haybuster 1130 with 3" Screens	Haybuster 1130 with 1" Screens*	Haybuster 1130 with 2" Screens
< 3 mm	17%	8%	5%	26%	18%
3–12.7 mm	60%	29%	28%	62%	66%
12.7–24.1 mm	18%	31%	25%	11%	12%
24.1–31.3 mm	3%	10%	18%	0%	1%
> 31.3 mm	0%	20%	22%	0%	2%
Total	98%	97%	98%	99%	99%

* Required Pre-processing with 2" Screens.

Table 15. Summary of the CanmetEnergy Ottawa physiochemical properties analysis of woody biomass produced in 2018-19 at Ellerslie Short-Rotation Woody Crops Technical Development Site.

	9 yr-old Clonal Aspen mix, Full-tree Chipped	17 yr-old Hybrid Aspen Residues Chipped	15 yr-old Walker Hybrid Poplar Residues Chipped	14 yr-old Northwest Hybrid Poplar Residues Chipped	5 yr-old *Salix dasyclados* Full Stem Chipped	6 yr-old *Salix purpurea* Full Stem Mulch
Bulk Density (kg/m³,dry)	173.3	170.1	170.1	170.1	114.4	84.9
Moisture As Received	30.90%	34.80%	43.30%	32.90%	38.80%	39.20%
Ash (%wt,dry)	2.60%	1.80%	3.70%	3.50%	2.50%	2.40%
Volatile (%wt,dry)	79.90%	81.60%	78.70%	79.60%	80.60%	80.10%
Fixed Carbon (%wt,dry)	17.50%	16.60%	17.70%	16.90%	16.90%	17.50%
Carbon (%wt,dry ash-free)	51.00%	50.60%	51.50%	51.30%	50.90%	51.00%
Gross Calorific Value (MJ/kg,dry)	19.64	19.64	19.43	19.41	19.52	19.65
Cl (mg/kg,dry)	51	38	32	31	49	54
F (mg/kg,dry)	< 10	< 10	< 10	< 10	< 10	< 10
Br (mg/kg,dry)	< 10	< 10	< 10	< 10	< 10	< 10
SiO_2 (%wt of ash,dry)	3.80%	5.80%	3.00%	1.70%	11.80%	8.20%
AL_2O_3 (%wt of ash,dry)	0.90%	1.20%	0.70%	0.50%	2.40%	1.50%
Fe_2O_3 (%wt of ash,dry)	0.50%	0.50%	0.80%	0.20%	1.20%	0.70%
TiO_2 (%wt of ash,dry)	0.10%	0.10%	0.00%	0.00%	0.20%	0.10%
CaO (%wt of ash,dry)	36.70%	35.50%	42.70%	42.10%	35.50%	37.80%
MgO (%wt of ash,dry)	4.10%	4.50%	4.30%	3.40%	3.40%	3.50%
SO_3 (%wt of ash,dry)	1.60%	1.80%	1.80%	1.70%	3.30%	2.80%
Na_2O (%wt of ash,dry)	0.10%	0.20%	0.10%	< 0.002	0.30%	0.30%
K_2O (%wt of ash,dry)	16.70%	16.30%	15.80%	12.80%	11.50%	12.60%
Barium (%wt of ash,dry)	0.06%	0.10%	0.06%	0.04%	0.07%	0.09%
Strontium (%wt of ash,dry)	0.12%	0.11%	0.13%	0.12%	0.11%	0.11%
Vanadium (%wt of ash,dry)	< 0.0005%	< 0.0005%	< 0.0005%	< 0.0005%	< 0.0005%	< 0.0005%
Nickel (%wt of ash,dry)	< 0.0005%	0.01%	< 0.0005%	< 0.0005%	0.01%	0.01%
Manganese (%wt of ash,dry)	0.03%	0.05%	0.02%	0.03%	0.07%	0.09%
Chromium (%wt of ash,dry)	0.01%	0.01%	< 0.0005%	0.01%	0.02%	0.01%
Copper (%wt of ash,dry)	0.01%	0.01%	0.00%	< 0.0005%	0.01%	0.01%
Zinc (%wt of ash,dry)	0.20%	0.17%	0.16%	0.14%	0.26%	0.28%
Loss on fusion (wt% of ash,dry)	29.93%	26.84%	33.94%	29.73%	26.63%	27.94%

Technology Transfer Activities

The Technical Development Group emphasized the importance of technology transfer in all aspects of the operational research conducted at Ellerslie. The goal was to ensure the operational research was available for all interested parties to provide first-hand experience and increase stakeholder uptake. Significant time and resources were spent creating self-guided trails and information signs to enhance the knowledge exchange aspect of SRWC operational research (Figure 29). Topic specific tours were conducted routinely with various interested stakeholders. These groups included forest and afforest industry personnel, international students and SRWC experts, Federal and Provincial Government personnel, Indigenous groups, reclamation contractors, academic researchers and university student groups. In addition to the personal, topic specific field tours, Ellerslie was showcased in several large-scale events from 2004 to 2019. As a rule, the Technical Development Group coordinated and hosted interested peer researchers and staff at NoFC to visit Ellerslie for private tours prior to the large-scale events. This was arranged so non-participants could utilize the focused infrastructure. Table 16 summarizes the larger scale events that showcased the operational research being conducted at Ellerslie.

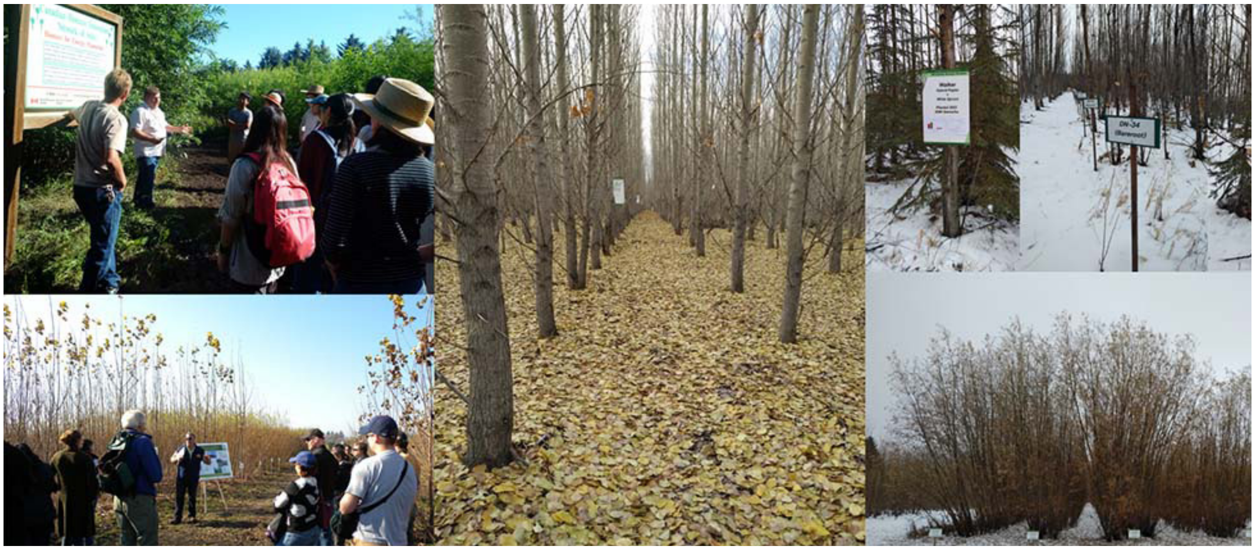


Figure 29. Examples of technology transfer events and on-site infrastructure for knowledge exchange activities at Ellerslie Short-Rotation Woody Crops Technical Development Site.

Table 16. Large-scale technology events showcasing SRWC operational research at Ellerslie Short-Rotation Woody Crops Technical Development Site.

Year	Host	Event	Date	Title
2004	CIF/SAF	Field Tour	06-Oct-04	CIF/SAF Technical Field Workshop # 10
2005	RATC 2005	Field Tour	01-Dec-05	RATC Afforestation and Bioenergy Technical Field Workshop
2005	CFS	Field Tour	20-Oct-05	Woodlot Association of Alberta Field Tour
2006	CWFC	Field Day	26-Sep-06	CFS - Forestry Week Field Day
2008	CWFC	Field Day	10-Sep-08	CWFC - Introduction to SRWC - Day 1
2008	CWFC	Field Day	11-Sep-08	CWFC - Introduction to SRWC - Day 2
2009	CWFC	Field Tour	10-Nov-09	CWFC - Role of SRWC in Alberta's Bio-Economy
2011	CWFC - Poplar Council of Canada	Field Tour	22-Sep-11	Poplar Council of Canada, International Poplar Commission and Poplar Council of the United States AGM Post Conference Tour Stop: September 22, 2012, "Developing Short-rotation Woody Crop Systems in Canada"
2012	CWFC/Univ of AB	Field Tour	22-Jun-12	Boreal Mixedwoods Post Conference Field Tour
2013	CWFC	Field Day	25-Oct-13	CWFC - Developing Innovative Biomass Production and Conversion Systems
2014	CWFC	Field Day	26-May-14	CWFC - Gyro-Trac Bioenergy Baling System Demonstration
2016	CWFC/Univ of AB	Field Tour	22-Jul-16	University of Alberta International Student Studies Field Tour
2018	CWFC	Field Day	26-Nov-18	Operational SRWC Harvesting Demonstrations
2019	CWFC	Field Day	25-Jan-19	Operational SRWC Processing Demonstrations

2018 High-Yield Afforestation Harvesting Summary

In 2018–19, the site was harvested with funding received as part of the Forest Innovation Program in support of the forest bioeconomy. The Ellerslie site presented a unique opportunity to evaluate, from establishment to end-user, growth and yield, physical and chemical characterization, carbon sequestration, and economics associated with high-yield afforestation (hybrid poplar and aspen) and concentrated afforestation (willow and hybrid poplar) plantations in Canada. The main objective of this project was to evaluate operational SRWC harvesting and processing. This was done to improve the economics and efficiency of logistics for the utilization of woody feedstock from high yield afforestation and concentrated biomass sites.

Harvesting activities were completed in a manner that prioritized detailed data collection in relation to equipment productivity and site mass accumulations, rather than minimizing actual costs. To accomplish this goal, all equipment was contracted on an hourly rate basis. It should be noted that cost savings could have been realized by utilizing a contracted per tonne rate. However, this would be done at the risk of losing the ability to accurately track productivity and systematic operational monitoring. High yield afforestation sections of the Ellerslie SRWC Technical Development Site were harvested using a feller buncher (Figure 30). The feller buncher was instructed to place all felled stems adjacent to the access roads to eliminate the need for a skidding phase during harvesting operations. This may have resulted in a small reduction in harvesting productivity. However, it is believed that the overall harvesting cost was reduced when the low skidding productivity and small block size of the various research trials were taken into consideration. All stems were then delimbed and processed tree length to a top diameter of 7.5 cm using a dangle head processor (Figure 31). The processed stems were then hauled, weigh scaled and utilized in the production of pulp at the Alberta-Pacific pulp mill. Roadside harvesting debris was processed using a small-scale chipper and weighed to determine biomass proportions. A summary of the 2018 hourly costs of the equipment used for the harvesting and processing activities is outlined in Table 17.

Figure 30. John Deere 753G Feller-Buncher at Ellerslie Short-Rotation Woody Crops Technical Development Site.

Figure 31. Timberjack 608 with Waratah processing head at Ellerslie Short-Rotation Woody Crops Technical Development Site.

Table 17. Harvesting equipment costs summary at Ellerslie Short-Rotation Woody Crops Technical Development Site (2018).

Equipment Costing Summary	Hourly Contract Rate	Service Truck Costs Per Operating Hour	Operator Travel Costs Per Operating Hour	Lowbed Costs Per Operating Hour*	Feed Excavator Costs Per Operating Hour	Operator Costs Per Operating Hour	Total Costs Per Billed Hour
John Deere 753G Feller Buncher	220.00	22.50	17.36	24.00	N/A	Included	**283.86**
Timberjack 608 w/ Waratah Processing Head	220.00	22.90	17.66	16.68	N/A	Included	**277.24**
Pezzolato PTH700 Chipper	175.00	10.37	19.92	Included	44.09	59.07	**308.45**
926 Fendt Tractor	165.00	21.67	16.71	16.00	N/A	Included	**219.38**
Claas Jaguar Harvester	350.00	Included	Included	175.00	N/A	Included	**525.00**
Anderson BioBaler	55.00	Included	Included	Included	N/A	Included	**55.00**
Haybuster 1130	50.00	Included	Included	Included	N/A	Included	**50.00**
John Deere 6430 Tractor	65.00	N/A	N/A	N/A	N/A	Included	**65.00**
Friggstad Greenbelt Dump Wagon	45.00	N/A	N/A	N/A	N/A	Included	**45.00**
Western Star Treelength Haul Truck w/ Loader	165.00	N/A	N/A	N/A	N/A	Included	**165.00**

NA: Not Applicable, *Calculated: Total Lowbed Cost/Operating hours.

Harvesting operations commenced on November 27, 2018 and were completed for the most part on December 24, 2018, as outlined in Table 18.

Tree length log hauling was completed on January 25, 2019 with 34 loads delivering 1032.7 tonnes of pulp logs and an average of 30.4 tonnes per load.

Table 18. Ellerslie SRWC Technical Development Site harvesting and processing equipment operations summary (2018–19).

Equipment	Start	Completed	Total Hours Billed
John Deere 753G Feller Buncher	27-Nov-18	12-Dec-18	70
Timberjack 608 w/ Waratah Processing Head	06-Dec-18	24-Dec-18	107
Western Star Treelength Haul Truck w/ Loader	14-Dec-18	25-Jan-19	225
Claas Jaguar Harvester	28-Nov-18	29-Nov-18	8
926 Fendt w/ Anderson BioBaler	27-Nov-18 27-Apr-19 27-May-19 16-Jun-19	01-Dec-18 28-Apr-19 27-May-19 17-Jun-19	45
926 Fendt w/ Haybuster 1130	03-Dec-18 10-Dec-18 12-Dec-18 23-Aug-19	03-Dec-18 10-Dec-18 12-Dec-18 23-Aug-19	25
Pezzolato PTH700 Chipper	15-Dec-18 10-Jan-19 22-Jan-19 27-May-19	21-Dec-18 16-Jan-19 24-Jan-19 29-May-19	207

Approximately 18 tonnes of additional tree length logs were left onsite for demonstration purposes and to use in additional operational equipment testing. A summary of harvested weights by clone and establishment year is outlined in Table 19.

To demonstrate and evaluate the impacts of harvesting schedule on coppice growth potential of concentrated biomass plantations, a series of small-scale operational harvesting trials were completed until June 17, 2019. Chipping operations of roadside harvest residues were completed for the most part by January 24, 2019, apart from a series of operational trials that were completed in May of 2019. Bale processing using the Haybuster tub grinder was completed for the most part on December 12, 2018, apart from a series of operation trials that were completed in August 2019.

Table 19. 2018 Harvesting tree length weight summary at Ellerslie Short-Rotation Woody Crops Technical Development Site.

Planting Year	Clone/Species	Tree Length Weight Summary (kg)
2003	Walker	29,567
2002	Northwest	35,161
2002	Green Giant	21,291
2002	Hyb Aspen	38,599
2002	Walker x 2	71,169
2002	Other	93,242
2004	Hill	122,720
2004	Assiniboine	165,425
2004	Walker	178,085
2005	Hill 615	98,702
2005	Green Giant	23,355
2005	Northwest	31,480
2005	Hill	55,949
2005	Brooks 1	73,904
2005	Hybrid Aspen	12,038

2002-03 High Yield Afforestation

The initial design consisted of nine 50 m x 50 m (0.25 ha) blocks to evaluate clonal suitability. The original design evolved over the course of 17 years. The evolution included the addition of a series of additional trials within gaps resulting from clonal unsuitability and reductions of trial areas caused by City of Edmonton infrastructure installations. Of the additional trials added post 2002, only the 2003 Walker High Yield Mixedwood Trial block warranted detailed monitoring during the 2018 harvesting operations. The 2003 Walker Mixedwood Trial was established in 2003 in a manner consistent with the original clonal trial design (2000 stems/ha) with white spruce seedlings planted between each hybrid poplar within each row (Figure 32). The remainder of the post 2002 installations were harvested and utilized as demonstrations and contractor training opportunities for biomass processing and handling.

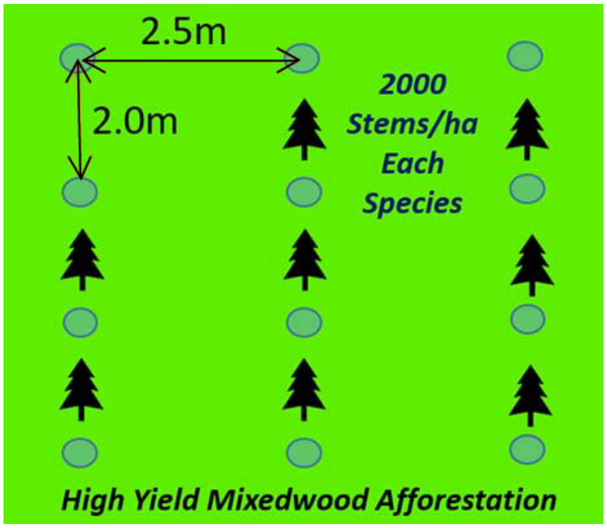


Figure 32. Walker Mixedwood Trial design at Ellerslie Short-Rotation Woody Crops Technical Development Site (2003).

Detailed harvesting monitoring results (Table 20) identify a range of 167.5 to 271.8 or an average of 208.2 tonnes^{-ha} of total aboveground mass, an average of 193.0 m$^{3\text{-}ha}$ merchantable volume (pulp logs) and 69.8 m$^{3\text{-}ha}$ of biomass. This totals 262.8 m$^{3\text{-}ha}$, which equals 15.46 m$^{3\text{-}ha}$ per year Mean Annual Increment (MAI) over 17 years. Feller-Buncher productivity ranged from 29.5 to 60.0 tonnes per productive hour, with an average of 39.6 tonnes per productive hour. The felling cost averaged $7.17 per tonne, ranging from $4.73 to $9.61 per tonne for the blocks established in 2002.

Table 20. Detailed harvesting results of 2002-03 high yield afforestation sites at Ellerslie Short-Rotation Woody Crops Technical Development Site.

Map Legend Number	4	16	6 + 15	14	N/A	3
Clone	2002 Northwest	2002 Hybrid Aspen	2002 Walker	2002 Green Giant	All	2003 Walker
Area (ha)	0.1875	0.25	0.5	0.15	**1.0875**	0.175
Total Pulp Logs (Tonnes)	35.161	38.599	71.169	21.291	**166.220**	29.567
Total Afforestation Biomass (Tonnes)	6.500	29.339	12.622	11.703	**60.164**	6.615
Total Weight (Tonnes)	41.661	67.938	83.791	32.994	**226.384**	36.182
Tonnes/ha	222.190	271.752	167.582	219.962	**208.169**	206.756
Mass/m^3 (kg)	854.695	803.282	766.371	743.782	**792.032**	766.371
M^3/ha (Merchantable Stem)	219.404	192.206	185.731	190.837	**192.980**	220.462
M^3/ha (Full Tree)	259.964	338.303	218.669	295.734	**262.829**	269.785
Feller Buncher Tonnes/Hr (Productive)	59.967	48.013	33.610	29.547	**39.581**	21.173
Feller Buncher Cost/Tonne (Productive)	$4.73	$5.91	$8.45	$9.61	**$7.17**	$13.41
Processor Tonnes/Hr (Productive)	28.170	21.124	17.138	14.147	**18.998**	13.483
Processor Cost/Tonne (Productive)	$9.84	$13.12	$16.18	$19.60	**$14.69**	$20.56
Feller Buncher Tonnes/Hr (Gross)	58.357	45.125	29.754	29.547	**36.797**	21.173
Feller Buncher Cost/Tonne (Gross)	$4.86	$6.29	$9.54	$9.61	**$7.58**	$13.41
Processor Tonnes/Hr (Gross)	20.830	10.631	13.550	11.500	**12.978**	10.209
Processor Cost/Tonne (Gross)	$13.31	$26.08	$20.46	$24.11	**$20.99**	$27.16

Processing productivity ranged from 14.1 to 28.1 tonnes per productive hour, with an average of 19.0 tonnes per productive hour. The processing cost averaged $14.69 per tonne, ranging from $9.84–$19.60 per tonne for the blocks established in 2002.

The harvesting cost for the 2003 Walker Mixedwood Trial site was higher than the average at $13.41 per tonne. The increased harvesting cost can be attributed to the additional "walking" required by the harvester to forward the felled stems roadside without rotating the cab. It is believed that the increased harvesting cost is offset by the value of the "insta-forest" remaining post harvest (Figure 33).

Figure 33. Harvesting and post harvest images of 2003 Walker Mixedwood Trial at Ellerslie Short-Rotation Woody Crops Technical Development Site.

2004 High Yield Afforestation

Detailed harvesting monitoring results (Table 21) identify a range of 164.6 to 220.7 or an average of 196.6 tonnes per hectare of total aboveground mass. The results also demonstrate an average of 208.8 $m^{3\text{-}ha}$ merchantable volume (pulp logs) and 42.1 $m^{3\text{-}ha}$ of biomass. This totals 250.9 $m^{3\text{-}ha}$, which equals 16.73 $m^{3\text{-}ha}$ per year Mean Annual Increment (MAI) over 15 years.

Feller-Buncher productivity ranged from 50.8 to 56.9 tonnes per productive hour, with an average of 54.2 tonnes per productive hour. The felling cost averaged $5.27 per tonne, ranging from $4.99 to $5.58 per tonne for the blocks established in 2004. Processing productivity ranged from 15.9 to 17.9 tonnes per productive hour, with an average of 16.9 tonnes per productive hour. The processing cost averaged $16.59 per tonne, ranging from $15.52 to $18.53 per tonne for the blocks established in 2004.

In addition to detailed monitoring of harvesting activities, the 2004 portion of the Ellerslie SRWC Technical Development Site was selected for focused post harvest assessments, as it was the largest trial within the site. Post harvest assessments were completed during the spring of 2019 to determine post harvest residues, litter and belowground root and stump masses.

Table 21. Detailed harvesting results of 2004 high yield afforestation sites at Ellerslie Short-Rotation Woody Crops Technical Development Site.

Map Legend Number	26	25	24	N/A
Clone	2004 Walker	2004 Assiniboine	2004 Hill	2004 All
Area (ha)	0.95	0.95	0.95	2.85
Total Pulp Logs (Tonnes)	178.085	165.425	122.720	466.230
Total Afforestation Biomass (Tonnes)	31.583	28.932	33.612	94.127
Total Weight (Tonnes)	209.668	194.357	156.332	560.357
Tonnes/ha	220.703	204.586	164.560	196.617
Mass/m^3 (kg)	766.371	807.037	777.197	783.535
M^3/ha (Merchantable Stem)	244.605	215.766	166.211	208.784
M^3/ha (Full Tree)	287.985	253.503	211.736	250.935
Feller Buncher Tonnes/Hr (Productive)	56.936	54.319	50.835	54.215
Feller Buncher Cost/Tonne (Productive)	$4.99	$5.23	$5.58	$5.27
Processor Tonnes/Hr (Productive)	17.631	17.864	14.961	16.868
Processor Cost/Tonne (Productive)	$15.72	$15.52	$18.53	$16.59
Feller Buncher Tonnes/Hr (Gross)	54.863	50.857	46.226	50.825
Feller Buncher Cost/Tonne (Gross)	$5.17	$5.58	$6.14	$5.63
Processor Tonnes/Hr (Gross)	14.843	15.787	13.280	14.666
Processor Cost/Tonne (Gross)	$18.68	$17.56	$20.88	$19.04

Harvest residue mass was determined by collecting all woody debris (> 2 mm diameter) within a series of the 2.5 m x 2.5 m plots (Figure 34). Litter mass was determined by collecting all leaf/litter (including woody debris < 2 mm diameter) within the same series of 2.5 m x 2.5 m plots. The residue samples were then weighed (total wt/plot) and a sub-sample (200 g min) returned to the lab, weighed, dried at 105 °C until constant weight, and weighed again to determine moisture content. The litter samples were then returned to the lab, oven-dried at 65 °C until constant weight and weighed. To determine belowground root and stump mass, three stumps per clone, linked to permanent sample plots stems with average diameters at breast height, were excavated. The stumps remained outside to open air dry for a period of 2 months and were then cleaned of soil and weighed (Figure 35). Samples were returned to the lab, weighed, dried at 105 °C until constant weight, and weighed again to determine moisture content. Oven dried summary data (Table 22) identifies that harvesting activities that include the utilization of roadside harvest residues have an average of 34.28% of the biomass (within block harvest residues, litter, stump and roots) remaining on site. The data also identifies that harvesting and deactivation activities including stump and root removal would remove only 83.86% of the biomass, leaving 16.14% on-site. This would be incorporated into the soil during post deactivation discing activities.

Figure 34. Post harvest sampling within the 2004 high yield afforestation portion at Ellerslie Short-Rotation Woody Crops Technical Development Site.

Figure 35. Post harvest stump and root excavation within the 2004 high yield afforestation portion at Ellerslie Short-Rotation Woody Crops Technical Development Site.

Table 22. Post harvest assessment summary (oven-dried tonnes/ha) of 2004 high yield afforestation sites at Ellerslie Short-Rotation Woody Crops Technical Development Site.

Component	2004 Assiniboine	2004 Hill	2004 Walker	2004 Avg
Pulp Logs	85.854	67.593	91.615	81.687
Chips	15.015	18.513	16.248	16.592
Harvest Residue	6.975	7.502	8.276	7.585
Litter	15.010	16.015	18.610	16.545
Stump + Roots	24.795	20.109	36.472	27.125
Total	**147.649**	**129.733**	**171.221**	**149.534**

The post harvest assessment data can also be used to calculate the carbon sequestration realized over 15 years in the 2004 high yield afforestation portion of the Ellerslie SRWC Technical Development Site. Soil assessments completed in 2004, prior to the initial site preparation treatments and then again in 2019 following the harvest, identify an average increase of 11.9 tonnes per hectare of carbon in the top 15 cm of soil (Table 23). Overall, the high yield afforestation site sequestered an average of 87.7 tonnes per hectare or 321.7 tonnes CO_2 eq per hectare, averaging 21.4 tonnes of CO_2 eq per hectare per year.

Table 23. Carbon* sequestration summary for 2004 high yield afforestation site at Ellerslie Short-Rotation Woody Crops Technical Development Site.

Component	2004 Assiniboine	2004 Hill	2004 Walker	2004 Avg
Pulp Logs	44.129	34.743	47.090	**41.987**
Chips	7.718	9.516	8.351	**8.528**
Stump + Roots	12.744	10.336	18.747	**13.942**
Harvest Residue	3.585	3.856	4.254	**3.898**
Litter	6.755	7.207	8.375	**7.445**
15yr Soil Increase	16.121	7.061	12.591	**11.924**
Grand Total	**91.052**	**72.719**	**99.407**	**87.726**
Above Ground	62.186	55.322	68.070	**61.859**
Below Ground	28.865	17.397	31.337	**25.867**
Total CO_2 eq	**333.856**	**266.635**	**364.494**	**321.662**
Total CO_2 eq/Year	**22.257**	**17.776**	**24.300**	**21.444**

* :@51.4% ratio for hybrid poplar as per CANMET 2019.

Ecosystem Carbon Analysis

Ecosystem carbon (C) (sum of all C pools i.e., utilized biomass, residues, litter, soil, and stumps and roots) in 2018 (pre-harvest), using harvested and utilized volumes (pulp logs and roadside biomass) and post-harvest parameters sampled post harvest in 2019 (residues, litter, soil, and stumps and roots) was greatest under Walker (177.9 Mg C ha^{-1}). It was followed by Assiniboine (169.5 Mg C ha^{-1}) and Hill (151.2 Mg ha^{-1}) across all treatment plots (Figure 36). Carbon accumulation rates in biomass averaged at 5.05 Mg C ha^{-1} year^{-1} for the site for the 15 years of growth. Overall, the high yield afforestation site sequestered an average of 87.7 tonnes per hectare or 321.7 tonnes CO_2 eq per hectare, averaging 21.4 tonnes of CO_2 eq per hectare per year.

The data shows that harvesting activities resulted in 57% of the carbon (merchantable stems and roadside biomass) being removed from the site and 43% remaining on-site following harvesting activities (Figure 37). The data also identifies that harvesting and operational deactivation activities including residue piling and stump and root removal of the 15-year old high yield afforestation plantation would remove only 78% of the ecosystem carbon. The residual 22% (soil increase and litter) would remain on-site prior to future site preparation activities.

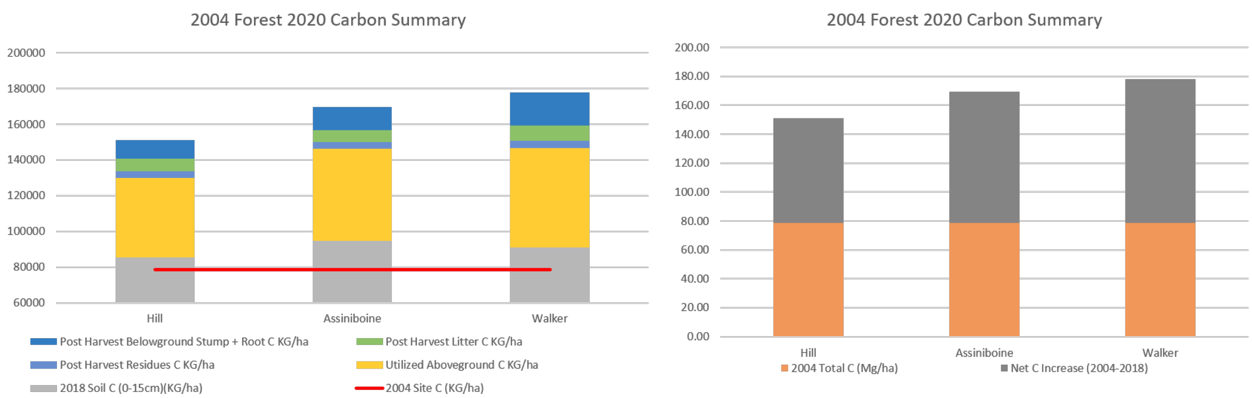


Figure 36. Breakdown of ecosystem carbon from 2004 to 2018 for Forest 2020 Research Trial completed at Ellerslie Short-Rotation Woody Crops Technical Development Site.

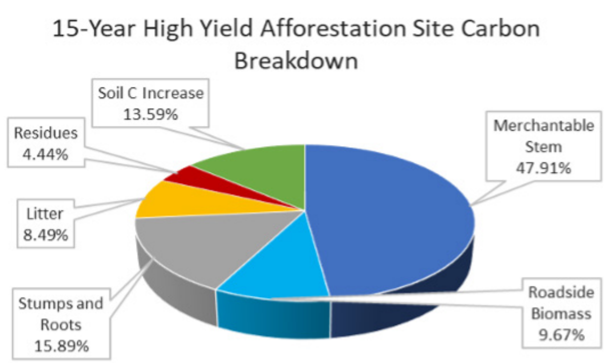


Figure 37. Site carbon breakdown of 15-year old high yield afforestation site at Ellerslie Short-Rotation Woody Crops Technical Development Site.

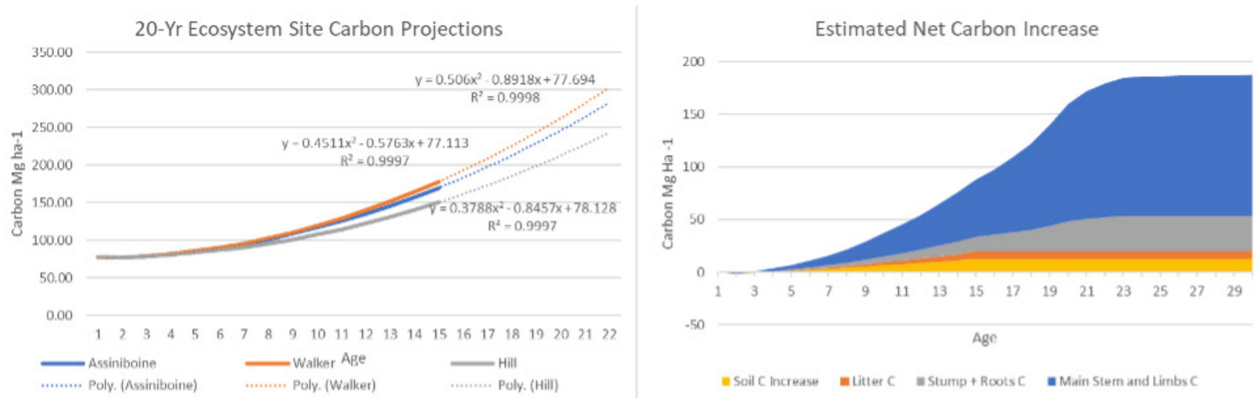


Figure 38. Site carbon projections of high yield afforestation site at Ellerslie Short-Rotation Woody Crops Technical Development Site.

To evaluate the carbon sequestration potential of high yield afforestation plantations, an exercise was completed to estimate the potential net carbon impact of high yield afforestation at Ellerslie if harvesting had been postponed until after year 20. Assuming soil and litter carbon remained stable over the years (Figure 38), the net carbon increase of the site at year 20 is forecasted to be an average of 159.75 Mg C ha^{-1} (585.74 Mg CO^2e ha^{-1} or 29.29 Mg CO^2e ha^{-1} year^{-1}). Based on clonal projections, Walker would result in the highest net increase at 183.77 Mg C ha^{-1} (673.82 Mg CO^2e ha^{-1} or 33.69 Mg CO^2e ha^{-1} yr^{-1}), followed by Assiniboine at 167.54 Mg C ha^{-1} (614.30 Mg CO^2e ha^{-1} or 30.72 Mg CO^2e ha^{-1} year^{-1}) and Hill at 134.24 Mg ha^{-1} (492.23 Mg CO^2e ha^{-1} or 24.61 Mg CO^2e ha^{-1} year^{-1}). Overall, high yield afforestation SRWC plantations have the potential to supply considerable amounts of woody biomass across the Prairies. The establishment of high-yielding plantations provided encouraging data on plantation deployment, survival, growth and C sequestration potential of these systems.

2005 High Yield Afforestation

Detailed harvesting monitoring results (Table 24) identify a range of 132.8 to 167.7 or an average of 151.6 tonnes per hectare of total aboveground mass. The results also demonstrate an average of 143.0 m^{3-ha} merchantable volume (pulp logs) and 43.9 m^{3-ha} of biomass. This totals 186.9 m^{3-ha}, which equals 13.35 m^{3-ha} per year Mean Annual Increment (MAI) over 14 years.

Table 24. Detailed harvesting results of 2005 high yield afforestation sites at Ellerslie Short-Rotation Woody Crops Technical Development Site.

Clone	2005 Northwest	2005 Brooks 1	2005 Green Giant	2005 Hill	All
Map Legend Number	31	45	32 + 43	27, 44 + 46	N/A
Area (ha)	0.3	0.58	0.22	1.342	**2.442**
Total Pulp Logs (Tonnes)	31.48	73.904	23.355	154.651	**283.39**
Total Afforestation Biomass (Tonnes)	8.36	23.376	12.837	42.358	**86.931**
Total Weight (Tonnes)	39.84	97.28	36.192	197.008	**370.321**
Tonnes/ha	132.801	167.724	164.509	146.802	**151.646**
Mass/m³ (kg)	854.695	870.607	743.782	777.197	**811.57**
M³/ha (Merchantable Stem)	122.774	146.359	142.726	148.275	**142.992**
M³/ha (Full Tree)	155.378	192.652	221.178	188.887	**186.856**
Feller Buncher Tonnes/Hr (Productive)	47.649	39.842	54.629	21.62	**28.371**
Feller Buncher Cost/Tonne (Productive)	$5.96	$7.12	$5.20	$13.13	**$7.85**

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(Continued from p. 45)

Clone	2005 Northwest	2005 Brooks 1	2005 Green Giant	2005 Hill	All
Processor Tonnes/Hr (Productive)	17.659	15.17	16.788	12.508	**13.935**
Processor Cost/Tonne (Productive)	$15.70	$18.28	$16.51	$22.16	**$18.16**
Feller Buncher Tonnes/Hr (Gross)	47.649	34.592	12.869	21.62	**23.78**
Feller Buncher Cost/Tonne (Gross)	$5.96	$8.21	$22.06	$13.13	**$12.34**
Processor Tonnes/Hr (Gross)	14.291	13.16	15.905	10.717	**12.008**
Processor Cost/Tonne (Gross)	$19.40	$21.07	$17.43	$25.87	**$20.94**

Feller-Buncher productivity ranged from 21.6 to 54.6 tonnes per productive hour, with an average of 28.4 tonnes per productive hour. The felling cost averaged $7.85 per tonne, ranging from $5.20 to $13.13 per tonne for the blocks established in 2005. Processing productivity ranged from 12.5 to 17.7 tonnes per productive hour, with an average of 13.9 tonnes per productive hour. The processing cost averaged $18.16 per tonne, ranging from $15.70 to $22.16 per tonne for the blocks established in 2005. The remainder of the post 2005 installations were harvested and utilized as demonstrations and contractor training opportunities for biomass processing and handling.

Transportation

Transportation of tree-length material to the Alberta-Pacific Forest Industries Inc. pulp mill (215 km one-way) was completed using a self-loading log truck (Figure 39). A total of 34 loads were delivered, totalling 1032.7 tonnes. Each load averaged 30.37 tonnes. A detailed summary of pulp logs by establishment year and cultivar have been identified in Tables 20, 21 and 24 as "Total Pulp Logs (Tonnes)." The average travel time (6.5 hrs round trip) resulted in an average trucking cost of $35.31 per tonne.

Figure 39. Self-loading log truck used at Ellerslie Short-Rotation Woody Crops Technical Development Site.

2018 Concentrated Biomass Harvesting Summary

The concentrated biomass SRWC sections were harvested using an Anderson BioBaler and a Claas Jaguar Harvester to evaluate the productivity of the two concentrated biomass SRWC harvesting options available in Alberta (Figure 40). Following harvesting activities, the bales created by the BioBaler were processed using an 1130 Haybuster tub grinder previously included in Figure 28.

Figure 40. Anderson BioBaler (Left) and Claas Jaguar Harvester (Right) at Ellerslie Short-Rotation Woody Crops Technical Development Site.

2005 Concentrated Biomass

Harvesting operations were completed using the Anderson BioBaler (BioBaler) for the 2005 concentrated biomass demonstration sites. The BioBaler is based on an agricultural round baler platform, reinforced to handle woody crops and modified with a specialized harvesting header able to cut, condition and feed the stems into the bale compression chamber. The BioBaler is suitable for harvesting larger biomass stems (< 13 cm base diameter), with the potential to harvest up to 40 bales per hour (Anderson website) under optimal conditions. It can average 10 to 15 bales per hour operationally. The end-product is a round, moderately compacted bale that is 122 cm in diameter.

The 2005 concentrated biomass sites were previously harvested in 2008 and 2011. Previous harvesting trials completed at several sites in Saskatchewan, Ontario and at the Ellerslie SRWC Technical Development Site identified an average harvesting cost in excess of $60 per tonne. As an option to reduce harvesting costs, the scheduled 2014 harvesting activities were postponed until 2017 to evaluate the economic and growth impacts of prolonging the usual 3-year rotation schedule to 6 years. The harvest schedule was postponed an additional year to coincide with the harvesting of the entire site. Extending the rotation length to 7 years is not recommended. It resulted in much larger than anticipated site growth, with over 80 oven dried tonnes (ODT) per hectare for the NM-6 hybrid poplar and more than 77 ODT per hectare for the *Salix dasyclados* (*S.*

dac) (Figure 41). The added growth resulted in much larger stems (up to 15 cm) than anticipated. The high volumes associated with the extended rotation length resulted in reduced productivity and a portion of the site (NM-6 and P-38 hybrid poplar and *Salix dasyclados* cultivars) requiring harvesting with the Feller-Buncher (Figure 42). The remaining cultivars were harvested using the BioBaler. A total of 88 bales with an average weight of 382.36 kg per bale (Table 25) were produced. The reduced productivity resulted in a cost of $77.30 per tonne, or an increase of 28.8% when compared to the previous average harvesting cost per ton. The annual above ground biomass growth for the 7-year rotation, on a 13-year-old root system, was the greatest in the NM-6 hybrid poplar. The hybrid poplar averaged 11.48 ODT^{-ha-yr} and the *Salix dasyclados* averaged 11.10 ODT^{-ha-yr} (Figure 43).

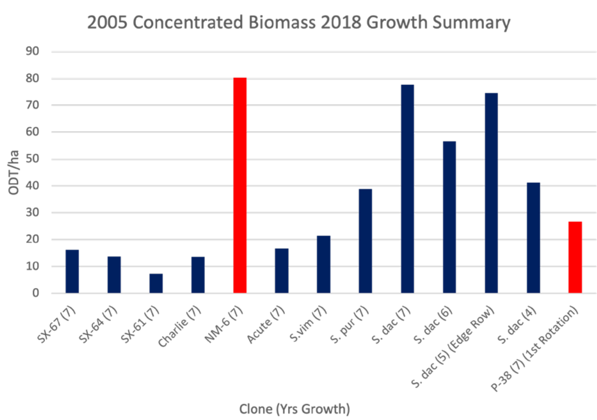

Figure 41. Growth Summary of 2005 concentrated biomass demonstrations at Ellerslie Short-Rotation Woody Crops Technical Development Site (2018).

Figure 42. Feller-Buncher harvesting large diameter 2005 concentrated biomass at Ellerslie Short-Rotation Woody Crops Technical Development Site.

Table 25. BioBaler operational concentrated biomass harvesting summary at Ellerslie Short-Rotation Woody Crops Technical Development Site (2018).

Item	Results
Bales Harvested	88
Mass Harvested (kg)	33647.47
Average Mass Per Bale (kg)	382.36
Average Moisture Content (% Wet Wt)	45.00%
BioBaler Productivity (g/hr)	2788.44
BioBaler Productivity (Bales/hr)	7.29
BioBaler Cost/Tonne (Productive)	$77.30

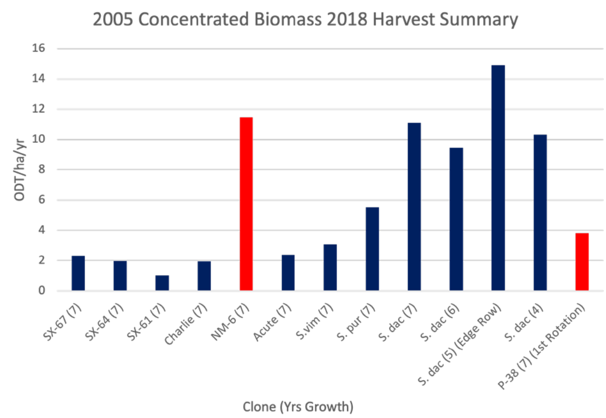

Figure 43. Annual growth summary of 2005 concentrated biomass demonstrations at Ellerslie Short-Rotation Woody Crops Technical Development Site.

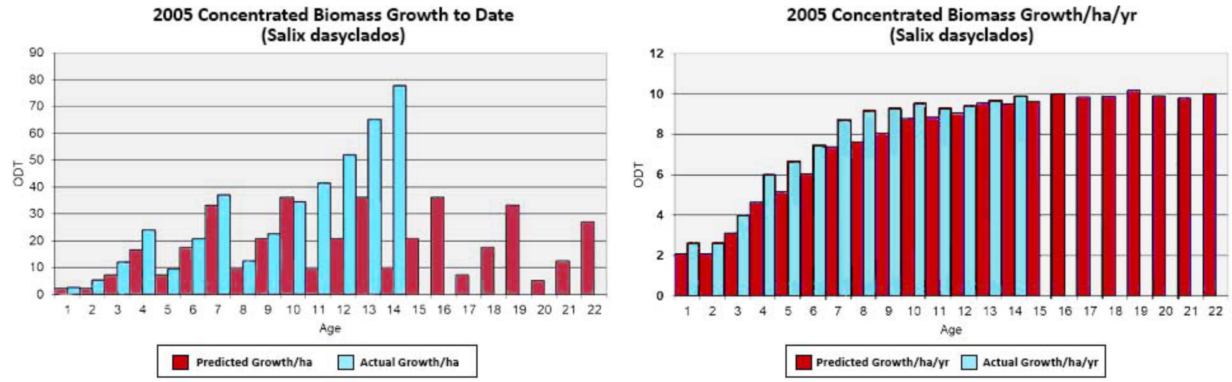

Figure 44. *Salix dasyclados* rotational growth summaries from 2005 to 2018 at Ellerslie Short-Rotation Woody Crops Technical Development Site (2005).

All the remaining cultivars averaged less than 6 ODT^{-ha-yr} with only *Salix purpurea* and P-38 hybrid poplar having an average biomass growth per year above 3.1 ODT^{-ha}. This includes the native salix acutifolia, with an average of 2.38 ODT^{-ha-yr}. Overall, the *Salix dasyclados* concentrated biomass beds established in 2005 have exceeded the growth predicted based on the bio-geo-climatic parameters of the Ellerslie SRWC Technical Development Site, with an average growth per hectare per year of 9.91 ODT's (Figure 44).

A small technology transfer demonstration, nested within the *Salix dasyclados* concentrated biomass beds, showcased the growth associated with various rotation lengths ranging from 4 to 7 years. During the harvested operations, the 80 m^2 plots were harvested. The annual growth ranged from 9.4 ODT^{-ha-yr} for the 6 year rotation and 14.9 for the 5 year rotation, albeit linked to being an edge row. The resulting growth can be viewed as the maximum growth potential for concentrated biomass plantations at Ellerslie.

2006 SUNY Concentrated Biomass Clonal Trial

The SUNY Clonal Trial was previously harvested in 2009 and 2012. As an option to reduce harvesting costs, the scheduled 2015 harvesting activities were postponed until 2018 to evaluate the economic and growth impacts of prolonging the usual 3-year rotation schedule to 6 years. Harvesting operations were completed using the Claas Jaguar Harvester (Harvester). The Harvester utilizes an agricultural forage harvester platform, reinforced to handle woody crops. It produces consistent chipped woody biomass, which is expelled into an adjacent trailer that is towed in unison with the harvester. A ranking of the 24 cultivars, based on growth for all harvesting events from 2006 to 2018, is outlined in Table 26.

Table 26. SUNY Clonal Trial rotational growth summaries from 2006 to 2018 at Ellerslie Short-Rotation Woody Crops Technical Development Site (2006).

Ranking	Clone	Average Green Tonnes-ha-yr Rotation 1	Average Green Tonnes-ha-yr Rotation 2	Average Green Tonnes-ha-yr Rotation 3
1-4	94001 99217-023 99202-011 9871-31	6.24	12.66	15.47
5-8	9882-34 99217-015 99207-018 99201-007	4.82	9.73	11.90

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Ranking	Clone	Average Green Tonnes-ha-yr Rotation 1	Average Green Tonnes-ha-yr Rotation 2	Average Green Tonnes-ha-yr Rotation 3
9–12	SX-64 9882-41 99239-015 9970-036	3.28	8.09	9.88
13–16	9980-005 99113-012 SX-61 9870-1	2.72	6.20	7.58
17–20	SV1 9879 9870-23 9832-49	1.99	5.07	6.20
21–24	00X-032-094 S25 9837-77 00X-026-082	0.76	1.64	2.01

The Harvester is suitable for harvesting small biomass stems (< 8-10 cm base diameter) planted in a 1 or 2 row concentrated biomass design. Extending the rotation length to 6 years resulted in portions of the SUNY trial being too large (> 10 cm base diameter) for the Harvester to handle. To prepare the site for the Harvester, portions of the SUNY Clonal Trial were harvested using the BioBaler.

The remaining portion of the site was harvested using the Harvester at an average of 11.09 green tonnes per productive hour. It cost $41.47 per tonne or $67.72 per ODT (Table 27).

Table 27. SUNY Clonal Trial harvesting summary for the Claas Jaguar Harvester at Ellerslie Short-Rotation Woody Crops Technical Development Site (2018).

Item	Results
Jaguar Cost/hr	$350.00
Tractor Cost/hr	$65.00
Dump Trailer Cost/hr	$45.00
Total Cost/Hr (Without Transport)	$460.00
Average Harvest Time/Load (Productive)	0:24:54
Average Idle Time/Load (Idle)	0:12:45
Average Tonnes/Load	4.60
Jaguar Tonnes/Hr (Productive)	11.09
Jaguar ODT/Hr (Productive)	6.79

(Continued on p. 51)

(Continued from p. 49)

Item	Results
Jaguar Cost/Tonne (Productive)	$41.47
Jaguar Cost/ODT (Productive)	$67.72
Jaguar Tonnes/Hr (Gross)	7.34
Jaguar ODT/Hr (Gross)	4.49
Jaguar Cost/Tonne (Gross)	$62.71
Jaguar Cost/ODT (Gross)	$102.40
Chip Size < 3 mm	5%
Chip Size 3-12.7 mm	76%
Chip Size 12.7-24.1 mm	18%
Chip Size > 24.1 mm	< 1%

During the harvesting operations, the harvester was idle while the loaded trailer was dumped at a designated location 30 metres from the 2006 SUNY Clonal Trial. This accounted for 33.87% of the gross time of harvesting activities and increased the harvesting cost to $62.71 per tonne or $102.40 per ODT. Physical characteristic analysis completed by CanmetEnergy Ottawa of the chipped material produced by the Harvester during the harvest of the 2006 SUNY Clonal Trial identified that 81% of the chips were less than 12.7 mm in size.

2007 Concentrated Biomass Design Trial

The trial was not coppiced in 2007–08, and the 4-year growth was harvested in 2010. To reduce trial management costs, the site grew untouched until 2018. It was harvested using the BioBaler in conjunction with the remainder of the Ellerslie SRWC Technical Development Site. The 2018 harvest resulted in 5590 oven dried kilograms (ODKG) of biomass from the 3-row design plot (1440 m^2 net area) and 5861 ODKG from the 1-row design plot (1620 m^2 net area). This equates to 38.82 ODT (net) per hectare (4.853 ODT^{-ha-yr}) for the 3-row design plot and 36.18 ODT (net) per hectare (4.522 ODT^{-ha-yr}) for the 1-row design plot (Figure 45).

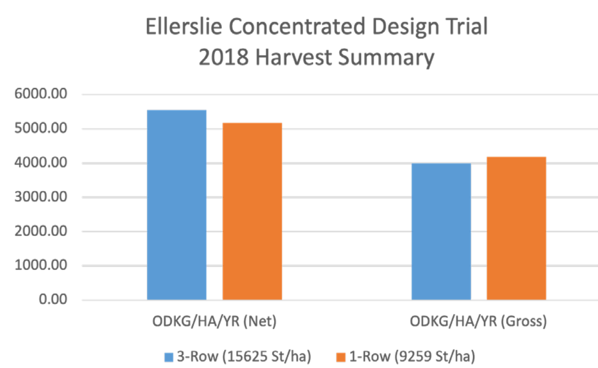


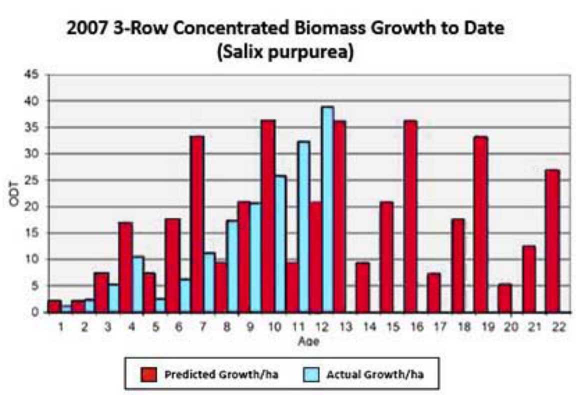
Figure 45. Concentrated Biomass Design harvested growth summary at Ellerslie Short-Rotation Woody Crops Technical Development Site (2018).

Including all harvests, a total of 49.32 ODT per ha have been harvested from the 3-row design portion of the trial and 51.06 ODT per hectare have been harvested from the 1-row design portion of the 2007 Concentrated Biomass Design Trial (Table 28). Overall, for the 12 years of the trial, the 3-row design has produced 4.11 ODT^{-ha-yr} and the 1-Row Design has produced 4.25 ODT^{-ha-yr} (Figures 46 and 47). To date, there is little difference in the growth and yield associated with the 1-row and 3-row establishment designs for concentrated biomass plantations. When compared to the establishment costs of each concentrated biomass establishment design, the differences become evident.

The added costs associated with the additional 6365 cuttings per hectare required for the 3-row establishment design equal $2,864.25 per hectare at $0.45 per cutting.

Table 28. Concentrated Biomass Design Trial harvesting summary at Ellerslie Short-Rotation Woody Crops Technical Development Site (2018).

Parameter	1-Row	3-Row
BioBaler Cost/hr	$78.00	$78.00
Tractor Cost/hr	$165.00	$165.00
Total Cost/hr	$243.00	$243.00
Harvesting	3:36:21	4:19:37
Idle - Operating	1:52:23	1:01:02
Green Tonnes	10.657	10.165
BioBaler Tonnes/Hr (Productive)	2.956	2.349
BioBaler ODT/Hr (Productive)	1.626	1.292
BioBaler Cost/Tonne (Productive)	$82.22	$103.44
BioBaler Cost/ODT (Productive)	$149.49	$188.07
BioBaler Tonnes/Hr (Gross)	1.945	1.902
BioBaler ODT/Hr (Productive)	1.070	1.046
BioBaler Cost/Tonne (Gross)	$124.93	$127.76
BioBaler Cost/ODT (Gross)	$227.14	$232.29
ODKG/Ha (Net)	36181.50	38824.08
ODKG/HA (Gross)	29307.02	27953.34
ODKG/HA/YR (Net)	5168.79	5546.30
ODKG/HA/YR (Gross)	4186.72	3993.33
ODT/HA Harvested to Date	51.06	49.32
ODT/HA/YR Harvested to Date	4.25	4.11
Establishment Cost/ha	$6,717.00	$9,581.25
Establishment Cost/ Tonne To Date	$131.55	$194.27



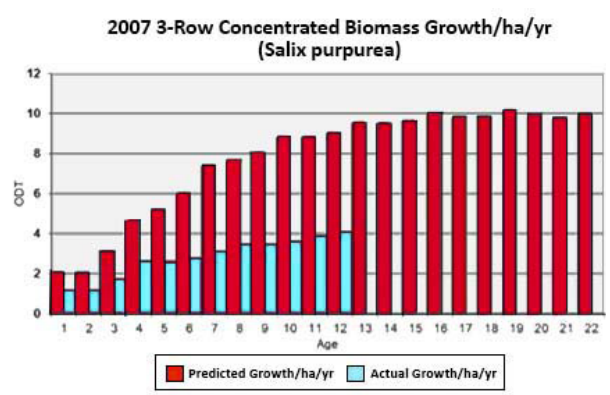


Figure 46. Concentrated Biomass Design: 3-row (*S. purpurea*) rotational growth summaries from 2005 to 2018 at Ellerslie Short-Rotation Woody Crops Technical Development Site (2007).

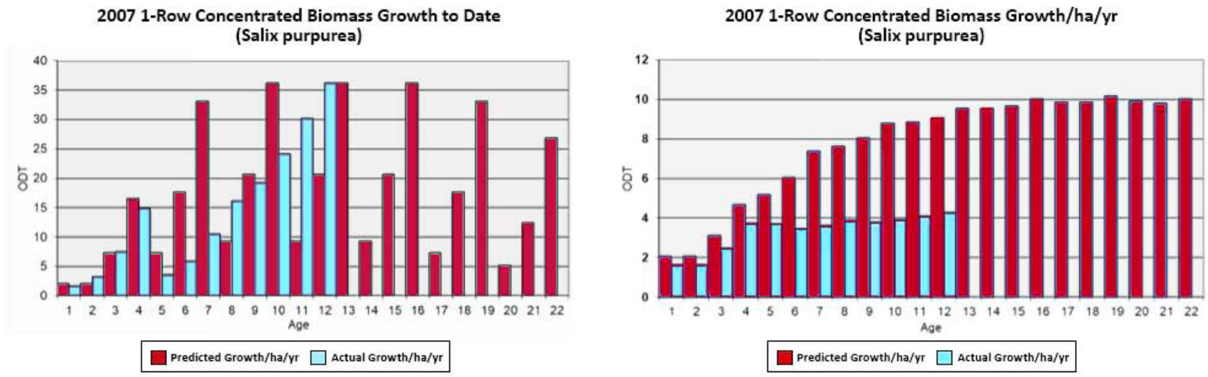


Figure 47. Concentrated Biomass Design: 1-row (*S. purpurea*) rotational growth summaries from 2005 to 2018 at Ellerslie Short-Rotation Woody Crops Technical Development Site (2007).

To date, this equates to an added cost of \$62.72 per ODT of biomass harvested for the 3-row concentrated biomass design (\$194.28/ODT) when compared to the 1-row concentrated biomass design (\$131.56/ODT). As a comparison, the *Salix dasyclados* cultivar of the 2005 Concentrated Biomass Trial (3-row design) has produced 138.7 ODT^{-ha} to date, equalling \$69.08 per ODT of biomass harvested. The 2005 high yield afforestation sites ($\$3250^{-ha}$ establishment costs) averaged 79.35 ODT^{-ha}, equalling \$40.96 per ODT of biomass harvested. The 2004 high yield afforestation sites averaged 98.28 ODT^{-ha}, equalling \$33.07 per ODT of biomass harvested.

2018-19 Woody Biomass Processing Summary

Woody biomass physical characterization (material size) requirements of wood biomass facilities differ based on facility design and production parameters. To evaluate the costs associated with the production and supply of various sizes of woody biomass, the Canadian Forest Service completed detailed timing of woody biomass processing. They evaluated the bales harvested from the concentrated biomass sites by the BioBaler using a Haybuster 1130 tub grinder, which was supplied by Agriculture and Agri-Food Canada in Indian Head, SK. They also evaluated the roadside residues from the high yield afforestation sites using the Pezzolato PTH700 Drum Chipper, which was supplied by Biomass Innovations in Drayton Valley, AB.

Chipping operations using the Pezzolato drum chipper were conducted to obtain accurate roadside residue weights for each high yield afforestation cultivar. This was done to evaluate equipment productivity and cost, and to create products for physical characterization and physiochemical analysis. An excess of 208 tonnes of chips were produced from roadside harvest residues (Table 29) and weighed by cultivar.

Table 29. Pezzolato PTH700 drum chipper operational summary at Ellerslie Short-Rotation Woody Crops Technical Development Site (2018-19).

Parameters	Harvest Residues - With Screens	Harvest Residue - Without Screens	Concentrated Biomass - With Screens
Pezzolato PTH700 Chipper Cost/hr	$175.00	$175.00	$175.00
Tractor (Chipper) Cost/hr	Included	Included	Included
Excavator (Loading) Cost/hr	$44.09	$44.09	$44.09
Total Cost/hr	$219.09	$219.09	$219.09
Mass (Green) Tonnes	206.24	2.52	35.15
Chipping Time (hh:mm:ss)	97:30:00	00:30:00	07:35:00
Chipping Time (Dec)	97.50	0.5	7.583
Mass/hr (Green Tonnes)	2.12	5.03	4.64
Mass/hr (ODT)	1.13	3.24	2.37
Chipping Cost/Green Tonne	$103.58	$43.56	$47.26
Chipping Cost/ODT	$194.20	$67.68	$92.60
Chip Size			
< 3 mm	8.00%	4.00%	Not Analyzed
3-12.7 mm	48.00%	22.00%	
12.7-24.1 mm	41.00%	48.00%	
24.1-31.3 mm	2.00%	12.00%	
> 31.3 mm	0.00%	14.00%	
Total	100.00%	100.00%	

A detailed summary of chips produced by establishment year and cultivar have been identified in Tables 20, 21 and 24 as “Total Afforestation Biomass (Tonnes). ”The objective of the roadside residue processing was to create the “best quality chip possible” to investigate possible product options. To achieve this, the counter knife and drum knives were positioned at their narrowest spacing. The drum chipper was operated with the screens in place. With this configuration, physical characteristic analysis completed by CanmetEnergy Ottawa identified 56% of the chips produced were less than 12.7 mm in size and 98% were 24.1 mm or less. The productivity was 2.12 tonnes per hour, at a cost of $103.58 per tonne. Residues processed with the counter knife and drum knives positioned at their widest spacing with the screens removed had only 26% of chips at less than 12.7 mm and 74% at 24.1 mm or less. The productivity was 5.03 tonnes per hour at a cost of $43.56 per tonne.

Tub grinding operations using the Haybuster 1130 tub grinder were conducted to evaluate equipment productivity and cost for processing of hybrid poplar and Salix bales. They were harvested using the BioBaler from concentrated biomass sites. They were completed to create woody biomass products of various sizes for potential end-users and physical characterization and physiochemical analysis. A series of demonstrations were completed by processing a minimum of 20, 1.22 m diameter newly harvested round bales. This was accomplished using the Haybuster 1130, equipped with different screens. These ranged from screens with 5” holes (5” screens) to screens with 2” holes (2” screens). Productivity of the Haybuster 1130 ranged from 12.86 tonnes per hour or $21.77 per tonne (5” screens), to 5.86 tonnes per hour or $47.81 per tonne (2” screens) (Table 30).

Table 30. Haybuster 1130 tub grinder operational summary at Ellerslie Short-Rotation Woody Crops Technical Development Site (2018–19).

	Recently Harvested Bales					Stored (3 Yr+) Bales	
Processin Screens	5" Screens	4" Screens	3" Screens	2" Screens	1" Screens*	2" Screens	1" Screens*
Haybuster 1130 Cost/hr	$50.00	$50.00	$50.00	$50.00	$50.00	$50.00	$50.00
Tractor (Haybuster) Cost/hr	$165.00	$165.00	$165.00	$165.00	$165.00	$165.00	$165.00
Tractor (Loading) Cost/hr	$65.00	$65.00	$65.00	$65.00	$65.00	$65.00	$65.00
Total Cost/hr	$280.00	$280.00	$280.00	$280.00	$280.00	$280.00	$280.00
Mass (Green) kg	8665.45	8003.22	7264.79	17063.87	9034.36	10850.05	5425.03
Grinding Time (hh:mm:ss)	0:40:26	0:39:00	0:48:50	2:54:50	1:45:55	2:02:57	0:33:30
Grinding Time (Dec)	0.67389	0.65000	0.81389	2.91389	1.76528	2.04917	0.55833
Mass/hr (Green Tonnes)	12.86	12.31	8.93	5.86	5.12	5.29	9.72
Mass/hr (ODT)	7.07	6.77	4.91	3.22	2.81	4.11	7.53
Grinding Cost/Green Tonne	$21.77	$22.74	$31.37	$47.81	$54.71	$52.88	$28.82
Grinding Cost/ODT	$39.59	$41.35	$57.03	$86.93	$99.47	$68.21	$37.17

* Using material previously processed with 2" screens.

To conduct the demonstration, the Haybuster 1130 was equipped with the screens with 1" holes (1" screens). The bales were first processed using the 2" screens. The mulched woody biomass was then loaded and reprocessed with the Haybuster 1130, equipped with 1" screens. The added cost of the reprocessing at 5.12 tonnes per hour was $54.71 per tonne. The final cost was $102.52 per tonne. The cost included processing the round bales produced from the BioBaler to a size where over 95% of the material was less than 24.1 mm (summarized previously in Table 29).

Additional demonstrations were conducted using historic bales that were stored on-site from previous harvesting activities. The storage of the bales in the field (uncovered) resulted in an approximate 50% reduction in moisture content to 22.47%, based on wet weight. The long-term storage of the bales also reduced the processing cost from $86.93 per ODT for the newly harvested bales, to $68.21 per ODT for the stored bales when using the 2" screens. The newly harvested material dropped from $99.47 per ODT to $37.17 per ODT using the 1" screens. The older, drier material also resulted in smaller physical size profile, with 96% of the material processed from older bales using 2" screens being less than 24.1 mm in size compared to 68% for the newly harvested bales processed with the 2" screens (Table 14).

2019 Woody Biomass Compaction Prototype Trial

The cost associated with transportation of woody biomass is an important factor in any woody biomass supply chain. Overall cost is often identified as the limiting factor with the economic feasibility of woody biomass utilization. To reduce the transportation cost of woody biomass, a local Albertan company, Biomass Innovations Ltd. (from Drayton Valley, AB), has designed and built a woody biomass compaction unit prototype powered by a 165 horsepower diesel engine. The prototype consists of a collection hopper, equipped with belt conveyors that transport the woody biomass into the compaction and baling unit. The biomass is fed to a rear-mounted compaction and baling system that produces compacted round bales (1.22 m in diameter and 1.18 m in width). The bales are wrapped in an average of 584 grams of plastic or biodegradable wrap. The unit is easily loaded and transported on a lowbed trailer, enabling its transportation from site to site (Figure 48). As part of the "Refining Woody Biomass Supply Chain Options through Technology Development and Analysis Using a Controlled Afforestation Biomass Production Site in Alberta" project, CWFC staff conducted an operational assessment of the prototype. Utilizing material originally harvested by the BioBaler and processed by the 1130 Haybuster during the "Woody Biomass Physical Characterization Trial", a series of tests were conducted using material that was processed with 1", 2", 3" and 5" screens.

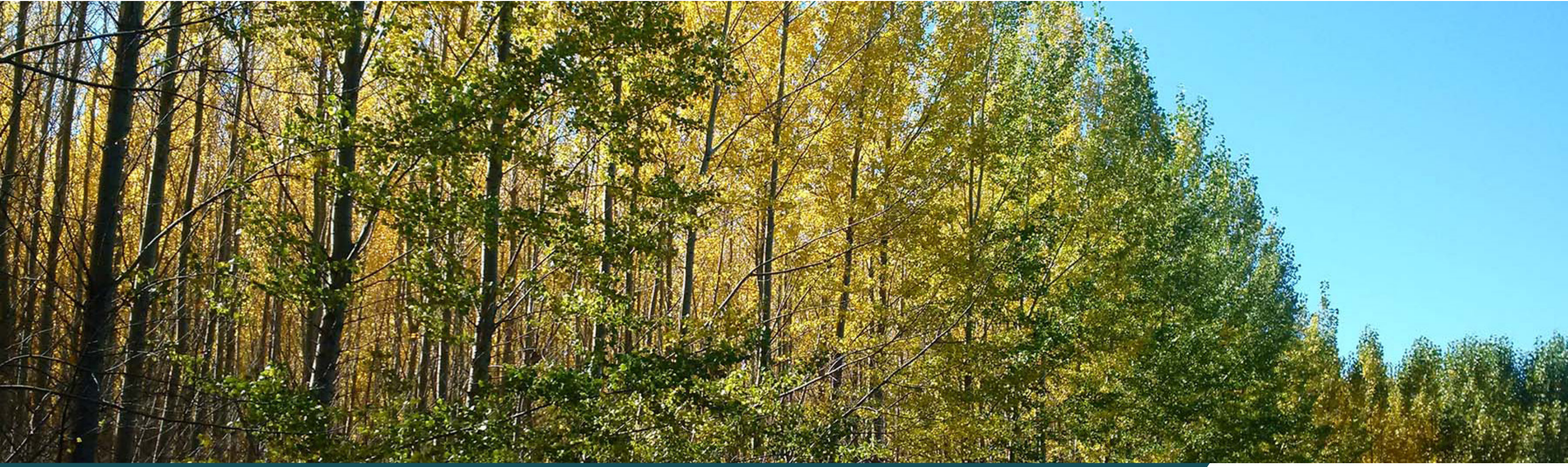
Figure 48. Woody biomass compaction unit prototype operational testing at Ellerslie Short-Rotation Woody Crops Technical Development Site.

The trial resulted in a total of 81 bales produced by the BioBaler, averaging 300.4 kg/bale or 162.4 ODKG/bale. This totalled 24,336 kg. They were re-processed using the 1130 Haybuster to be compacted into 37 bales, averaging 555 kg/bale or 353.1 ODKG/bale. This included 584 grams of wrapping (Table 31).

Each compacted bale was consistent in size with the original bales produced by the BioBaler, except that the bulk density of the compacted bales increased from 210.7 kg/m³ to 402.2 kg/m³. The increased bulk density raised transport payload capacity. This ranged from 46.12% for the material process using the 1130 Haybuster equipped with 5" screens, to 124.96% for the material processed using the 1130 Haybuster equipped with 1" screens. This resulted in reduced transportation cost for the woody biomass. The feasibility of incorporating a compaction treatment prior to transporting woody biomass tested prototype would be directly proportional to hauling distance. The operational information collected from this trial is included in Appendix XII.

Table 31. Biomass Innovations Ltd. compaction unit prototype bale summary evaluated in 2019 at Ellerslie Short-Rotation Woody Crops Technical Development Site.

Processed Size	1" Screens	2" Screens	3" Screens	5" Screens	All
BioBaler Bale Summary					
BioBaler Bales	21	21	19	20	81
BioBaler Mass	6775	5810	6219	5533	24336
Average Mass/Bale (kg)	322.62	276.65	327.29	276.65	300.45
Moisture Content (wet)	49.50%	44.35%	50.50%	39.50%	45.96%
ODKG	3421.38	3233.07	3078.16	3347.47	13150.65
Volume/Bale (m³)	1.38	1.38	1.38	1.38	1.38
Bulk Density (kg/m³)	226.21	193.98	229.49	193.98	210.67
Truckload Wt (kg @ 42 Bales/Load)	13550	11619.3	13746.18	11619.3	12618.75
Compacted Bale Summary					
Compacted Bales	8	9	9	11	37
Compacted Bale Mass	5806	5265	5012	4447	20530
Average Mass/Bale (kg)	725.75	585.00	556.89	404.25	554.86
Moisture Content (wet)	41.35%	39.05%	39.05%	25.97%	36.35%
ODKG	3405.49	3209.06	3054.86	3291.99	12961.39
Volume/Bale (m³)	1.38	1.38	1.38	1.38	1.38
Bulk Density (kg/m³)	526.13	424.10	403.72	293.06	402.24
Truckload Wt (kg @ 42 Bales/Load)	30481.50	24570.00	23389.33	16978.31	23303.98
Compaction Impact Summary					
Bulk Density Change (kg/m³)	299.92	230.11	174.23	99.08	191.58
Bulk Density Increase (%)	132.58%	118.63%	75.92%	51.07%	90.94%
Truck Payload Change (kg)	16931.50	12950.70	9643.15	5359.01	10685.23
Truck Payload Increase (kg)	124.96%	111.46%	70.15%	46.12%	84.68%



Discussion

The Ellerslie Short Rotation Woody Crops Technical Development Site has been a stable piece in the SRWC National Network of Sites, showcasing SRWC practices and growth potential in Canada. Over the life of Ellersie, the consistent goal of the Technical Development Group has been to find answers to operational questions related to the establishment, management, economics and sustainability of SRWC in Canada. The ability to evaluate full rotation, high-yield afforestation and concentrated biomass SRWC plantations at Ellerslie and to compare the results to other establishment and management protocols across Canada provided important insight to the impacts of the various components required to grow, manage and utilize woody biomass from SRWC.

Ellerslie was home to many formal knowledge exchange and technical transfer events for local, national and international groups. It was the site for countless informal tours for local stakeholders, industry representatives and scientific researchers. It has been the testing and proving ground for operational and focused SRWC research in Canada. The site has been the home of operational research trials responsible for the conception, development, refinement and validation of SRWC establishment and management protocols, growth and yield and site suitability models, woody biomass utilized for SRWC, industrial revegetation, reclamation and bio-remediation projects in Canada.

Ellerslie has also hosted continuous evaluations and operational testing for woody biomass harvesting, processing and mid supply chain options to advance woody biomass delivery and utilization in Canada. The site has been utilized for many SRWC research trials including, but not limited to:

1. Clonal growth and yield trials for hybrid poplar, trembling and hybrid aspen, and salix cultivars
2. Comparing carbon stocks and soil surface efflux of hybrid poplar stands with other land uses
3. Ecosystem carbon stocks and distribution under different land-uses
4. Soil fertility and sustainability of short rotation woody crop production for bioenergy
5. Soil respiration in four different land use systems
6. Carbon, water and energy exchanges of a hybrid poplar plantation
7. Evapotranspiration, surface conductance and water-use efficiency of two young hybrid-poplar plantations
8. Stand age and productivity control soil carbon dioxide efflux and organic carbon dynamics

The authors understand that the reasons for establishing SRWC differ greatly between the various stakeholders and landowners. Ellerslie provided a unique opportunity to evaluate, from establishment to end-user, growth and yield, physical and chemical characterization, carbon sequestration, and economics associated with high-yield afforestation (hybrid poplar and aspen) and concentrated afforestation (willow and hybrid poplar) plantations in Canada. To evaluate the results of the operational research conducted at Ellerslie, one must understand the goals (management objectives) of the Technical Development Group responsible for the establishment and management of the operational SRWC research. The management objectives were simple – maximize growth and minimize costs associated with growing woody biomass using SRWC techniques. The key findings of the operational research conducted at Ellerslie to meet these management objectives are extensive. However, they can be summarized by establishment, management and woody biomass harvesting and processing phases by evaluating the growth and yield and economic implications of SRWC.

Key Finding # 1 – Site Selection (better quality lands grow more woody biomass at a lower cost when consistent and proven establishment and management protocols are utilized)

The Technical Development Group has been fortunate to have had the opportunity to conduct operational SRWC research on lands classified by Canada Land Inventory for agriculture as Site Class 1. This site type is generally described to be level to nearly level, deep and well to imperfectly drained. It also possesses effective nutrient and water holding capacity. The University of Alberta research site provided the location to evaluate the growth potential of SRWC in the Prairies. Understanding that there is a finite amount of financial resources available and that decisions are needed to identify suitable lands for SRWC, the CFS has developed a SRWC Site Suitability Index modelling system (Joss et al., 2008) to predict SRWC growth and yield for agricultural lands in Canada (Figure 49). Extensive validation and evaluation of the modelled results with actual high-yield afforestation site sampling has validated that "better quality lands grow more woody biomass at a lower cost when consistent and proven establishment and management protocols are utilized."

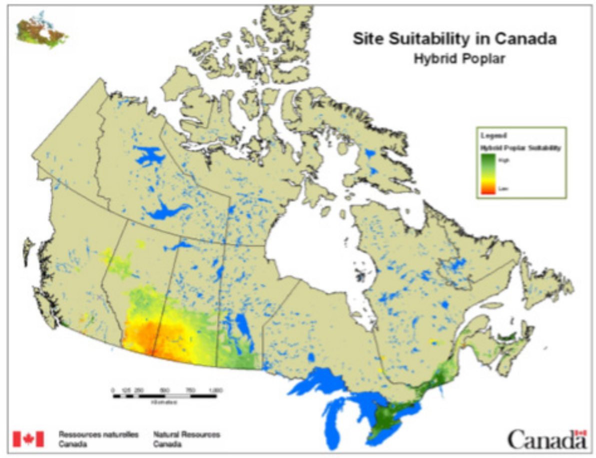


Figure 49. Site Suitability Index in Canada for hybrid poplar. (Image supplied by B. Joss)

The term "marginal lands" has been used on numerous occasions when evaluating SRWC potential in Canada. An important factor that needs to be accounted for when referring to "marginal lands" is that not all marginal lands are considered equal. Each location may have a different reason for being designated as "marginal." These reasons/factors need to be identified and incorporated into the estimated site preparation cost. Another important factor is that growth expectations need to be defined accordingly, depending on the reason(s) for being deemed "marginal." The CFS Site Suitability Index modelling tool is a proven option for estimating growth and yield potential (if SRWC evaluation is viable). Figure 50 illustrates the estimated (Ellerslie Site - SSI) and actual growth and yield results for the 2004 Forest 2020 high-yield afforestation operational research site at Ellerslie.

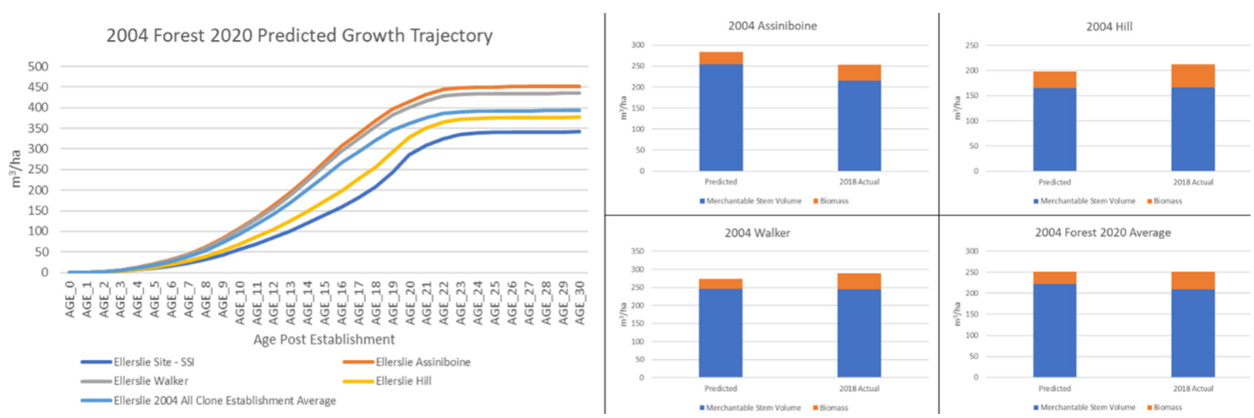


Figure 50. Predicted and actual harvest volumes (2018) for the 2004 Forest 2020 high-yield afforestation site at Ellerslie Short-Rotation Woody Crops Technical Development Site.

Key Finding # 2 – Site Preparation (create an environment in which trees love to grow)

Establishing successful SRWC plantations is a costly undertaking. The cost of the planting material needed in year-1 is one of the major components of the high cost. That is why it is key to ensure that site preparation treatments "create an environment in which trees love to grow." SRWC require adequately mixed soils that will enable them to thrive for their entire 12 to 25-year rotation to reach their growth potential and to allow stakeholders and landowners to realize the economic benefits. Operational research at Ellerslie, coupled with evaluations of plantations across the Prairies, validated that SRWC plantations require a suitable rooting environment of 25 to 30 cm over the entire plantation. This is to allow seedlings to extend their roots deeper into the soil. This enables seedlings to be better prepared to deal with the effects of periodic climatic events, such as drought and flooding. The landscape is littered with examples of trees planted in an afforestation environment that have not reached their full potential. In many instances, the reduced long-term growth can be linked to inadequate site preparation and vegetation management. Attempts to reduce site preparation costs of SRWC plantations by using selective site preparation options along the planting row have resulted in reduced long-term growth and increased vegetation management costs. This process can be accomplished either by completing intermittent deep mixing using a narrow ripper tooth site preparation treatment or by limiting mixing depth using improper discing attachments. These treatments are all counter productive and result in increased risk of mortality and rotational woody biomass costs. These options forgo long-term volume growth for a short-term benefit.

Key Finding # 3 – Clone Selection (do your homework)

Fast growing species such as hybrid poplar and Salix have similar benefits in terms of yield and remediation capabilities. Each one has a large number of clonal varieties that require and thrive in different environments. Although the different clones may look similar, not all clones are suitable for all locations. The key to selecting the most suitable clones for your specific location is to "do your homework." There are multiple options for assistance when selecting acceptable clonal varieties for your location. Contact local landowners that have existing hybrid poplar or Salix plantations, or reach out to afforestation experts in your local area for guidance. The Technical Development Group has been involved in establishing and monitoring SRWC plantations across Canada with regional experts. They may be able to assist in reaching out to local experts to select the suitable clones for your area.

Key Finding # 4 – SRWC System Selection (select the system that best links to your management objectives)

The three most common types of SRWC plantations (systems) are high yield afforestation, mixedwood afforestation and concentrated woody biomass plantations. The key is to select the system that "best links to your management objectives." Each system has its operational benefits and hindrances and a series of potential end uses at time of harvest (Table 32). For example, high-yield afforestation and mixedwood afforestation plantations are expected to have large diameter (> 20 cm) stems with a high white wood to bark ratio that can be used for conventional forest products. These products include lumber, pulp, oriented strand board and woody biomass. Concentrated biomass plantations are expected to have small diameter (< 10 cm) stems with a high bark to white wood ratio that is primarily used for woody biomass.

Table 32. Potential operational benefits, hindrances and end uses for SRWC Systems.

Benefits	Hindrances	End Uses
	High-Yield Afforestation	
Multiple Product Options	Single Rotation	Conventional Forest Products
Reduced Establishment Costs	Long Wait Time to Harvest	
Longer Carbon Storage Potential		Woody Biomass
Reduced Harvesting Costs		
Harvesting Equipment Readily Available		
	Mixedwood Afforestation	
Same as High-Yield Afforestation	Increased Harvesting Costs	Conventional Forest Products
Longest Forest Cover Duration (> 80 Years)	Long Wait Time to Harvest	
Extended Carbon Storage Potential		Woody Biomass
	Concentrated Biomass	
Multiple Rotations	Increased Establishment Costs	Woody Biomass
Reduced Wait Time for Utilizing Biomass	Increased Harvesting Costs	
	Lack of Available Harvesting Equipment	

Regardless of the SRWC system chosen, the completion of harvesting operations in 2018 at Ellerslie identified minimal differences in woody biomass yields between high-yield afforestation and concentrated biomass systems (Table 33). The woody biomass harvested for growth between year-7 and year-14 (interpreted as the maximum annual harvest volumes based on the site lifecycle) resulted in a mean harvest of 10.60 green tonnes per hectare, per year. This is consistent with the 2005 high-yield afforestation sites' mean harvest of 10.58 green tonnes per hectare, per year.

Overall, the Technical Development Group recommends an average of 6 to 10 oven-dried tonnes per hectare, per year be used for full rotational SRWC production during the planning stage.

Table 33. Annual woody biomass yields (green tonnes per hectare per year) for high-yield afforestation and concentrated biomass sites at Ellerslie Short-Rotation Woody Crops Technical Development Site.

Site	Age	Min	Max	Mean
		High-Yield Afforestation		
2002 Sites	17	9.86	15.99	12.39
2004 Sites	15	10.42	13.98	13.15
2005 Sites	14	7.57	11.98	10.58
		Concentrated Biomass		
2005 Sites (3rd Rotation Only)	14	1.89	20.18	10.60

Key Finding # 5 – SRWC Economics (make sure you understand where you will land before you jump)

As previously mentioned, the management objectives of the Technical Development Group were to maximize growth and minimize costs. When evaluating growth, the results of operational research at Ellerslie show that the growths of high-yield afforestation and concentrated woody biomass SRWC systems were consistent when the recommended establishment and management protocols for SRWC were followed. The results also validate the benefits from a growth and cost perspective, incorporating full coverage site preparation treatments using existing agriculture implements to a depth of 25 to 30 cm. Operational vegetation management trials validated the importance of maintaining a site free of competing vegetation until crown closure. They also validated the cost effectiveness and ecological benefits of shallow (2 to 5 cm depth) mechanical cultivation. In some cases, chemical herbicide applications may be selected as the treatment of choice. It may be less difficult to implement, but the overall costs are often higher to achieve the same vegetation management results.

To evaluate the impacts of SRWC options from an economic perspective, the Technical Development Group participated in an economic analysis of SRWC options using operational research results from Ellerslie. The results (Table 34) showed that high-yield afforestation demonstrated the greatest economic potential. The orchard style plantations reduced establishment and harvesting costs, and yield the greatest potential volume of fibre per hectare.

Table 34. Economic analysis summary of SRWC incorporating data obtained at Ellerslie Short-Rotation Woody Crops Technical Development Site.

SRWC Design	High Yield Afforestation			Concentrated Biomass		
Species	Hybrid Poplar and/or Aspen			Hybrid Poplar and/or Willow		
Management Design	1100-1600 Stems/ha			1-Row (9,260 Stems per Ha)	2-Row (14,815 Stems per Ha)	3-Row (15,625 Stems per Ha)
Site Productivity	Low	Average	High	Maximum Estimated Yields		
Rotation Age (Years)	20	20	20	22	22	22
Rotations	1	1	1	7	7	7
Average Tree DBH @ Harvest (cm)	25-30	25-30	2-30	< 10	< 10	< 10
Average Height @ Harvest (m)	18-24	18-24	18-24	4-6	4-6	4-6
Stem Volume Yield/ha at Harvest (m^3)	285.54	361.58	415.38	N/A	N/A	N/A
Biomass Yield/ha at Harvest (m^3)	22.13	30.72	23.97	N/A	N/A	N/A
Total Aboveground Yield/ha at Harvest (m^3)	307.67	392.30	439.35	N/A	N/A	N/A
Total Belowground Biomass/ha at Harvest (m^3)	71.16	90.11	103.51	N/A	N/A	N/A
Total Site Yield/ha Available at Harvest (m^3)	378.83	482.40	542.86	N/A	N/A	N/A
Total Aboveground (Full Tree) Yield/ha/yr (m^3)	15.38	19.61	21.97	N/A	N/A	N/A
Stem Volume Yield/ha at Harvest (ODT)	109.52	138.68	164.30	N/A	N/A	N/A
Biomass Yield/ha at Harvest (ODT)	8.49	11.78	9.48	241.00	241.00	241.00

(Continued on p. 64)

(Continued from p. 63)

SRWC Design	High Yield Afforestation			Concentrated Biomass		
Species	Hybrid Poplar and/or Aspen			Hybrid Poplar and/or Willow		
Management Design	1100-1600 Stems/ha			1-Row (9,260 Stems per Ha)	2-Row (14,815 Stems per Ha)	3-Row (15,625 Stems per Ha)
Site Productivity	Low	Average	High	Maximum Estimated Yields		
Total Aboveground Yield/ha at Harvest (ODT)	118.01	150.46	173.78	241.00	241.00	241.00
Total Belowground Biomass/ha at Harvest (ODT)	27.29	34.56	40.94	N/A	N/A	N/A
Total Site Yield/ha Available at Harvest (ODT)	145.30	185.02	214.73	241.00	241.00	241.00
Total Aboveground (Full Tree) Yield/ha/yr (ODT)	**5.90**	**7.52**	**8.69**	**10.95**	**10.95**	**10.95**
SRWC Economic Data						
Establishment and Management Costs/ha	$3,250.00	$3,250.00	$3,250.00	$6,717.00	$9,216.75	$9,581.25
Establishment and Management Costs /ODT	$27.54	$21.60	$18.70	$27.87	$38.24	$39.76
Harvest Cost/ODT	$25.90	$25.90	$25.90	$52.36	$52.36	$52.36
Processing Cost/ODT	$19.19	$16.45	$14.39	$31.66	$31.66	$31.66
Transport Cost/ODT (50km Radius)	$16.79	$16.79	$16.79	$16.79	$16.79	$16.79
Harvest, Processing and Transport (50km) Costs/ODT	$61.88	$59.14	$57.08	$100.81	$100.81	$100.81
Total Delivered Cost/ODT	$89.42	$80.74	$75.79	$128.68	$139.05	$140.56
Delivered Biomass Value/ODT (@$50/Green Tonne + 50%MC)	$100.00	$100.00	$100.00	$100.00	$100.00	$100.00
Net Delivered Biomass Value/ODT (@$50/Green Tonne + 50%MC)	**$10.58**	**$19.26**	**$24.21**	**-$28.68**	**-$39.05**	**-$40.56**

These findings of Jensen et al. (2021) are consistent with the findings of Shooshtarian et al. (2018). Incorporating non-operational values can potentially create scenarios where any SRWC system is viable. The key is to "make sure you understand where you will land before you jump." Specifically, once established, understand that the management, harvesting and product options of the selected SRWC system all have long-term economic implications. Incorporating values associated with carbon offsets may enhance the economic scenario of each SRWC scenario. However, the results showcase that the net delivered values associated with the low site productivity of high-yield afforestation are higher than the maximum estimated yields of concentrated biomass, which remain unchanged. This is due to the offset values being linked to biomass yields and only being applicable to end users.

Various impediments in 2020 restricted landowners from receiving income from afforestation plantations. The largest impediments in 2020 were 1) the lack of consistent, country-wide afforestation protocols in Canada and 2) availability of options for individual landowners and non-industrial stakeholders to realize a monetary benefit from carbon sequestration.

Results from applied afforestation research conducted by the CWFC at the Ellerslie (Figure 51) shows that merchantable 15-year-old high-yield afforestation hybrid poplar plantations have resulted in an average site carbon increase from 78 to 164 tonnes per hectare, or 110% when compared to pre-establishment levels. The 57.58% of resulting carbon was harvested and taken off-site, while 42.42% remained on-site following harvesting operations. Afforestation plantations (in an agricultural scenario) allow for longer cropping rotations and result in increased carbon sequestration sinks or offsets. If a country wide SRWC protocol existed across Canada, landowners would be able to realize a steady rate of return from their plantations every year prior to the final harvest.

The harvesting operations and monitoring associated with the completion of full-rotational SRWC operational research at Ellerslie have validated the growth projections associated with high yield afforestation site suitability models and establishment protocols. These protocols were developed by CFS operational researchers. They included validated information from establishment to end-user on topics such as growth and yield, physical and chemical characterization, carbon sequestration, and economics associated with high-yield afforestation (hybrid poplar and aspen) and concentrated afforestation (willow and hybrid poplar) plantations in Canada.

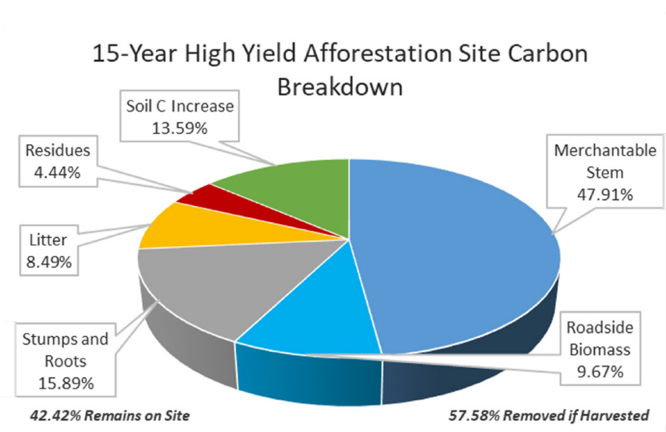


Figure 51. Summary of utilized and residual carbon components of 2004 high-yield afforestation plantations at Ellerslie Short-Rotation Woody Crops Technical Development Site.

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From establishment to harvest, there have been many researchers and staff from various government agencies and academia that have utilized the Ellerslie SRWC Technical Development Site and whose work, guidance and "fingerprints" are all over the site. These groups have been instrumental in the completion of this report. Though too numerous to mention individually, their assistance has been greatly appreciated over the years. A few of the key personnel include Dick Puurveen, Susan Cassidy, Nancy Mayo, Cheryl Ritz, Jared Salvail, Mike Hobbs, Alberto Orchansky, Lionel Jensen, Karl Benke, Shaun Ridell, Alex Evans, Antoine Blanchette, Hughie Jones, Kirsten Mortensen, Cassy Stor, Brent Joss, Tony Kryzanowski and Wendy Mills. The authors are forever indebted to you all!

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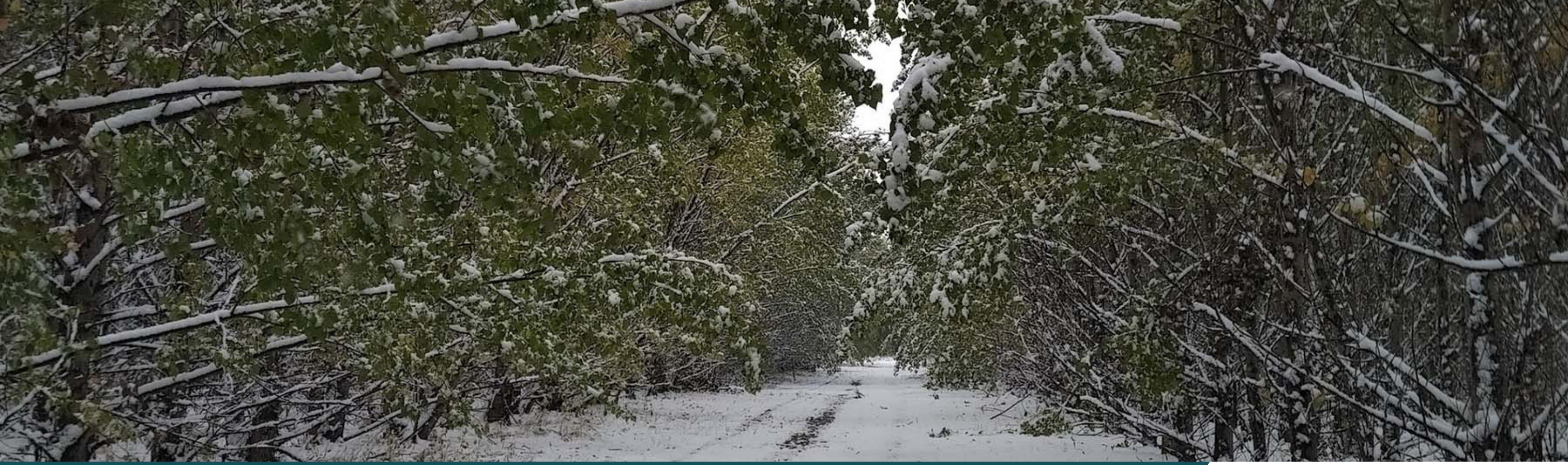

Appendix I

Table A1. Hybrid poplars, hybrid aspens and willow clones tested under the high-yield afforestation and concentrated biomass management designs at Ellerslie Short-Rotation Woody Crops Technical Development Site, Edmonton, Alberta.

Species	Clone Name	Alternative Name	Parentage
Hybrid Poplar	Assiniboine	OPW-130L-86	*P. deltoides* × *P.* × *petrowskyana*[1]
Hybrid Poplar	Brooks 1	Griffin	*P. deltoides* × *P.* × *petrowskyana*[2]
Hybrid Poplar	Brooks 6	Green Giant	*P. deltoides* × *P.* × *petrowskyana*[2]
Hybrid Poplar	DN-17	Robusta	*P. deltoides* × *P. nigra*
Hybrid Poplar	DN-182	Raverdeau	*P. deltoides* × *P. nigra*
Hybrid Poplar	DN-2	Baden 431	*P. deltoides* × *P. nigra*
Hybrid Poplar	DN-34	Imperial, Eugenei	*P. deltoides* × *P. nigra*
Hybrid Poplar	DN-5	Gelrica	*P. deltoides* × *P. nigra*
Hybrid Poplar	DN-74		*P. deltoides* × *nigra*
Hybrid Poplar	Hill	FNS 44–55	*P. deltoides* × *P.* × *petrowskyana*[2]
Hybrid Poplar	Katepwa	OPW-180H-86	*P. deltoides* × *P.* × *petrowskyana*[1]
Hybrid Poplar	NM-06	Max-5	*P. nigra* × *P. maximowiczii*
Hybrid Poplar	Northwest		*P. deltoides* × *P. balsamifera*
Hybrid Poplar	P-Chey		*P. deltoides* × *P. deltoides*
Hybrid Poplar	P38P38	Quebec poplar	*P. balsamifera* × *P. simonii*
Hybrid Poplar	Prairie Sky	MRS #78101	*P. deltoides* × *P. nigra*
Hybrid Poplar	Q-1150		
Hybrid Poplar	Tristis		*P. balsamifera* × *P. tristis*
Hybrid Poplar	Walker	FNS 44–52	*P. deltoides* × *P.* × *petrowskyana*[2]
Improved Aspen	1115		*P. tremuloides* × *P. tremula*
Improved Aspen	1122		*P. tremuloides* × *P. tremula*
Improved Aspen	1126		*P. tremuloides* × *P. tremula*
Improved Aspen	1152		*P. tremuloides* × *P. tremula*
Improved Aspen	1156		*P. tremuloides* × *P. tremula*
Improved Aspen	1157		*P. tremuloides* × *P. tremula*
Improved Aspen	1160		*P. tremuloides* × *P. tremula*
Improved Aspen	3047		*P. tremuloides* × *P. tremula*
Improved Aspen	3085		*P. tremuloides* × *P. tremula*
Improved Aspen	3085		*P. tremuloides* × *P. tremula*
Improved Aspen	3089		*P. tremuloides* × *P. tremula*

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Species	Clone Name	Alternative Name	Parentage
Improved Aspen	3104		*P. tremuloides* × *P. tremula*
Improved Aspen	3106		*P. tremuloides* × *P. tremula*
Improved Aspen	3109		*P. tremuloides* × *P. tremula*
Improved Aspen	3120		*P. tremuloides* × *P. tremula*
Improved Aspen	19309		*P. tremuloides* × *P. tremula*
Improved Aspen	94-007-A		*P. tremuloides* × *P. tremula*
Salix	94001		*S. purpurea*
Salix	00X-026-082		*S. eriocephala*
Salix	00X-032-094		*S. eriocephala*
Salix	9832-49		*S. eriocephala*
Salix	9837-077		*S. eriocephala*
Salix	Acute	Acute leaf willow	*S. acutifolia*
Salix	Allegany	99239-015	*S. koriyanagi*
Salix	Alpha		*S. viminalis*
Salix	Canastota	9970-036	*S. miyabeana*
Salix	Charlie		*S. alba* × *S.* × *glatfelterii*[3]
Salix	Cicero	9870-001	*S. miyabeana*
Salix	Fish Creek	9882-34	*S. purpurea*
Salix	Hotel		*S. purpurea*
Salix	India		*S. dasyclados*
Salix	Juliet		*S. eriocephala*
Salix	Marcy	9870-23	*S. miyabeana*
Salix	Millbrook	99217-015	*S. purpurea* × *S. miyabeana*
Salix	Oneida	9980-005	*S. purpurea* × *S. miyabeana*
Salix	Oneonta	9879	*S. purpurea* × *S. miyabeana*
Salix	Onondaga	99113-012	*S. koriyanagi*
Salix	Otisco	99201-007	*S. viminalis* × *S. miyabeana*
Salix	Owasco	99207-018	*S. viminalis* × *S. miyabeana*
Salix	Pseudo		*S. alba*
Salix	S25		*S. eriocephala*
Salix	Saratoga	99217-023	*S. purpurea* × *S. miyabeana*
Salix	Sherburne	9871-031	*S. miyabeana*
Salix	SV1		*S.* × *dasyclados*[4]
Salix	SX61		*S. miyabeana*
Salix	SX64		*S. miyabeana*
Salix	SX67		*S. miyabeana*
Salix	Tully Champion Viminalis	99202-011	*S. viminalis* × *S. miyabeana* *S. viminalis*
Salix	Wolcott	9882-41	*S. purpurea*

[1] Crossed with unknown male parent
[2] *P.* × *petrowskyana* = *P. laurifolia* × *P. nigra*
[3] *S.* × *glatfelterii* = *S. nigra* × *S. amygdaloides*
[4] *dasyclados* = *S. viminalis* × *S. cinerea* × *S. caprea*

Appendix II

Table A2. List of operational research trials and corresponding placements (Figure 21) of hybrid poplar, hybrid aspens, willow clones and understory tree species tested at Ellerslie Short-Rotation Woody Crops Technical Development Site, Edmonton, Alberta (2002 to 2018).

No.	Trial Type	Species and Clone Information	Year Established
1	High Yield Afforestation	DN-34 (Fallow)	2002
2	High Yield Afforestation	DN-34	2002
3	Mixedwood Afforestation	Walker	2003
4	High Yield Afforestation	Northwest	2003
5	Clonal Suitability Trial	Hybrid Poplar Clonal Trial[1]	2003
6	High Yield Afforestation	Walker	2002
7	Operational Stock Assessment Trial	Forest 2020 | C2C Stock Trial[2]	2004
8	High Yield Afforestation	DN-182 (Fallow)	2002
9	Operational Fall Planting Trial	Improved Aspen Fall Planting Trial[3]	2003
10	High Yield Afforestation	DN-182	2002
11	Operational Whip Suitability Trial	Hybrid Poplar Whip Trial[4]	2003
12	High Yield Afforestation	Walker	2002
13	Operational Clonal Suitability Trial	Hybrid Aspen	2002
14	High Yield Afforestation	Green Giant	2002
15	High Yield Afforestation	Walker	2002
16	High Yield Afforestation	Hybrid Aspen	2002
17	Operational Clonal Suitability Trial	Walker	2002
18	Operational Clonal Suitability Trial	Northwest	2002
19	Operational Clonal Suitability Trial	Green Giant	2002
20	Operational Clonal Suitability Trial	Green Giant	2002
21	Operational Clonal Suitability Trial	Walker	2002
22	Operational Stoolbeds	Hybrid Poplar Stool Beds[5]	2003
23	Operational Clonal Suitability Trial	Northwest	2002
24	Forest 2020 Operational Trial	Hill	2004
25	Forest 2020 Operational Trial	Assiniboine	2004
26	Forest 2020 Operational Trial	Walker	2004
27	Forest 2020 Operational Stock Trial (615)	Hill	2005
28	Mixedwood Species Suitability Trial	White Spruce Understory	2015
29	Mixedwood Species Suitability Trial	Black Spruce Understory	2015

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No.	Trial Type	Species and Clone Information	Year Established
30	Mixedwood Species Suitability Trial	Douglas Fir Understory	2015
31	Forest 2020 Operational Stock Trial (615)	Northwest	2005
32	Forest 2020 Operational Stock Trial (415)	Green Giant	2005
33	WEY Operational Clonal Trial	Improved Aspen 3085	2010
34	WEY Operational Clonal Trial	Improved Aspen 3109	2010
35	WEY Operational Clonal Trial	Improved Aspen 3120	2010
36	WEY Operational Clonal Trial	Improved Aspen 94-007-A	2010
37	WEY Operational Clonal Trial	Improved Aspen 3047	2010
38	WEY Operational Clonal Trial	Improved Aspen 3089	2010
39	WEY Operational Clonal Trial	Improved Aspen 3104	2010
40	WEY Operational Clonal Trial	Improved Aspen 3106	2010
41	WEY Operational Clonal Trial	Improved Aspen 3109	2010
42	WEY Operational Clonal Trial	Improved Aspen 94-007-A	2010
43	Forest 2020 Operational Stock Trial (415)	Green Giant	2005
44	Forest 2020 Operational Stock Trial (415)	Hill	2005
45	Forest 2020 Operational Stock Trial (415)	Brooks-1	2005
46	Forest 2020 Operational Stock Trial (415)	Hill	2005
47	Forest 2020 Operational Stock Trial (615)	Hill	2005
48	Operational Stoolbeds	Bioenergy Stool Beds[6]	2005
49	Concentrated Biomass	India	2005
50	Concentrated Biomass	Pseudo	2005
51	Concentrated Biomass	Hotel	2005
52	Concentrated Biomass	Alpha	2005
53	Concentrated Biomass	Acute	2005
54	Concentrated Biomass	NM-06	2005
55	Concentrated Biomass	Charlie	2005
56	Concentrated Biomass	P38P38	2010
57	Concentrated Biomass	SX-61, SX-64, SX-67	2005
58	Concentrated Biomass	P38P38	2011
59	Concentrated Biomass Design Trial (1-Row)	Hotel	2007
60	Concentrated Biomass	Improved Aspen 3085	2010
61	Concentrated Biomass	Improved Aspen 3106	2010
62	Concentrated Biomass Design Trial (3-Row)	Hotel	2007
63	Concentrated Biomass	Green Giant	2008
64	Concentrated Biomass	P38P38	2011
65	Concentrated Biomass	P38P38	2011
66	Concentrated Biomass	Improved Aspen 3120	2010
67	Concentrated Biomass	Improved Aspen 3089	2010
68	Concentrated Biomass	P38P38	2011
69	SUNY Clonal Trial	SUNY Willow Clonal Trial[7]	2006
70	Operational Clonal Suitability Trial	DN-74	2014
71	Operational Concentrated Biomass	SX-67	2006
72	Operational Concentrated Biomass	Alpha	2006
73	Operational Concentrated Biomass	Juliet	2006

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No.	Trial Type	Species and Clone Information	Year Established
74	Operational Concentrated Biomass	Charlie	2006
75	Operational Concentrated Biomass	SV-1	2006
76	Operational Concentrated Biomass	SX-64	2006
77	Operational Concentrated Biomass	Hotel	2005
78	Operational Concentrated Biomass	Hotel	2005
79	Operational Concentrated Biomass	Hotel	2005
80	Operational Concentrated Biomass	Hill	2005
81	Operational Concentrated Biomass	Hill	2005
82	Operational Concentrated Biomass	Walker	2005
83	Operational Concentrated Biomass	Walker	2005
84	Operational Concentrated Biomass	Charlie	2005
85	Operational Concentrated Biomass	Charlie	2005
86	Operational Concentrated Biomass	India	2005
87	Operational Concentrated Biomass	India	2005
88	Operational Concentrated Biomass	SX-61	2006
89	Operational Concentrated Biomass	SX-61	2006
90	Operational Concentrated Biomass	SX-64	2006
91	Operational Concentrated Biomass	SX-64	2006
92	Operational Concentrated Biomass	SX-67	2006
93	Operational Concentrated Biomass	SX-67	2006
94	Improved Aspen Demonstration	Improved Aspen	2005
95	Operational Concentrated Biomass	P38P38	2011
96	Operational Concentrated Biomass	Improved Aspen 3047	2010
97	Operational Concentrated Biomass	P38P38	2011
98	Operational Concentrated Biomass	P38P38	2011
99	Mixedwood Species Suitability Trial	White Spruce Understory	2014
100	Mixedwood Species Suitability Trial	Black Spruce Understory	2014
101	Mixedwood Species Suitability Trial	Douglas Fir Understory	2014

[1] See Appendix III, OP Site 5 for specific hybrids tested.
[2] See Appendix III, OP Site 7 for specific hybrids and stock types tested.
[3] See Appendix III, OP Site 9 for specific clones tested.
[4] See Appendix III, OP Site 11 for specific hybrids tested.
[5] See Appendix III, OP Site 22 for specific clones propagated.
[6] See Appendix III, OP Site 48 for specific clones propagated.
[7] See Appendix III, OP Site 69 for specific clones tested.

Appendix III

Overview of high-yield afforestation and concentrated biomass plantation trials conducted at Ellerslie SRWC Technical Development Site, Edmonton, Alberta.

Sites Established in 2002

The oldest section of the Ellerslie was established in 2002 (Figure 52) as part of the afforestation clonal transect trial, funded through the Feasibility Assessment of Afforestation for Carbon Sequestration (FAACS) Initiative. The trial consisted of a transect of several sites established from Piney, Manitoba to Peace River, Alberta to evaluate clonal site suitability of various hybrid poplar and aspen cultivars (Figure 53). Initial site preparation was completed using a 3-phase site preparation tool developed by Canadian Forest Service staff. The tool consisted of a ripper shank + high-speed mixer + elevated bedding attachment. The site preparation was designed to create a series of parallel beds with a spacing of 2.5 m, centre-to-centre. The planting material (30 cm, unrooted cuttings for all hybrid poplar and rooted seedlings for the hybrid aspen) was planted at a spacing of 2.0 m within the beds to create a density of 2000 stems ha^{-1}. The initial design consisted of nine 50 m x 50 m (0.25 ha) blocks to evaluate clonal suitability. The original design evolved over the 17 years due to the addition of a series of supplementary trials within gaps, resulting from clonal unsuitability and City of Edmonton infrastructure installations.

Figure 52. Section of Ellerslie SRWC Technical Development Site established in 2002.

Figure 53. Clonal transect establishment overview.

Operational Research Sites 1 and 2

Established as part of the Clonal Transect Suitability Trial, the entire 0.25 ha was originally planted with DN-34 hybrid poplar cuttings (25 cm) to evaluate the suitability of the clone in the Edmonton, Alberta area. The area suffered multiple years of extensive damage during overwintering, resulting in re-sprouting from the base and a large component of dead standing stems. In 2010, Area 1 was deactivated and left fallow until the site was harvested in 2018. Area 2 was retained for demonstration purposes. In 2018, the site was excluded from harvest to protect the magpie nests that were inhabited by northern flying squirrels (*glaucomys sabrinus*).

Operational Research Site 3

Established as part of the Clonal Transect Suitability Trial, the entire 0.25 ha was originally planted with hill hybrid poplar cuttings (25 cm) to evaluate the suitability of the clone in the Edmonton, Alberta area. Due to poor stock quality from the supplier, the entire 0.25 ha block suffered post planting mortality. (See Sites Established in 2003 for more information)

Operational Research Site 4

Established as part of the Clonal Transect Suitability Trial, the entire 0.25 ha was originally planted with northwest hybrid poplar (615 container) to evaluate the suitability of the clone in the Edmonton, Alberta area. In 2007, 15 metres of the southern edge of the plantation was removed for the City of Edmonton's water line installation. The remaining area was actively sampled until it was harvested in 2018.

Operational Research Site 5

An operational hybrid poplar clonal trial was established to evaluate (on a small scale) the operational suitability of each clone in the Edmonton, Alberta area. In 2007, 15 metres of the southern edge of the plantation was removed for the City of Edmonton's water line installation. The remaining clones were retained for demonstration purposes until 2018, at which time they were harvested and chipped for the operational testing of a small-scale chipping system.

Table A3. Clones evaluated in 2002-03 Operational Hybrid Poplar Clonal Trial.

Map Legend Number	Clones (North to South)	Year Established
5	Walker	2003
	Northwest	2003
	Hill	2003
	DN-34	2003
	DN-5	2003
	DN-182	2003
	Prairie Sky	2003
	Green Giant	2003
	Tristis	2002
	Q-1150	2002
	Assiniboine	2003
	NM-6	2003
	DN-17	2003
	DN-74	2003
	Brooks 1 (Removed 2007)	2003
	P-Chey (Removed 2007)	2003
	Walker (Removed 2007)	2003
	Green Giant (Removed 2007)	2003
	Prairie Sky (Removed 2007)	2003

Operational Research Site 6

Established as part of the Clonal Transect Suitability Trial, the entire 0.20 ha was originally planted with Walker hybrid poplar bareroot seedlings supplied by Lakeshore Nursery in Saskatoon, Saskatchewan to evaluate the suitability of the clone in the Edmonton, Alberta area. The area was actively sampled until it was harvested in 2018.

Operational Research Sites 8 and 10

Established as part of the Clonal Transect Suitability Trial, the entire 0.25 ha was originally planted with DN-182 hybrid poplar cuttings (25 cm) to evaluate the suitability of the clone in the Edmonton, Alberta area. The area suffered multiple years of extensive damage during overwintering, resulting in re-sprouting from the base and a large component of dead standing stems. In 2003, Area 8 was deactivated and left fallow until the site was harvested in 2018. Area 10 was retained for demonstration purposes. In 2018, Area 10 was harvested and chipped for the operational testing of a small-scale chipping system.

Operational Research Site 12

Established as part of the Clonal Transect Suitability Trial, the entire 0.125 ha was originally planted with Walker hybrid poplar container stock to evaluate the suitability of the clone in the Edmonton, Alberta area. The area was periodically sampled until it was harvested in 2018.

Operational Research Site 13

Originally established as a buffer for the Clonal Transect Suitability Trial, the entire 0.05 ha was originally planted with open pollinated hybrid aspen bareroot stock to evaluate the various physical characteristics of each open pollinated cross and the suitability of the clone in the Edmonton, Alberta area. The area was periodically operationally evaluated until it was harvested in 2018 as a portion of the perimeter harvesting strata.

Operational Research Site 14

Established as part of the Clonal Transect Suitability Trial, the entire 0.25 ha was originally planted with Green Giant hybrid poplar 30 cm cuttings supplied by Lakeshore Nursery in Saskatoon, Saskatchewan to evaluate the suitability of the clone in the Edmonton, Alberta area. In 2003, white spruce seedlings were planted within each row at the midpoint between the hybrid poplar. A portion of the area was used as an operational sub-trial to evaluate the year-2 growth impacts of incorporating various seedling shelters using Free-Gro, Mesh Shelters (Figure 54). Four shelter sizes were installed in 2 x 25-unit plots, with a control plot of 25 unsheltered units between each plot. All shelter sizes resulted in equal increased growth when compared to the control units. Although the shelters resulted in short term increased growth, once the shelters were removed after the 6-week trial, stem rigidity was lacking in the sheltered stems. At the end of the 2004 growing season, with the lack of rigidity persisting in the sheltered stems, all hybrid poplar stems within the rows used for the shelter trial were coppiced at a height of 10 cm. Post establishment DNA analysis completed by Saskatchewan Research Council in Saskatoon, Saskatchewan found that Green Giant and Brooks 6 were deemed to have the same genetic properties. They were identified as identical clones with different names created by the suppliers. The area was actively sampled until it was harvested in 2018.

Figure 54. Free-Gro shelter sub-trial within Operational Research Site 14.

Operational Research Site 15

Established as part of the Clonal Transect Suitability Trial, the entire 0.25 ha was originally planted with Walker hybrid poplar container seedlings supplied by PRT Nursery, Saskatchewan to evaluate the suitability of the clone in the Edmonton, Alberta area. The area was actively sampled until it was harvested in 2018.

Operational Research Site 16

Established as part of the Clonal Transect Suitability Trial, the entire 0.25 ha was originally planted with open pollinated hybrid aspen bareroot stock to evaluate the various physical characteristics of each open pollinated cross and the suitability of the clone in the Edmonton, Alberta area. Hybrid aspens (originating from Minnesota) were created by crossbreeding two closely related species of aspen. In this case, they are the artificial interspecific hybrids of *P. tremuloides* and *P. tremula* or *P. davidiana* (Chinese or Korean poplar, which is a variety of *P. tremula*). In 2003, white spruce seedlings were planted within each row at the midpoint between the hybrid aspen. A portion of the area was used as an operational sub-trial to evaluate the year-2 growth impacts of incorporating 60 cm x 60 cm vegetation control mats for each hybrid aspen within the odd numbered rows. Operational evaluations conducted to year-5 of the sub-trial showed no growth impacts, positive or negative. Therefore, it was deemed that incorporating vegetation control mats in the future was not economically feasible. The area was actively sampled until it was harvested in 2018.

Operational Research Site 17

Established as a buffer for the Clonal Transect Suitability Trial, the entire 0.05 ha was originally planted with Walker bareroot stock to evaluate the operational clonal suitability of the clone in the Edmonton, Alberta area. The area was periodically operationally evaluated until it was harvested in 2018 as a portion of the perimeter harvesting strata.

Operational Research Site 18

Established as a buffer for the Clonal Transect Suitability Trial, the entire 0.05 ha was originally planted with northwest bareroot stock (1.5 m tall) to evaluate the impacts of incorporating larger planting stock and operational clonal suitability of the clone in the Edmonton, Alberta area. The area was periodically operationally evaluated until it was harvested in 2018 as a portion of the perimeter harvesting strata.

Operational Research Site 19

Established as a buffer for the Clonal Transect Suitability Trial, the entire 0.05 ha was originally planted with Brooks 6 bareroot stock (1.0 m tall) to evaluate the impacts of incorporating larger planting stock and operational clonal suitability of the clone in the Edmonton, Alberta area. The area was periodically operationally evaluated until it was harvested in 2018 as a portion of the perimeter harvesting strata.

Operational Research Site 20

Established as a buffer for the Clonal Transect Suitability Trial, the entire 0.10 ha was originally planted with Green Giant cuttings (25 cm, not conditioned) to evaluate the impacts of ignoring pre-planting conditioning for unrooted cuttings and operational clonal suitability of the clone in the Edmonton, Alberta area. The area was periodically operationally evaluated until it was harvested in 2018 as a portion of the perimeter harvesting strata.

Operational Research Site 21

Established as a buffer for the Clonal Transect Suitability Trial, the entire 0.05 ha was originally planted with northwest container stock to evaluate operational clonal suitability of the clone in the Edmonton, Alberta area. The area was periodically operationally evaluated until harvested in 2018 as a portion of the perimeter harvesting strata. Figure 55 showcases the 17-year growth achieved by Operational Research Site 21.

Figure 55. Example of 17-year northwest hybrid poplar growth of Operational Research Site 21.

Sites Established in 2003

Information obtained by the Technical Development Group during year 1 of operational SRWC research at Ellerslie resulted in additional questions and identified potential SRWC options moving forward. In addition to the vegetation management and protocol development outlined in the previous Operational Protocol Development Overview section, four additional operational research sites were established in 2003 (Figure 56).

Figure 56. Operational research sites established at Ellerslie SRWC Technical Development Site in 2003.

Operational Research Site 3

The Walker Mixedwood Trial was planted with Walker hybrid poplar cuttings (25 cm) at a density consistent with the 2002 Clonal Transect Suitability Trial (2000 stems/ha). The goal of this trial was to mimic native boreal mixedwood forests. White spruce seedlings were planted within each row at the midpoint between the hybrid poplar. The area was actively sampled until it was harvested in 2018.

Operational Research Site 9

The Improved Aspen Fall Planting Trial was established in October 2003 using container seedlings grown in the NoFC greenhouse. Improved aspen seedlings were propagated from root cuttings supplied by Daishowa-Marubeni International (DMI) Ltd. These improved aspen cuttings were part of the controlled crosses developed within the tree breeding program of the Western Boreal Aspen Cooperative. This organization was comprised of four member companies: DMI, Weyerhaeuser Canada, Ainsworth and Footner Forest Products. The trial was evaluated in 2004 and retained for demonstration purposes until 2018, at which time the area was harvested and chipped for the operational testing of a small-scale chipping system.

Table A4. Hybrid aspen fall planting trial conducted at the Ellerslie Short-Rotation Woody Crops Technical Development Site.

Map Legend Number	Clones	Year Established	Stock Types	Survival %
9	Improved Aspen 1115	2003	Container	100
	Improved Aspen 1152	2003	Container	100
	Improved Aspen 1126	2003	Container	100
	Improved Aspen 1122	2003	Container	100
	Improved Aspen 1157	2003	Container	80
	Improved Aspen 19309	2003	Container	100
	Improved Aspen 1160	2003	Container	100
	Improved Aspen 1156	2003	Container	40

Operational Research Site 11

The Operational Whip Suitability Trial was established using 2 m non-rooted hybrid poplar whips to evaluate the survival potential and growth implications of large unrooted planting stock. To improve the success rate of whip planting, the lower buds and branches were removed. This left 4 to 6 live buds near the top to avoid excessive moisture loss when the whip started to grow in the spring and drip irrigation was utilized. There are differences between various clones based on how well their roots grow when planted as an unrooted, dormant cutting. For this trial, the Technical Development Group tested 6 different hybrid poplar clones in 2003. The trial was evaluated in 2004 for survival. It was retained for demonstration purposes until 2018, at which time the area was harvested and chipped for the operational testing of a small-scale chipping system. Long-term evaluations identified no benefits associated with the use of larger whips (for enhancing growth).

Operational Research Site 22

The operational stoolbeds were established using 25 cm cuttings to grow material to harvest annually. This material was designated for use in future operational research trials. Using the elevated beds established in 2002, 2 rows of cuttings for each clone were planted in a single bed at a spacing of 20 cm x 20 cm. The stoolbeds were utilized until the site was harvested in 2018.

Table A5. Hybrid poplar whip trials conducted at the Ellerslie Short-Rotation Woody Crops Technical Development Site.

Map Legend Number	Clones	Year Established	Stock Types
11	DN-2	2003	Non-rooted whips
	DN-17	2003	Non-rooted whips
	DN-34	2003	Non-rooted whips
	DN-182	2003	Non-rooted whips
	Katepwa	2003	Non-rooted whips
	NM-06	2003	Non-rooted whips

Table A6. Hybrid poplar stoolbeds established in 2003 at the Ellerslie Short-Rotation Woody Crops Technical Development Site.

Map Legend Number	Clones (North to South)	Year Established	Stock Types
22	Walker	2003	25cm Cuttings
	Green Giant	2003	25cm Cuttings
	Assiniboine	2003	25cm Cuttings
	DN-182	2003	25cm Cuttings
	DN-74	2003	25cm Cuttings
	Katepwa	2003	25cm Cuttings

Sites Established in 2004

The 2004 portion of the Ellerslie SRWC Technical Development Site (Figure 57) was established as a trial of the newly developed SRWC establishment protocol of recommended practices. This protocol was developed by Canadian Forest Service staff for the implementation of the Forest 2020: Plantation Demonstration and Assessment Initiative. The 2-year, $20 million federal initiative focused on 1) establishing demonstrations of fast-growing tree plantations across Canada to mitigate greenhouse gas emissions and generate more wood fibre, and 2) exploring investment mechanisms to attract funds to establish plantations in the future. The primary objective and focus of the plantation installations were fast-growing tree species under moderate to high intensity management systems. Specifically, species with a yield potential of 8 times the average growth of native species in Canada and 13.6 cubic metres per year mean annual increment (MAI).

Operational Research Site 7

The Forest 2020 Operational Stock Assessment Trial was established in 2004 as an "early warning" stock assessment trial for the Prairies' operational plantation demonstration phase of the Forest 2020 Plantation Demonstration and Assessment Initiative. In preparation for the operational plantation establishment phase, the Technical Development Group developed, tested and initiated a novel hybrid poplar container seedling propagation protocol for the growth of approximately 1.5 million seedlings. The protocol incorporated utilizing newly harvested cutting material (obtained in December), a 16-week greenhouse growth component and a minimum 28-day dormancy freezer component. The dormancy freezer component would allow for a desired spring field planting program. In addition to conducting stock over-wintering viability tests in the NoFC Greenhouse, the Technical Development Group established a field planting trial of all clones and stock type combinations to be used in 2004 Forest 2020 plantation establishment programs. The trial was evaluated throughout the 2004 and 2005 growing seasons for survival. It was retained for demonstration purposes until 2018 at which time the area was harvested and chipped for the operational testing of a small-scale chipping system.

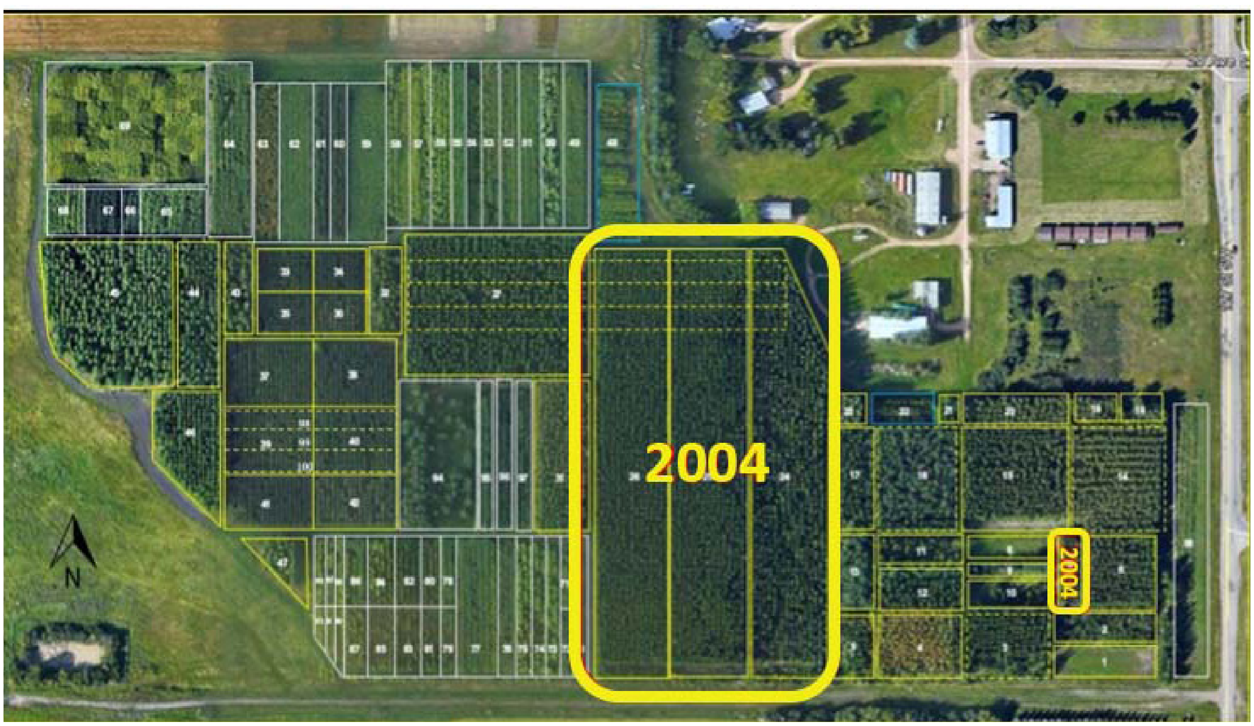


Figure 57. Operational research sites established at Ellerslie SRWC Technical Development Site in 2004.

Table A7. Forest 2020 | C2C stock trials conducted at the Ellerslie Short-Rotation Woody Crops Technical Development Site.

Map Legend Number	Clones	Year Established	Stock Types
7	Assiniboine	2004	Accelerated Transplants
	Assiniboine	2004	Container
	Brooks-1	2004	Accelerated Transplants
	DN-17	2004	Bareroot
	DN-17	2004	Container
	DN-182	2004	Bareroot
	DN-182	2004	Container
	DN-34	2004	Accelerated Transplants
	DN-34	2004	Bareroot
	DN-34	2004	Container
	Green Giant	2004	Container
	Hill	2004	Container
	NM-06	2004	Bareroot
	NM-06	2004	Container
	Northwest	2004	Container
	P-Chey	2004	Accelerated Transplants
	Prairie Sky	2004	Accelerated Transplants
	Walker	2004	Accelerated Transplants
	Walker	2004	Container

Operational Research Site 24

Established as part of the Forest 2020 Operational Trial, the entire 0.9 ha was originally planted with Hill hybrid poplar 415 1+0 container stock to evaluate the operational applicability of the newly developed SRWC establishment and management protocols. The protocols incorporated a combination of deep and shallow soil mixing for the entire area and a mechanical vegetation management regime that commenced weeks following planting and continued as needed until crown closure, which occurred in year-4. Mechanical marking and manual planting operations created a grid style design, incorporating 1600 stems ha^{-1} (2.5 m x 2.5 m). To evaluate the potential of SRWC for carbon sequestration, pre-treatment carbon sampling was completed. Detailed periodic assessments were also conducted. In 2007, 15 metres of the southern edge of the plantation was removed for the City of Edmonton's water line installation. The remaining area was actively sampled until it was harvested in 2018. Detailed post harvest sampling was completed. The sampling incorporated soils, stump and root excavations, post harvest residues and litter. This procedure developed a full rotation carbon summary for the Operational Research Site.

Operational Research Site 25

Established as part of the Forest 2020 Operational Trial, the entire 1.0 ha was originally planted with Assiniboine hybrid poplar 415 1+0 container stock to evaluate the operational applicability of the newly developed SRWC establishment and management protocols. The protocols incorporated a combination of deep and shallow soil mixing for the entire area. They also included a mechanical vegetation management regime that commenced weeks following planting and continued as needed until crown closure, which occurred in year-4. Mechanical marking and manual planting operations created a grid style design, incorporating 1600 stems ha^{-1} (2.5 m x 2.5 m). To evaluate the potential of SRWC for carbon sequestration, pre-treatment carbon sampling was completed. Detailed periodic assessments were also conducted. In 2007, 15 metres of the southern edge of the plantation was removed for the City of Edmonton's water line installation. The remaining area was actively sampled until it was harvested in 2018. Detailed post harvest sampling was completed. The sampling incorporated soils, stump and root excavations, post harvest residues and litter. This procedure developed a full rotation carbon summary for the Operational Research Site.

Operational Research Site 26

Established as part of the Forest 2020 Operational Trial, the entire 1.0 ha was originally planted with Walker hybrid poplar 415 1+0 container stock to evaluate the operational applicability of the newly developed SRWC establishment and management protocols. The protocols incorporated a combination of deep and shallow soil mixing for the entire area. They also included a mechanical vegetation management regime that commenced weeks following planting and continued as needed until crown closure, which occurred in year-4. Mechanical marking and manual planting operations created a grid style design, incorporating 1600 stems ha^{-1} (2.5 m x 2.5 m). To evaluate the potential of SRWC for carbon sequestration, pre-treatment carbon sampling was completed. Detailed periodic assessments were also conducted. In 2007, 15 metres of the southern edge of the plantation was removed for the City of Edmonton's water line installation. The remaining area was actively sampled until it was harvested in 2018. Detailed post harvest sampling was completed. The sampling incorporated soils, stump and root excavations, post harvest residues and litter. This procedure developed a full rotation carbon summary for the Operational Research Site.

Sites Established in 2005

The 2005 portion of the Ellerslie SRWC Technical Development Site (Figure 58) was established as a continuation of the 2004 trial of the newly developed SRWC establishment protocol. This protocol consisted of recommended practices and incorporated additional cultivars and stock-types. The protocols also included a combination of deep and shallow soil mixing for the entire area and a mechanical vegetation management regime. The regime commenced weeks following planting and continued until crown closure, which occurred in year-4. Mechanical marking and manual planting operations created a grid style design, incorporating 1600 stems ha^{-1} (2.5 m x 2.5 m). There was increased interest around developing a renewable woody biomass feedstock option without the 12 to 20-year lag time associated with high yield afforestation. The Technology Development Group established 2 concentrated biomass demonstrations and an operational stoolbed at the Ellerslie SRWC Technical Development Site. The objectives of the demonstration were to develop establishment and management protocols using equipment available off-the-shelf in Canada, and to evaluate clonal suitability linked to growth and yield potential.

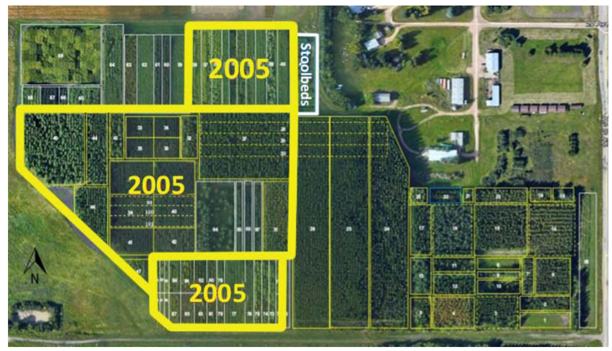


Figure 58. Operational research sites established at Ellerslie SRWC Technical Development Site in 2005.

Operational Research Site 27

Established as part of the Forest 2020 Operational Trial, the entire 1.0 ha was originally planted with Hill hybrid poplar 615 1+0 container stock to evaluate the operational applicability of using larger planting stock in the newly developed SRWC establishment and management protocols. The protocols incorporated a combination of deep and shallow soil mixing for the entire area and a mechanical vegetation management regime. The regime commenced weeks following planting and continued until crown closure, which occurred in year-4. The area was actively sampled until it was harvested in 2018.

Operational Research Site 31

Established as part of the Forest 2020 Operational Trial, the entire 0.3 ha was originally planted with Northwest hybrid poplar 615 1+0 container stock to evaluate the operational applicability of using larger planting stock in the newly developed SRWC establishment and management protocols. The protocols incorporated a combination of deep and shallow soil mixing for the entire area and a mechanical vegetation management regime. The regime commenced weeks following planting and continued until crown closure, which occurred in year-4. The area was actively sampled until it was harvested in 2018.

Operational Research Sites 32-38 and 43

Established as part of the Forest 2020 Operational Trial, the entire 1.0 ha was originally planted with Green Giant hybrid poplar 415 1+0 container stock to evaluate the operational applicability of the newly developed SRWC establishment and management protocols. The protocols incorporated a combination of deep and shallow soil mixing for the entire area and a mechanical vegetation management regime. The regime commenced weeks following planting and continued until crown closure, which occurred in year-4. In 2008, a portion of this area was deactivated to create opportunities for additional operational SRWC research trials. The remaining area was actively sampled until it was harvested in 2018. (See Sites Established in 2010 for more information)

Operational Research Sites 39-42

Established as part of the Forest 2020 Operational Trial, the entire 1.0 ha was originally planted with Northwest hybrid poplar 415 1+0 container stock to evaluate the operational applicability of the newly developed SRWC establishment and management protocols. The protocols incorporated a combination of deep and shallow soil mixing for the entire area and a mechanical vegetation management regime. The regime commenced weeks following planting and continued until 2008. In 2008, the entire area was deactivated to create opportunities for additional operational SRWC research trials. The remaining area was actively sampled until it was harvested in 2018. (See Sites Established in 2010 for more information)

Operational Research Sites 44 and 46

Established as part of the Forest 2020 Operational Trial, the entire 1.0 ha was originally planted with Hill hybrid poplar 415 1+0 container stock as a comparison to Operational Research Site 27. The goal was to evaluate the operational applicability of using larger planting stock in the newly developed SRWC establishment and management protocols. The protocols incorporated a combination of deep and shallow soil mixing for the entire area and a mechanical vegetation management regime. The regime commenced weeks following planting and continued until crown closure, which occurred in year-4. The area was actively sampled until it was harvested in 2018.

Operational Research Site 45

Established as part of the Forest 2020 Operational Trial, the entire 1.0 ha was originally planted with Brooks 1 hybrid poplar 415 1+0 container stock to evaluate the operational applicability of using larger planting stock in the newly developed SRWC establishment and management protocols. The protocols incorporated a combination of deep and shallow soil mixing for the entire area and a mechanical vegetation management regime. The regime commenced weeks following planting and continued until crown closure, which occurred in year-4. The area was actively sampled until it was harvested in 2018.

Operational Research Site 47

Established as part of the Forest 2020 Operational Trial, the entire 1.0 ha was originally planted with Hill hybrid poplar 615 1+0 container stock to evaluate the operational applicability of using larger planting stock in the newly developed SRWC establishment and management protocols. The protocols incorporated a combination of deep and shallow soil mixing for the entire area and a mechanical vegetation management regime. The regime commenced weeks following planting and continued until crown closure, which occurred in year- 4. The area was periodically sampled until it was harvested in 2018.

Operational Research Site 48

The operational stoolbeds were established using a combination of 25 cm cuttings, container and bareroot seedlings (to grow hybrid poplar), and salix material to harvest annually for future operational research trials. The stoolbeds that were established in 2005-06 incorporated a 2-row bed design of two rows of cuttings for each clone. The cuttings were planted in a single bed at a spacing of 20 cm x 20 cm. All subsequent beds were planted with a 1-row design using 30 cm spacing within the row. The stoolbeds were utilized until the site was harvested in 2018.

Table A8. Operational stoolbeds for the various hybrid poplar and willow clones at Ellerslie Short-Rotation Woody Crops Technical Development Site.

Map Legend Number	Hybrid or Clone (South to North)	Year Established	Stock Types
48	Viminalis (MBG)	2005	Container
	Viminalis	2005	Cutting
	DN-74	2014	Bareroot
	S-67	2006	Cutting
	NM-06	2005	Cutting
	S-61	2006	Cutting
	S-64	2005	Cutting
	S-67	2005	Cutting
	S-301	2005	Cutting
	DN-154	2014	Bareroot
	FFC-1	2014	Bareroot
	SX-61	2005	Cutting
	SX-64	2005	Cutting
	SV-1	2005	Cutting
	Q-1150	2006	Container
	P38P38	2011	Container
	Hotel	2005	Cutting
	Alpha	2011	Cutting
	Viminilas	2005	Cutting
	SV-1	2006	Cutting
	SV-1	2006	Cutting
	Walker	2005	Container
	Hill	2005	Container
	Assiniboine	2005	Container
	Brooks-1	2005	Container
	Brooks-1	2005	Container
	Northwest	2005	Container
	NM-06	2005	Cutting
	NM-06	2005	Cutting
	Alpha	2011	Cutting

Operational Research Sites 49–58

The initial concentrated biomass trial demonstration was established in 2005 to evaluate newly developed establishment and management protocols for concentrated biomass plantations. It was also designed to evaluate Salix and hybrid poplar clonal suitability linked to growth and yield potential. The establishment protocol included deep mixing of the soils, to a depth of 25 to 30 cm. This was done to enhance rooting potential and a subsequent shallow discing (10 to 15 cm). It was also intended to facilitate enhanced productivity for subsequent treatments. The site was mechanically marked at a spacing of 3.2 m to ensure uniform spacing between beds. Unrooted 30 cm cuttings for numerous Salix and hybrid poplar clones were mechanically planted in a 3-row concentrated biomass design (15,625 stems ha^{-1}), at least 25 to 28 cm into the soil (Figure 59).

A mechanical vegetation management regime was incorporated and commenced weeks following planting. It continued until crown closure, which occurred in year-3. A list of the Salix and hybrid clones that were operationally evaluated is available below. The site was completely harvested during the fall and winter of 2007–08 and 2011–12. Portions were periodically harvested for operational evaluations until the Ellerslie site was harvested in 2018.

Figure 59. Concentrated biomass establishment design overview: 3-row.

Table A9. Concentrated biomass trial conducted at the Ellerslie Short-Rotation Woody Crops Technical Development Site.

Map Legend Number	Clone	Year Established	# of Beds	Design | Spacing
49	S. x India	2005	4	3-row
50	S. x Pseudo	2005	3	3-row
51	S. x Hotel	2005	5	3-row
52	S. x Alpha	2005	4	3-row
53	S. x Acute	2005	4	3-row
54	HP - NM-06	2005	2	3-row
55	S. x Charlie	2005	4	3-row
56	HP - P38P38	2011	1	1-Row
57	S. SX-61, S. SX-64, S. SX-67	2006	1 Each	3-Row
58	HP - P38P38	2011	2	1-Row

Operational Research Sites 71-93

The second concentrated biomass trial demonstration was established as an operational comparison to evaluate newly developed establishment and management protocols for concentrated biomass plantations. It was also designed to evaluate Salix and hybrid poplar clonal suitability linked to growth and yield potential. The establishment protocol implemented included deep mixing of the soils to a depth of 25 to 30 cm. This was done to enhance rooting potential. A subsequent shallow discing (10–15 cm) was implemented to facilitate enhanced productivity for subsequent treatments. The site was mechanically marked at a spacing of 3.2 m to ensure uniform spacing between beds. Unrooted 30 cm cuttings for numerous Salix and hybrid poplar clones were mechanically planted in a 3-row concentrated biomass design (15,625 stems ha^{-1}), at least 25 to 28 cm into the soil (Figure 56). Mechanical vegetation management regime was not incorporated for the initial 3-year rotation. This resulted in substantially lower volumes. During the second rotation, vegetation management activities were completed and the growth improved. A list of the Salix and hybrid clones that were operationally evaluated is available in below. The site was completely harvested during the fall and winter of 2007–08 and 2011–12. Portions were periodically harvested for operational evaluations and vegetative propagation material until the Ellerslie site was harvested in 2018 for operator training.

Table A10. Bioenergy-No Management Trial conducted at the Ellerslie Short-Rotation Woody Crops Technical Development Site.

Map Legend Number	Clone[1]	Year Established	# of Beds	Design | Spacing
70	HP - DN-74	2014	3 beds	1-Row
71	S x SX-67	2006	1 Bed	3-Row
72	S. x Alpha	2006	1 Bed	3-Row
73	S. x Juliet	2006	7 beds	3-Row
74	S. x Charlie	2006	7 beds	3-Row
75	S. x SV-1	2006	3 beds	3-Row
76	S. x SX-64	2006	5 beds	3-Row
77	S. x Hotel	2005	5 beds	3-Row
78	S. x Hotel	2005	2 beds	3-Row
79	S. x Hotel	2005	2 beds	3-Row
80	HP - Hill	2005	5 beds	3-Row
81	HP - Hill	2005	5 beds	3-Row
82	HP - Walker	2005	4 beds	3-Row
83	HP - Walker	2005	4 beds	3-Row
84	S. x Charlie	2005	4 beds	3-Row
85	S. x Charlie	2005	4 beds	3-Row
86	S. x India	2005	4 beds	3-Row
87	S. x India	2005	4 beds	3-Row
88	S. x SX-61	2006	1 Bed	3-Row
89	S. x SX-61	2006	1 Bed	3-Row
90	S. x SX-64	2006	1 Bed	3-Row
91	S. x SX-64	2006	1 Bed	3-Row
92	S. x SX-67	2006	1 Bed	3-Row
93	S. x SX-67	2006	1 Bed	3-Row

[1] S. = Salix, HP = Hybrid Poplar.

Operational Research Site 94

The improved aspen demonstration site was established to display the use of improved trembling aspen clones, propagated from root cuttings supplied by Daishowa-Marubeni International (DMI) Ltd. These improved aspen cuttings were part of the controlled crosses (Appendix I). They were developed in the tree breeding program of the Western Boreal Aspen Cooperation. This organization was comprised of four member companies: DMI, Weyerhaeuser Canada, Ainsworth and Footner Forest Products. The site was retained for demonstration purposes until 2018, at which time the area was harvested and chipped for the operational testing of a small-scale chipping system.

Sites Established in 2006

The 2006 portion of the Ellerslie SRWC Technical Development Site (Figure 60) was limited to the establishment of a Salix clonal trial. This trial was established in collaboration with the State University of New York (SUNY). It was part of a larger experiment designed to understand the suitability of newly developed willow clones in various North American climates. It assessed ideal growing conditions for greater profitability and to enhance future breeding efforts. The other field trial locations selected for the bigger study were in Constableville, New York and Waseca, Minnesota (Johnson, et al., 2018). In 2006, 20 willow cultivars originating from the breeding program of the SUNY were tested at Ellerslie.

Operational Research Site 69

The establishment protocol included deep mixing of the soils to a depth of 25 to 30 cm. This enhanced rooting potential. A subsequent shallow discing (10 to 15 cm) facilitated enhanced productivity for subsequent treatments. The site was mechanically marked to ensure that the 2-row design was consistent with the other replicates established in the US. Plot size was 6.9 m x 7.9 m, allowing for three double rows of willow. Willow cuttings were spaced 60 cm apart within the row and 75 cm between rows. There was 150 cm between each set of twin rows, resulting in 13 plants along each row. This resulted in a planting density of 14,620 stems ha^{-1}. Unrooted cuttings were 25 cm long and planted at least 20 to 23 cm into the soil (Figure 61). All 20 SUNY cultivars and four cultivars (S25, SX61, SX64 and SV1) originating from the University of Toronto and the Ontario Ministry of Natural Resources were manually hand-planted. This was done following a randomized complete block design with four replications.

Figure 60. Operational research sites established at Ellerslie SRWC Technical Development Site in 2006.

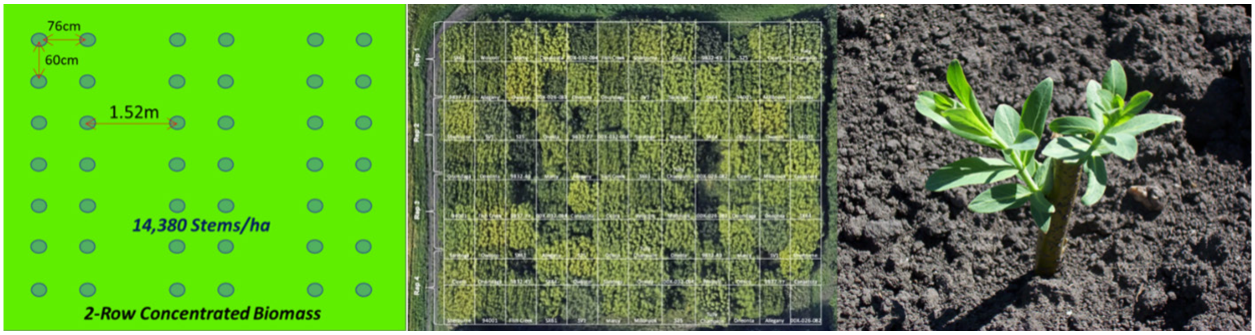


Figure 61. SUNY Clonal Trial 2-row concentrated biomass design.

Table A11. State University of New York (SUNY) willow clonal trial conducted at the Ellerslie Short-Rotation Woody Crops Technical Development Site.

Map Legend Number	Trial	Year Established	Stock Types
69	94001	2006	Unrooted cuttings
	00X-026-082	2006	Unrooted cuttings
	00X-032-094	2006	Unrooted cuttings
	9832-49	2006	Unrooted cuttings
	9837-077	2006	Unrooted cuttings
	Allegany	2006	Unrooted cuttings
	Canastota	2006	Unrooted cuttings
	Cicero	2006	Unrooted cuttings
	Fish Creek	2006	Unrooted cuttings
	Marcy	2006	Unrooted cuttings
	Millbrook	2006	Unrooted cuttings
	Oneida	2006	Unrooted cuttings
	Oneonta	2006	Unrooted cuttings
	Onondaga	2006	Unrooted cuttings
	Otisco	2006	Unrooted cuttings
	Owasco	2006	Unrooted cuttings
	Saratoga	2006	Unrooted cuttings
	Sherburne	2006	Unrooted cuttings
	Tully Champion	2006	Unrooted cuttings
	Wolcott	2006	Unrooted cuttings
	S25	2006	Unrooted cuttings
	SV1	2006	Unrooted cuttings
	SX61	2006	Unrooted cuttings
	SX64	2006	Unrooted cuttings

Willow plants were coppiced after leaf desiccation following the first growing season. A mechanical vegetation management regime was incorporated. It commenced weeks following planting and continued until crown closure, which occurred in year-3. The SUNY Clonal Trial was harvested in 2009 and 2012 as part of the SUNY monitoring program. Upon the cessation of the program, the site was maintained at Ellerslie for demonstration purposes until it was harvested in 2018.

Sites Established in 2007

The 2007 portion of the Ellerslie SRWC Technical Development Site (Figure 62) was limited to the establishment of a Concentrated Biomass Design Trial. The goals of the trial were to evaluate the impacts of establishment design and planting density on obtainable biomass yield and actual cost per tonne of harvested biomass.

Figure 62. Operational research sites established at Ellerslie SRWC Technical Development Site in 2007.

Operational Research Sites 59 and 62

The establishment protocol implemented for the Concentrated Biomass Design Trial included deep mixing of the soils to a depth of 25 to 30 cm. This was done to enhance rooting potential. A subsequent shallow discing (10 to 15 cm) was implemented to facilitate enhanced productivity for subsequent treatments. The trial consisted of 2 plots, each 20 m in width and 90 m in length. Plot 1 (Site 59) was mechanically marked at a spacing of 1.8 m. This ensured uniform spacing between rows. Unrooted 25cm *Salix purpurea* cuttings were mechanically planted at 60cm intervals along the rows in a 1-row concentrated biomass design, at least 20 to 23 cm into the soil (Figure 63). A total of 10 rows were established within the 20 m wide plot, with a net plot width of 18 m and a net plot area of 1620 m^2. Plot 2 (Site 62) was mechanically marked at a spacing of 3.2 m to ensure uniform spacing between beds. Unrooted *Salix purpurea* cuttings (25 cm) were mechanically planted at 60 cm intervals along the rows in a 3-row concentrated biomass design, at least 20 to 23 cm into the soil. A total of 5 beds (15 rows) were established within the 20 m wide plot. The net plot width was 16m and the net plot area was 1440 m^2. Mechanical vegetation management regime was incorporated and commenced weeks following planting. It continued until crown closure, which occurred in year-3. The trial was not coppiced in 2007–08. The 4-year growth was harvested in 2010. Periodical assessments failed to identify a significant difference in obtainable volume for either design. Preliminary results, lower establishment and management costs, and similar yields are some of the advantages associated with the 1-row design for concentrated biomass plantations compared to the 2 and 3-row designs. The site was maintained at Ellerslie for demonstration purposes until it was harvested in 2018.

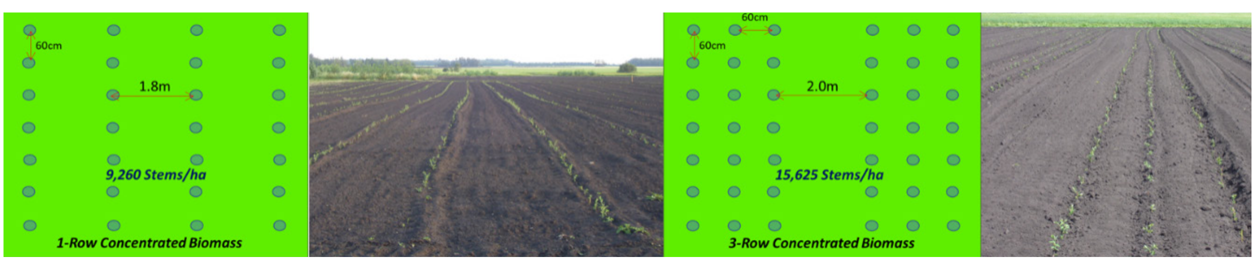


Figure 63. Concentrated Biomass Design Trial establishment designs (2007).

Sites Established in 2008

The 2008 portion of the Ellerslie SRWC Technical Development Site (Figure 64) was limited to the establishment of a Green Giant Concentrated Biomass Design operational trial. The goals of the trial were to evaluate the potential growth of Green Giant hybrid poplar as a suitable clone for concentrated biomass plantations, and to supply vegetative propagative material for future operational research trials.

Figure 64. Operational research sites established at Ellerslie SRWC Technical Development Site in 2008.

Operational Research Site 63

The establishment protocol implemented for the Green Giant Concentrated Biomass Design operational trial included deep mixing of the soils to a depth of 25 to 30 cm. This was done to enhance rooting potential. A subsequent shallow discing (10 to 15 cm) was implemented to facilitate enhanced productivity for following treatments. The site was mechanically marked at a spacing of 3.2 m to ensure uniform spacing between beds. Unrooted 30 cm cuttings for numerous Salix and hybrid poplar clones were mechanically planted in a 3-row concentrated biomass design (15,625 stems ha^{-1}), at least 25 to 28 cm into the soil. Mechanical vegetation management regime was incorporated and commenced weeks following planting. It continued until crown closure, which occurred in year-3. The 3-year first rotation growth of the Green Giant hybrid poplar was consistent with other Salix and hybrid poplar concentrated biomass beds. The site was maintained at Ellerslie for demonstration purposes until it was harvested in 2018.

Sites Established in 2010

The 2010 portion of the Ellerslie SRWC Technical Development Site (Figure 65) was focused on the establishment of improved aspen operational research trials. Aspen is the common name for another group of *Populus* species native to North America. These are also "true poplars." Trembling or quaking aspen (*Populus tremuloides*) have five subspecies. Bigtooth aspen (*Populus grandidentata*) consist of two subspecies. Trembling aspen is common across Canada and is prevalent in the Prairie Region and the Rocky Mountains. Bigtooth aspen grows in southern Manitoba, Ontario, Quebec and the Great Lakes region in the US. Aspens are better adapted to drier upland sites compared to poplars. Unlike poplars, they cannot readily propagate from unrooted cuttings. Instead, they regenerate naturally through seed dispersal or sucker vigorously from their root systems following harvest or forest fires.

Figure 65. Operational research sites established at Ellerslie SRWC Technical Development Site in 2010.

During the winter of 2009–10, Weyerhaeuser opted to drastically reduce their Tree Improvement Program in Alberta. This reduction resulted in an inventory of excess planting material housed in freezer storage. The material scheduled for out-planting trials was the culmination of 19 years of aspen tree improvement research conducted to improve artificial aspen regeneration in Alberta. The Technology Development Group was contacted by Weyerhaeuser with the hopes that the excess planting material could be utilized for SRWC operational research trials.

The CWFC established the improved aspen trials to evaluate the field performance of the Weyerhaeuser improved aspen clones in high yield afforestation and concentrated biomass designs. These trials analyzed their potential growth, cold tolerance, tree form, disease and insect resistance, site adaptability and wood quality.

Operational Research Sites 33-42

The Weyerhaeuser improved aspen clonal trial was established using a high yield afforestation block planting design for each available clone and stock type supplied by Weyerhaeuser. The SRWC establishment and management protocols include a combination of deep and shallow soil mixing for the entire area and a mechanical vegetation management regime. This regime commenced weeks following planting and continued as needed until crown closure, which occurred in year-4. Mechanical marking and manual planting operations created a grid style design incorporating 1600 stems ha^{-1} (2.5 m x 2.5 m). Mechanical vegetation management regime was incorporated and commenced weeks following planting and continued as needed until crown closure, which occurred in year-4. The area was actively sampled until it was harvested in 2018.

Table A12. Weyerhaeuser improved aspen clonal high yield afforestation trial conducted at the Ellerslie Short-Rotation Woody Crops Technical Development Site.

Map Legend Number	Clones	Year Established	Trial Design	Stock Types
33	Improved Aspen 3085	2010	High Yield Afforestation	Rooted whips
34	Improved Aspen 3109	2010	High Yield Afforestation	Rooted whips
35	Improved Aspen 3120	2010	High Yield Afforestation	Rooted whips
36	Improved Aspen 94-007-A	2010	High Yield Afforestation	Rooted whips
37	Improved Aspen 3047	2010	High Yield Afforestation	Bareroot seedlings
38	Improved Aspen 3089	2010	High Yield Afforestation	Bareroot seedlings
39	Improved Aspen 3104	2010	High Yield Afforestation	Bareroot seedlings
40	Improved Aspen 3106	2010	High Yield Afforestation	Bareroot seedlings
41	Improved Aspen 3109	2010	High Yield Afforestation	Bareroot seedlings
42	Improved Aspen 94-007-A	2010	High Yield Afforestation	Bareroot seedlings

Operational Research Sites 60, 61, 66, 67, and 96

The establishment protocol implemented for the Weyerhaeuser improved aspen concentrated biomass design operational trials included deep mixing of the soils to a depth of 25 to 30 cm. This was done to enhance rooting potential. A subsequent shallow discing (10 to 15 cm) was implemented to facilitate enhanced productivity for subsequent treatments. The site was mechanically marked at a spacing of 3.2 m to ensure uniform spacing between beds. The clones were manually planted in a 3-row concentrated biomass design (15,625 stems ha^{-1}). Mechanical vegetation management regime was incorporated and commenced weeks following planting. It continued until crown closure, which occurred in year-3. The area was periodically evaluated until it was harvested in 2018.

Table A13. Weyerhaeuser improved aspen clonal concentrated biomass trials conducted at the Ellerslie Short-Rotation Woody Crops Technical Development Site.

Map Legend Number	Clones	Year Established	Trial Design	Stock Types
60	Improved Aspen 3085	2010	Concentrated Biomass	Bareroot seedlings
61	Improved Aspen 3106	2010	Concentrated Biomass	Bareroot seedlings
66	Improved Aspen 3120	2010	Concentrated Biomass	Bareroot seedlings
67	Improved Aspen 3089	2010	Concentrated Biomass	Bareroot seedlings
96	Improved Aspen 3047	2010	Concentrated Biomass	Bareroot seedlings

Sites Established in 2011

The 2011 portion of the Ellerslie SRWC Technical Development Site (Figure 66) was focused on the establishment of several operational P38P38 hybrid poplar concentrated biomass design trials. During the winter of 2010–11, Alberta-Pacific Forest Industries Inc. (Al-Pac) opted to drastically reduce their afforestation program in Alberta. This reduction resulted in an inventory of excess planting material housed in freezer storage. The Technology Development Group was contacted by Al-Pac with the hopes that the excess planting material could be utilized for SRWC operational research trials. The goals of the trials were to evaluate the potential growth of P38P38 hybrid poplar as a suitable clone for concentrated biomass plantations and to supply vegetative propagative material for future operational research trials.

hybrid poplar concentrated biomass beds. The site was maintained at Ellerslie for demonstration purposes until it was harvested in 2018.

Sites Established in 2014

The 2014 portion of the Ellerslie SRWC Technical Development Site (Figure 67) was based mostly on establishing a conifer component in recently crown closed high yield afforestation plantations. The goal of the trial was to evaluate the long-term growth of various tolerant conifer species established in a recent crown closed SRWC plantation. The objective was to retain the conifer component following the harvesting of the overstory. In addition to the conifer installations, a small area of hybrid poplar concentrated biomass was established.

Figure 66. Operational research sites established at Ellerslie SRWC Technical Development Site in 2011.

Figure 67. Operational research sites established at Ellerslie SRWC Technical Development Site in 2014.

Operational Research Sites 64, 65, 68, 95, 97 and 98

The establishment protocol implemented for the P38P38 Concentrated Biomass Design operational trial included deep mixing of the soils to a depth of 25 to 30 cm. This was done to enhance rooting potential. A subsequent shallow discing (10 to 15 cm) was implemented to facilitate enhanced productivity for subsequent treatments. The site was mechanically marked at a spacing of 3.2 m to ensure uniform spacing between beds. The container seedlings were manually planted in a 3-row concentrated biomass design (15,625 stems ha^{-1}). Mechanical vegetation management regime was incorporated and commenced weeks following planting. It continued until crown closure, which occurred in year-3. The 3-year first rotation growth of the P38P38 hybrid poplar was consistent with other Salix and

Operational Research Site 70

The establishment protocol implemented for the DN-74 concentrated biomass operational trial included deep mixing of the soils to a depth of 25 to 30 cm. This was done to enhance rooting potential. A subsequent shallow discing (10 to 15 cm) was implemented to facilitate enhanced productivity for subsequent treatments. The site was mechanically marked at a spacing of 2.0 m to ensure uniform spacing between rows. Rooted cuttings were manually planted at 60 cm intervals along the rows in a 1-row concentrated biomass design. Mechanical vegetation management regime was incorporated and commenced weeks following planting. It continued until crown closure, which occurred in year-3. Originally established to supply vegetative propagation material for future operational research trials, the site was harvested in 2018.

Operational Research Sites 99, 100 and 101

These sites evaluated the timing of augmenting SRWC high yield afforestation plantations with understory conifer to develop mixedwood afforestation (Figure 68). The sites were designed for long-term carbon sequestration benefits. The Technical Development Group initiated a program to evaluate various species and scheduling to incorporate the conifer component. The tolerant conifer understory establishment trial incorporated three understory softwood tree species to create mixedwood afforestation sites. Site 99 was planted with white spruce (*picea glauca* (Moench) Voss.), Site 100 with black spruce (*picea mariana*) and Site 101 with douglas fir (*pseudotsuga menziesii* var. *menziesii*). The seedlings were planted equal distance from the existing overstory stems at the mid-point of the SRWC high yield afforestation design grid. The sites were evaluated for survival and utilized for demonstration purposes until they were harvested in 2018.

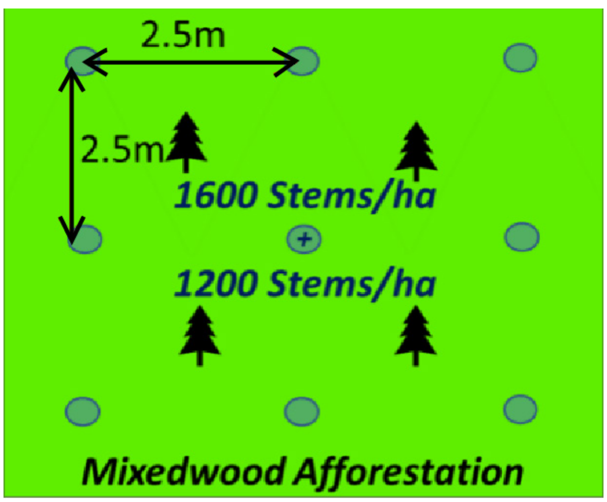


Figure 68. Mixedwood afforestation planting design.

Sites Established in 2015

The 2015 portion of the Ellerslie SRWC Technical Development Site (Figure 69) was a continuation of an establishment of a conifer component in high yield afforestation plantations. The 2015 program was incorporated to compare the growth and survival impacts of delaying the addition of the conifer component until year-10 of the high yield afforestation plantation.

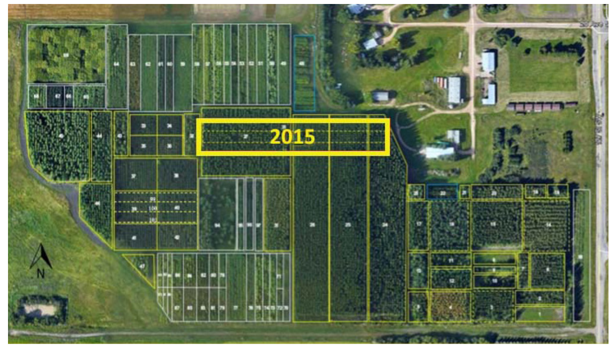
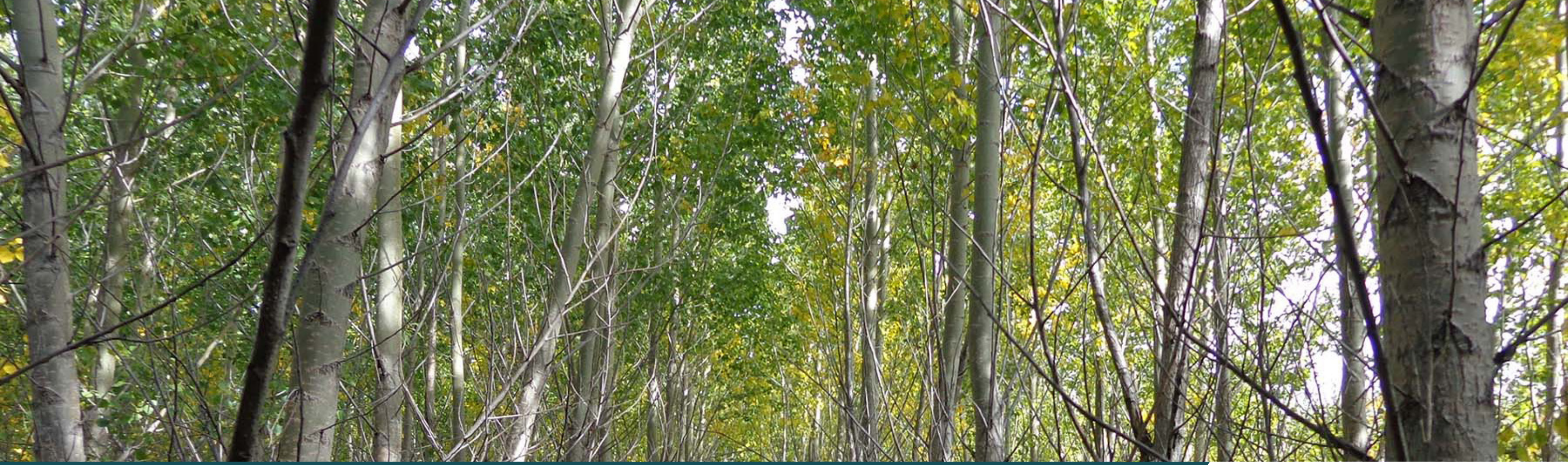


Figure 69. Operational research sites established at Ellerslie SRWC Technical Development Site in 2015.

Operational Research Sites 28, 29 and 30

Following the same protocol as 2014, three understory softwood tree species were planted to create mixedwood afforestation sites. Site 28 was planted with white spruce (*picea glauca* (Moench) Voss.), Site 29 with black spruce (*picea mariana*) and Site 30 with douglas fir (*pseudotsuga menziesii* var. *menziesii*). The seedlings were planted equal distance from the existing overstory stems at the mid-point of the SRWC high yield afforestation design grid. The sites were evaluated for survival and utilized for demonstration purposes until they were harvested in 2018.



Appendix IV

Equations used to calculate various performance parameters of High Yield Afforestation Plantations

1. **Percent survival**

$$\text{Percent survival} = \left(\frac{\text{\# of live trees counted}}{\text{Total \# of trees initially planted within plot}}\right) \times 100$$

2. **Average tree height**

$$\text{Average Ht} = \frac{\text{Sum height of all measured living tress}}{\text{Total number of living trees measured}}$$

3. **Root collar diameter (RCD, for trees under 1.3 m in height) or diameter at breast height (DBH, for trees over 1.3 m in height)**

$$\text{Average RCD or DBH} = \frac{\text{Sum RCD or DBH of all measured living trees}}{\text{Total number of living trees measured}}$$

4. **Stem Volume (m^3, trees under 1.3 m in height)**

$$\text{Stem Volume} = \pi \times \left(\frac{\text{RCD in mm}}{2}\right)^2 \times \frac{\text{Height in cm/3}}{100{,}000{,}000}$$

5. **Stem Volume (m^3, trees over 1.3 m in height) using the Ontario Production Hybrid Poplar Volume Equation**

$$\textit{Stem Volume} = \exp\left(-2.884601 + 1.604938 \times ln(\textit{dbh in cm}) + 1.203873 \times ln(\textit{height in m}) \times {}^{1.013914}/_{1000}\right)$$

6. **Average Weighted Stem Volume (m^3)**

$$\textit{Average Weighted Stem Volume} = \frac{\textit{Sum of volumes of all living stems}}{\textit{Total living stems}}$$

7. **Effective Plot Area (m^2)**

Effective Plot Area = *Total of trees initially planted within plot* ×
Planting design spacing width in m × *Planting design spacing length in m*

8. **Site Volume/ha (m^3), based on effective plot area**

$$\textit{Site}\ \frac{\textit{Volume}}{\textit{Ha}} = \textit{Sum plot stem volumes in } m^3 \times \frac{10\ 000\ \frac{m^2}{ha}}{\textit{Effective plot area in } m^2}$$

Appendix V

Table A14. Diameter at breast height (DBH), age, height, 2017 survival and site volume of selected clones tested under a high-yield management regime at Ellerslie Short-Rotation Woody Crops Technical Development Site, Edmonton, Alberta.

Map Legend Number	Clone	Year Planted	Year Measured	Age	Min DBH (cm)	Mean DBH (cm)	Max DBH (cm)	Min HT (m)	Mean HT (m)	Max HT (m)	2017 Survival (%)	Volume $^{-ha}$ (m^3)
						2002						
4	Northwest	2002	2006	5	1.60	5.78	7.60	3.40	6.10	6.95		21.09
		2002	2010	9	5.70	9.65	12.90	7.80	10.31	12.10		55.61
		2002	2013	12	6.10	11.96	15.50	8.80	12.78	15.00		134.95
		2002	2015	14	8.40	12.82	16.70	10.10	14.04	15.80		169.13
		2002	2017	16	6.00	12.90	17.70	9.20	18.20	24.40	95.24%	258.15
6	Walker	2002	2006	5					Not Sampled			
		2002	2010	9	2.20	8.56	15.00	4.50	10.64	13.60		61.72
		2002	2013	12					Not Sampled			
		2002	2015	14	2.70	12.51	19.50	4.90	15.29	17.90		194.17
		2002	2017	16	3.10	13.79	21.30	5.80	17.01	21.40	85.71%	258.95
14	Green Giant - Control	2002	2006	5					Not Sampled			
		2002	2010	9	5.30	11.80	16.40	7.00	10.54	12.10		65.72
		2002	2013	12	7.70	14.65	18.80	8.50	13.92	15.20		96.25
		2002	2015	14	8.20	15.25	19.50	7.60	14.10	15.20		104.57
		2002	2017	16	15.30	17.37	21.00	15.30	17.69	19.80	95.24%	144.30
14	Green Giant - Coppice	2002	2006	5					Not Sampled			
		2002	2010	9	2.20	2.87	3.50	4.20	4.86	5.80		2.01
		2002	2013	12	2.10	4.26	6.80	3.96	6.03	9.25		6.82
		2002	2015	14	1.40	3.77	7.00	2.90	5.35	9.90		7.24
		2002	2017	16	2.40	4.81	7.70	3.80	6.37	10.60		10.23
14	White Spruce-GG	2003	2006	4					Not Sampled			
		2003	2010	8					Not Sampled			
		2003	2013	11	0.60	1.80	3.30	0.45	2.36	2.44		< 0.1
		2003	2015	13	0.10	1.31	3.80	0.46	1.51	4.30		0.44
		2003	2017	15	0.90	2.19	5.00	0.50	1.85	4.90	100.00%	1.14
15	Walker	2002	2006	5	3.40	5.49	7.40	1.50	6.20	7.68		12.26
		2002	2010	9	7.30	10.91	14.80	10.00	12.08	13.60		64.39

(Continued on p. 97)

(Continued from p. 96)

Map Legend Number	Clone	Year Planted	Year Measured	Age	Min DBH (cm)	Mean DBH (cm)	Max DBH (cm)	Min HT (m)	Mean HT (m)	Max HT (m)	2017 Survival (%)	Volume $^{-ha}$ (m³)
		2002	2013	12	6.20	12.70	19.40	9.80	15.53	18.50		163.21
		2002	2015	14	6.10	13.25	20.60	9.50	15.98	19.10		187.11
		2002	2017	16	6.80	14.72	22.60	10.80	18.54	23.60	76.19%	252.66
16	Hybrid Aspen	2002	2006	5	3.80	5.34	7.00	2.60	6.26	8.04		16.13
		2002	2010	9	4.50	10.20	13.60	7.60	10.70	12.80		71.41
		2002	2013	12	5.70	11.99	17.60	9.20	14.01	16.80		160.97
		2002	2015	14	5.60	12.21	18.60	8.20	14.51	17.20		186.20
		2002	2017	16	5.30	12.81	21.30	7.80	16.20	21.10	76.19%	230.04
16		2003	2006	4	Not Sampled							
	White Spruce-HA	2003	2010	8	Not Sampled							
		2003	2013	11	0.70	0.70	0.70	0.54	0.98	1.70		< 0.1
		2003	2015	13	0.20	0.61	0.80	0.59	1.04	1.75		< 0.1
		2003	2017	15	0.60	1.44	2.20	0.60	1.17	2.20	100.00%	0.12
2003												
3	Walker	2003	2013	11	5.90	12.42	15.70	8.40	14.84	17.00		160.66
		2003	2015	13	6.00	13.04	16.10	9.20	16.00	17.50		191.07
		2003	2017	15	6.20	14.88	18.30	10.70	20.03	23.40	80.95%	312.40
3	White Spruce-WA	2003	2013	11	0.60	1.51	3.20	1.49	2.30	3.83		0.69
		2003	2015	13	0.90	2.08	4.40	1.50	2.42	4.00		1.23
		2003	2017	15	1.30	3.11	5.60	1.30	3.20	5.50	100.00%	3.39
2004												
25	Assiniboine	2004	2006	3	0.00	1.82	3.80	0.00	2.67	4.40		N/A
		2004	2009	6	1.60	8.34	11.50	3.70	8.47	10.11		35.90
		2004	2010	7	1.50	8.59	13.50	2.30	9.53	12.20		49.85
		2004	2013	10	2.50	12.98	19.90	5.70	15.12	17.90		153.51
		2004	2015	12	3.00	13.88	20.80	5.60	15.96	18.50		182.15
		2004	2017	14	2.90	15.47	21.40	6.20	20.32	27.30	84.13%	268.32
24	Hill	2004	2006	3	0.00	1.27	2.90	0.00	2.19	3.45		N/A
		2004	2009	6	2.40	7.52	10.40	4.21	7.33	8.38		26.73
		2004	2010	7	2.80	8.15	11.10	5.00	7.80	9.00		33.29
		2004	2013	10	4.50	12.30	15.50	8.20	12.57	14.10		104.64
		2004	2015	12	4.80	12.77	16.40	7.80	13.05	14.50		115.44
		2004	2017	14	3.50	14.24	18.70	5.50	15.51	19.80	90.48%	173.82
26	Walker	2004	2006	3	0.00	1.95	3.70	0.00	2.82	4.52		N/A
		2004	2009	6	1.70	8.03	11.80	3.83	8.63	10.02		34.98
		2004	2010	7	1.90	8.98	13.20	4.50	10.06	12.20		53.88
		2004	2013	10	2.50	13.14	18.00	5.20	15.35	17.90		153.68
		2004	2015	12	2.70	14.20	19.10	5.20	16.07	18.30		179.25
		2004	2017	14	2.70	15.36	21.30	5.40	18.98	24.10	87.30%	258.56

(Continued on p. 98)

(Continued from p. 97)

Map Legend Number	Clone	Year Planted	Year Measured	Age	Min DBH (cm)	Mean DBH (cm)	Max DBH (cm)	Min HT (m)	Mean HT (m)	Max HT (m)	2017 Survival (%)	Volume $^{-ha}$ (m^3)
						2005						
45	Brooks 1	2005	2006	2	1.50	1.50	1.50	0.58	1.49	2.52		N/A
		2005	2009	5	0.50	5.16	9.60	1.67	5.22	7.13		9.81
		2005	2010	6	1.00	6.25	10.80	2.20	6.38	8.20		19.51
		2005	2013	9	5.50	11.60	15.70	7.00	12.00	13.60		85.26
		2005	2015	11	5.30	12.42	16.60	6.80	13.15	14.80		88.52
		2005	2017	13	3.00	13.91	20.30	5.20	14.88	19.30	71.43%	180.67
27	Hill 615	2005	2006	2	1.00	1.00	1.00	0.40	1.09	1.82		N/A
		2005	2009	5	1.00	5.08	7.50	2.29	4.77	5.73		6.59
		2005	2010	6	2.30	6.12	9.40	3.70	6.46	7.60		14.35
		2005	2013	9	5.30	10.95	14.40	8.00	11.41	12.40		67.31
		2005	2015	11	6.00	12.09	16.00	8.50	12.08	13.60		83.23
		2005	2017	13	5.00	13.58	18.70	4.50	13.55	16.60	71.43%	140.38
31	Northwest	2005	2006	2	1.30	1.30	1.30	1.21	1.96	2.42		N/A
		2005	2009	5	2.90	6.00	8.40	4.29	6.18	7.70		17.92
		2005	2010	6	2.70	7.08	9.80	4.50	7.64	9.00		29.04
		2005	2013	9	5.70	11.12	14.10	8.00	11.83	13.70		99.47
		2005	2015	11	6.00	11.76	15.50	7.30	12.56	14.60		123.33
		2005	2017	13	5.90	12.75	17.40	8.70	17.08	22.00	95.24%	209.06
						2010						
37	Imp Aspen - 3047	2010	2013	4					Not Sampled			
		2010	2015	6	2.30	4.87	5.90	2.80	5.56	6.80		9.01
		2010	2017	8	5.70	8.32	9.80	6.70	9.35	10.30	76.19%	29.51
33	Imp Aspen - 3085	2010	2013	4	2.00	3.95	5.90	2.80	5.01	6.91		6.91
		2010	2015	6					Not Sampled			
		2010	2017	8					Not Sampled			
38	Imp Aspen - 3089	2010	2013	4					Not Sampled			
		2010	2015	6	1.20	4.53	6.30	2.40	5.32	6.90		7.81
		2010	2017	8	3.90	9.18	11.50	6.80	10.40	11.90	80.95%	51.95
39	Imp Aspen - 3104	2010	2013	4					Not Sampled			
		2010	2015	6	3.60	4.77	5.40	3.20	5.19	5.70		7.06
		2010	2017	8	4.90	8.11	10.40	4.70	8.38	9.90	80.95%	31.51
40	Imp Aspen - 3106	2010	2013	4					Not Sampled			
		2010	2015	6	2.60	4.97	6.60	2.60	5.35	6.30		8.63
		2010	2017	8	6.30	9.67	11.90	8.50	10.70	11.80	80.95%	56.10
41	Imp Aspen - 3109	2010	2013	4	1.80	4.06	5.40	2.70	4.22	5.10		5.55
		2010	2015	6	2.20	5.44	7.10	3.50	5.33	6.20		10.43
		2010	2017	8	6.90	10.51	12.40	7.30	9.99	11.30	80.95%	53.08
42	Imp Aspen - 94-007-A	2010	2013	4					Not Sampled			
		2010	2015	6	1.20	3.47	5.30	1.70	3.89	5.60		5.05
		2010	2017	8	4.00	8.35	11.10	4.90	8.21	11.30	80.95%	33.53

Appendix VI

Equations used to calculate various performance parameters of concentrated biomass plantations.

1. **Percent survival**

$$\text{Percent survival} = \left(\frac{\text{\# of live trees counted}}{\text{Total \# of trees initially planted within plot}} \right) \times 100$$

2. **Average maximum tree height (SUNY)**

$$\text{Average Max.Ht} = \frac{\text{Sum of max.height of all living trees}}{\text{Total number of living trees measured}}$$

3. **Average stems per plant (SUNY)**

$$\text{Average Stems/plant} = \frac{\text{Sum of all stems of all living trees}}{\text{Total number of living trees measured}}$$

4. **Percent damage (SUNY)**

$$\text{Percent Damage} = \left(\frac{\text{Sum of planted spots with damage}}{\text{Total \# of planted spots sampled}} \right) \times 100$$

5. **Average wet weight per plant (kg)**

$$\text{Average Wet Weight/plant} = \frac{\text{Sum of all weights of all live planted spots within a plot}}{\text{Total number of planted spots within a plot}}$$

6. **Average weight per planted spot**

$$\textit{Average weight per planted spot} = \frac{\textit{Weight per hectare}}{\textit{Original planting density}}$$

7. **Wet Weight/ha (Tonnes), based on plot area**

$$\textit{Wet Weight per Hectare} = \textit{Sum of plot (s) wet weight in tonnes} \times \frac{10\,000\,\frac{m^2}{ha}}{\textit{Plot area in } m^2}$$

8. **Wet Weight/ha (Tonnes), based on average weight per planted spot**

$$\textit{Wet Weight per Hectare} = \textit{Average wet weight per live planted spot in } \frac{kg}{1000} \times \textit{planting design stems per ha x percent survival}$$

9. **Harvest Residues per Hectare (Tonnes)**

$$\textit{Harvest Residues per Hectare} = \textit{Sum plot residue weight in tonnes} \times \frac{10\,000\,\frac{m^2}{ha}}{\textit{Plot area in } m^2}$$

10. **Chipping Loss (%)**

$$\textit{Percent Chipping Loss} = \left(\frac{\textit{Pre chipping mass} - \textit{post chipping mass}}{\textit{Pre chipping mass}}\right) \times 100$$

11. **Percent Moisture Content**

$$\textit{Moisture Content} = \frac{(\textit{Sample wet weight} - \textit{sample dry weight})}{\textit{Sample wet weight}}$$

Sample dry weight obtained by drying samples in oven at 100 °C for 72 hrs.

12. **Oven Dried Mass (OD)**

$$\textit{Oven Dried Mass} = \textit{Wet Weight x (1 – Moisture Content (decimal))}$$

Appendix VII

Historical assessment summary of the State University of New York (SUNY) Willow Clonal Trial established at the Ellerslie SRWC Technical Development Site, Edmonton, Alberta.

Table A15. SUNY Clonal Trial survival and stems per plant data collected at Ellerslie Short-Rotation Woody Crops Technical Development Site.

Map Legend Number	Clone Common Name	2006-07 Survival	2008 Summer Survival	2009-10 Survival	2011-12 Survival	Fall 2007 Mean Stems/ Plant	2010-11 Mean Stems/ Plant	2011-12 Mean Stems/ Plant
69	Oneonta	86.11%	93.06%	76.39%	69.44%	6	6	5
	94001	94.44%	95.83%	94.44%	94.44%	9	18	17
	00X-026-082	79.17%	95.83%	72.22%	48.61%	3	1	2
	00X-032-094	58.33%	81.94%	56.94%	56.94%	5	6	9
	9832-49	84.72%	100.00%	85.71%	76.39%	5	5	6
	9837-077	54.17%	100.00%	52.78%	47.22%	5	3	6
	Cicero	87.50%	95.83%	86.11%	83.33%	5	6	5
	Marcy	69.44%	69.44%	56.94%	56.94%	4	3	4
	Sherburne	95.83%	94.44%	95.83%	94.44%	10	15	9
	Fish Creek	93.06%	93.06%	90.28%	90.28%	7	13	12
	Wolcott	79.17%	95.83%	80.56%	75.00%	6	9	10
	Onondaga	70.83%	91.67%	72.22%	75.00%	10	10	9
	Otisco	94.44%	98.61%	91.67%	93.06%	4	10	7
	Tully Champion	91.67%	98.61%	91.67%	91.67%	5	11	9
	Owasco	86.11%	87.50%	84.72%	81.94%	7	10	8
	Millbrook	93.06%	97.22%	90.28%	91.67%	5	11	9
	Saratoga	91.67%	94.44%	93.06%	93.06%	9	15	12
	Allegany	94.44%	100.00%	93.06%	87.50%	9	14	12
	Canastota	80.56%	83.33%	80.56%	77.78%	8	9	7
	Oneida	77.78%	84.72%	76.39%	72.22%	6	7	6
	S25	70.83%	100.00%	69.44%	66.67%	5	5	6
	SV1	72.22%	98.61%	73.61%	70.83%	5	8	8
	SX61	79.17%	69.44%	76.39%	75.00%	6	7	7
	SX64	81.94%	88.89%	79.17%	75.00%	6	8	7

Table A16. SUNY Clonal Trial damage assessment data collected at Ellerslie Short-Rotation Woody Crops Technical Development Site.

Map Legend Number	Clone Common Name	2006 Browse Damage	2007-08 Browse Damage	2007-08 Mechanical Damage	2007-08 Girdling Damage	2008 Winter Dieback Damage	2008 Spring Mean Post Dieback Stem Ht (m)
69	Oneonta	25.00%	9.72%	0.00%	0.00%	75.00%	0.22
	94001	0.00%	0.00%	0.00%	0.00%	33.33%	0.36
	00X-026-082	50.00%	75.00%	0.00%	25.00%	0.00%	0.00
	00X-032-094	25.00%	100.00%	0.00%	0.00%	0.00%	0.00
	9832-49	50.00%	100.00%	0.00%	0.00%	0.00%	0.00
	9837-077	25.00%	100.00%	0.00%	0.00%	0.00%	0.00
	Cicero	25.00%	4.17%	6.94%	0.00%	77.78%	0.38
	Marcy	25.00%	26.39%	0.00%	0.00%	38.89%	0.18
	Sherburne	0.00%	0.00%	0.00%	0.00%	94.44%	0.48
	Fish Creek	0.00%	0.00%	0.00%	0.00%	87.50%	0.33
	Wolcott	25.00%	0.00%	0.00%	0.00%	59.72%	0.46
	Onondaga	25.00%	1.39%	0.00%	0.00%	33.33%	0.09
	Otisco	50.00%	0.00%	0.00%	0.00%	93.06%	0.24
	Tully Champion	75.00%	0.00%	0.00%	0.00%	98.61%	0.57
	Owasco	100.00%	0.00%	0.00%	0.00%	72.22%	0.17
	Millbrook	100.00%	0.00%	0.00%	0.00%	97.22%	0.58
	Saratoga	0.00%	0.00%	0.00%	0.00%	88.89%	0.47
	Allegany	50.00%	6.94%	0.00%	0.00%	47.22%	0.13
	Canastota	0.00%	4.17%	0.00%	0.00%	79.17%	0.14
	Oneida	50.00%	4.17%	0.00%	0.00%	59.72%	0.38
	S25	50.00%	100.00%	0.00%	0.00%	0.00%	0.00
	SV1	0.00%	27.78%	2.78%	0.00%	23.61%	0.04
	SX61	0.00%	2.78%	2.78%	0.00%	65.28%	0.14
	SX64	0.00%	4.17%	0.00%	0.00%	75.00%	0.25

Table A17. SUNY Clonal Trial maximum height data collected at Ellerslie Short-Rotation Woody Crops Technical Development Site.

Map Legend Number	Clone Common Name	2006 Mean Max Ht (m)	2007 Mean Max Ht (m)	Spring 2008 Mean Max Ht (m)	2010-11 Mean Max Ht (m)	2011-12 Mean Max Ht (m)
69	Oneonta	0.54	1.54	0.41	2.02	2.47
	94001	0.92	2.06	1.70	2.72	3.39
	00X-026-082	0.34	0.77	0.77	0.82	1.10
	00X-032-094	0.35	0.83	0.83	1.23	1.87
	9832-49	0.42	0.98	0.98	1.43	2.00
	9837-077	0.35	0.71	0.71	1.14	1.64
	Cicero	0.79	1.97	0.68	2.52	2.55
	Marcy	0.69	1.82	0.87	2.25	2.38
	Sherburne	1.17	2.78	0.54	3.20	3.23
	Fish Creek	0.91	2.05	0.46	2.62	3.09
	Wolcott	0.67	1.81	1.00	2.25	2.92
	Onondaga	0.74	1.64	0.99	2.37	2.46
	Otisco	0.65	2.26	0.28	2.72	3.11
	Tully Champion	0.61	2.53	0.59	3.17	3.46
	Owasco	0.73	2.32	0.55	2.59	3.03
	Millbrook	0.63	2.07	0.61	2.68	3.23
	Saratoga	0.74	2.24	0.57	2.75	3.46
	Allegany	0.60	1.75	0.92	2.05	2.27
	Canastota	0.84	2.02	0.24	2.45	2.66
	Oneida	0.65	1.29	0.76	1.93	2.69
	S25	0.38	0.96	0.96	1.01	1.52
	SV1	0.45	1.74	1.18	2.49	2.55
	SX61	0.84	2.22	0.70	2.68	2.98
	SX64	0.76	2.07	0.46	2.59	2.86

Table A18. SUNY Clonal Trial wet weight growth and yield data collected at Ellerslie Short-Rotation Woody Crops Technical Development Site.

Map Legend Number	Clone Common Name	2007 Spring Coppice Wet Weight^{-ha} (Tonnes)	2009-10 Wet Weight^{-ha} (Tonnes)	2012-13 Wet Weight^{-ha} (Tonnes)	2018-19 Wet Weight^{-ha} (Tonnes)	Total 2006-2018 Wet Weight^{-ha} (Tonnes)	2006-2018 Average Wet Weight^{-ha-yr} (Tonnes)
69	Oneonta	0.16	8.19	17.24	42.12	93.50	5.19
	94001	0.42	28.80	43.68	106.75	245.01	13.61
	00X-026-082	0.03	2.20	1.60	3.90	10.12	0.56
	00X-032-094	0.01	3.44	9.29	22.70	49.33	2.74
	9832-49	0.05	5.23	12.02	29.38	64.69	3.59
	9837-077	0.02	2.80	3.30	8.05	19.09	1.06
	Cicero	0.27	10.31	17.62	43.05	97.61	5.42
	Marcy	0.10	6.63	14.02	34.26	75.99	4.22
	Sherburne	0.70	23.69	33.41	81.66	189.46	10.53
	Fish Creek	0.24	16.30	31.88	77.90	174.02	9.67
	Wolcott	0.16	12.34	25.46	62.23	138.31	7.68
	Onondaga	0.30	10.71	18.99	46.42	104.84	5.82
	Otisco	0.12	18.93	26.28	64.23	148.91	8.27
	Tully Champion	0.14	24.49	36.43	89.03	204.60	11.37
	Owasco	0.38	20.57	27.54	67.31	157.02	8.72
	Millbrook	0.09	21.35	31.12	76.04	175.17	9.73
	Saratoga	0.50	22.89	38.41	93.86	213.14	11.84
	Allegany	0.42	13.06	24.25	59.25	133.26	7.40
	Canastota	0.33	13.82	21.21	51.84	118.94	6.61
	Oneida	0.14	10.67	19.75	48.27	108.40	6.02
	S25	0.03	3.71	5.51	13.47	30.98	1.72
	SV1	0.02	11.86	17.60	43.00	98.81	5.49
	SX61	0.36	11.86	18.08	44.17	101.52	5.64
	SX64	0.25	13.18	26.10	63.79	142.40	7.91

Table A19. SUNY Clonal Trial oven dried growth and yield data collected at Ellerslie Short-Rotation Woody Crops Technical Development Site.

Map Legend Number	Clone Common Name	2007 Spring Coppice ODT/ha	2009 - 10 ODT/ha	2012-13 ODT/ha	2018-19 ODT/ha	2006-18 ODT/ha/yr
69	Oneonta	0.08	5.44	10.77	25.79	3.24
	94001	0.20	20.04	26.62	65.37	8.63
	00X-026-082	0.01	1.57	0.96	2.39	0.38
	00X-032-094	0.01	2.25	5.76	13.90	1.69
	9832-49	0.03	3.54	7.09	17.99	2.20
	9837-077	0.01	1.94	1.93	4.93	0.68
	Cicero	0.14	6.54	10.34	26.36	3.34
	Marcy	0.05	4.20	8.07	20.98	2.56
	Sherburne	0.35	15.29	19.50	50.00	6.55
	Fish Creek	0.11	10.92	19.67	47.70	6.03
	Wolcott	0.08	8.15	15.08	38.11	4.72
	Onondaga	0.15	7.46	11.77	28.42	3.68
	Otisco	0.07	11.89	16.05	39.33	5.18
	Tully Champion	0.08	15.79	21.94	54.52	7.10
	Owasco	0.20	13.27	16.25	41.22	5.46
	Millbrook	0.05	12.99	17.90	46.57	5.96
	Saratoga	0.27	14.44	23.08	57.48	7.33
	Allegany	0.23	8.32	13.80	36.28	4.51
	Canastota	0.15	8.90	12.43	31.74	4.09
	Oneida	0.08	6.97	11.69	29.56	3.72
	S25	0.02	2.65	3.49	8.25	1.11
	SV1	0.01	8.22	11.04	26.33	3.51
	SX61	0.18	8.00	10.24	27.05	3.50
	SX64	0.13	8.51	15.43	39.06	4.86

Appendix VIII

Data summaries of the sampling completed in 2012-13 for concentrated biomass operational trials at Ellerslie SRWC Technical Development Site, Edmonton, Alberta.

Table A20. Ten percent sampling intensity summary of single year's growth of Bed #3 at Ellerslie Short-Rotation Woody Crops Technical Development Site.

Map Legend Number	Clone	Plot Number	Plot Area (m^2)	Total Plot Wet Wt (kg)	Average Max. Ht (m)	Survival	Wet Wt/Ha (kg)	Difference to Actual
49	India (Bed 3)	1	16 (10%)	22.5	3.05	100.00%	14062.5	30.28%
	India (Bed 3)	2	16 (10%)	20.9	2.89	91.67%	13062.5	21.02%
	India (Bed 3)	3	16 (10%)	17.4	2.63	75.00%	10875	0.75%
	India (Bed 3)	4	16 (10%)	19.2	2.68	95.83%	12000	11.18%
	India (Bed 3)	5	16 (10%)	19.5	2.7	87.50%	12187.5	12.91%
	India (Bed 3)	6	16 (10%)	14.2	2.43	91.67%	8875	-17.78%
	India (Bed 3)	7	16 (10%)	15.8	2.56	100.00%	9875	-8.51%
	India (Bed 3)	8	16 (10%)	17	2.57	96.30%	10625	-1.56%
	India (Bed 3)	9	16 (10%)	14.3	2.46	91.67%	8937.5	-17.20%
	India (Bed 3)	10	16 (10%)	11.9	2.4	100.00%	7437.5	-31.09%
	India (Bed 3)	All	160 (100%)	172.7	2.637	93.00%	10793.75	N/A

Table A21. Detailed sampling results using various plot sampling designs of single year's growth of Bed #4 at Ellerslie Short-Rotation Woody Crops Technical Development Site.

Map Legend Number	Clone	Plot Type	Row #	Plot Area	Avg Wet Wt per Plant (kg)	Sum Wet Wt per Row (kg)	Survival	Mean Max Ht (m)	Wet Wt/ha (Tonnes)
49	India (Bed 4)	Single Row Plot	1	1.92	0.90	0.90	33.33%	2.54	4.6875
	India (Bed 4)	Single Row Plot	2	1.92	1.30	3.90	100.00%	2.74	20.3125
	India (Bed 4)	Single Row Plot	3	1.92	1.10	2.20	66.67%	2.69	11.4583
	India (Bed 4)	Single Row Plot	4	1.92	0.67	2.00	100.00%	2.52	10.4167
	India (Bed 4)	Single Row Plot	5	1.92	0.83	2.50	100.00%	2.56	13.0208
	India (Bed 4)	Single Row Plot	6	1.92	0.45	0.90	66.67%	2.27	4.6875
	India (Bed 4)	Single Row Plot	7	1.92	0.65	1.30	66.67%	2.63	6.7708
	India (Bed 4)	Single Row Plot	8	1.92	0.73	2.20	100.00%	2.22	11.4583
	India (Bed 4)	Single Row Plot	9	1.92	0.60	0.60	33.33%	2.38	3.1250
	India (Bed 4)	Single Row Plot	10	1.92	0.60	1.80	100.00%	2.41	9.3750
	India (Bed 4)	Single Row Plot	11	1.92	0.70	2.10	100.00%	2.52	10.9375
	India (Bed 4)	Single Row Plot	12	1.92	0.47	1.40	100.00%	2.39	7.2917
	India (Bed 4)	Single Row Plot	13	1.92	0.30	0.30	33.33%	2.17	1.5625
	India (Bed 4)	Single Row Plot	14	1.92	0.67	2.00	100.00%	2.20	10.4167
	India (Bed 4)	Single Row Plot	15	1.92	0.70	2.10	100.00%	2.15	10.9375
	India (Bed 4)	Single Row Plot	16	1.92	0.25	0.50	66.67%	1.96	2.6042
	India (Bed 4)	Single Row Plot	17	1.92	0.67	2.00	100.00%	2.32	10.4167
	India (Bed 4)	Single Row Plot	18	1.92	0.47	1.40	100.00%	1.92	7.2917
	India (Bed 4)	Single Row Plot	19	1.92	0.25	0.50	66.67%	1.72	2.6042
	India (Bed 4)	Single Row Plot	20	1.92	0.30	0.60	66.67%	2.10	3.1250
	India (Bed 4)	Single Row Plot	21	1.92	0.60	1.20	66.67%	2.14	6.2500
	India (Bed 4)	Single Row Plot	22	1.92	0.23	0.70	100.00%	2.14	3.6458
	India (Bed 4)	Single Row Plot	23	1.92	0.40	0.80	66.67%	2.17	4.1667
	India (Bed 4)	Single Row Plot	24	1.92	0.85	1.70	66.67%	2.27	8.8542
	India (Bed 4)	Single Row Plot	25	1.92	0.40	0.80	66.67%	2.05	4.1667
	India (Bed 4)	Single Row Plot	26	1.92	0.63	1.90	100.00%	2.35	9.8958
	India (Bed 4)	Single Row Plot	27	1.92	0.53	1.60	100.00%	2.42	8.3333
	India (Bed 4)	Single Row Plot	28	1.92	0.30	0.60	66.67%	2.19	3.1250
	India (Bed 4)	Single Row Plot	29	1.92	0.73	2.20	100.00%	2.35	11.4583
	India (Bed 4)	Single Row Plot	30	1.92	0.62	1.85	100.00%	2.19	9.6354
	India (Bed 4)	Single Row Plot	31	1.92	0.67	2.00	100.00%	2.32	10.4167
	India (Bed 4)	Single Row Plot	32	1.92	0.63	1.90	100.00%	2.41	9.8958
	India (Bed 4)	Single Row Plot	33	1.92	0.65	1.30	66.67%	2.26	6.7708
	India (Bed 4)	Single Row Plot	34	1.92	0.45	0.90	66.67%	2.31	4.6875
	India (Bed 4)	Single Row Plot	35	1.92	1.10	2.20	66.67%	2.39	11.4583
	India (Bed 4)	Single Row Plot	36	1.92	1.07	3.20	100.00%	2.67	16.6667
	India (Bed 4)	Single Row Plot	37	1.92	0.50	1.50	100.00%	2.40	7.8125

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(Continued from p. 107)

Map Legend Number	Clone	Plot Type	Row #	Plot Area	Avg Wet Wt per Plant (kg)	Sum Wet Wt per Row (kg)	Survival	Mean Max Ht (m)	Wet Wt/ha (Tonnes)
	India (Bed 4)	Single Row Plot	38	1.92	0.80	1.60	66.67%	2.35	8.3333
	India (Bed 4)	Single Row Plot	39	1.92	0.50	1.00	66.67%	2.33	5.2083
	India (Bed 4)	Single Row Plot	40	1.92	0.40	1.20	100.00%	2.03	6.2500
	India (Bed 4)	Single Row Plot	41	1.92	0.75	1.50	66.67%	2.28	7.8125
	India (Bed 4)	Single Row Plot	42	1.92	0.70	1.40	66.67%	2.45	7.2917
	India (Bed 4)	Single Row Plot	43	1.92	0.75	1.50	66.67%	2.15	7.8125
	India (Bed 4)	Single Row Plot	44	1.92	0.65	1.30	66.67%	2.28	6.7708
	India (Bed 4)	Single Row Plot	45	1.92	0.80	2.40	100.00%	2.38	12.5000
	India (Bed 4)	Single Row Plot	46	1.92	0.53	1.60	100.00%	2.27	8.3333
	India (Bed 4)	Single Row Plot	47	1.92	0.63	1.90	100.00%	2.47	9.8958
	India (Bed 4)	Single Row Plot	48	1.92	0.37	1.10	100.00%	2.05	5.7292
	India (Bed 4)	Single Row Plot	49	1.92	0.60	1.20	66.67%	2.15	6.2500
	India (Bed 4)	Single Row Plot	50	1.92	0.25	0.50	66.67%	2.25	2.6042
	India (Bed 4)	Single Row Plot	51	1.92	0.70	2.10	100.00%	2.42	10.9375
	India (Bed 4)	Single Row Plot	52	1.92	0.37	1.10	100.00%	2.21	5.7292
	India (Bed 4)	Single Row Plot	53	1.92	0.33	1.00	100.00%	1.97	5.2083
	India (Bed 4)	Single Row Plot	54	1.92	0.25	0.75	100.00%	1.55	3.9063
	India (Bed 4)	2-Row Plot	C	3.84	0.42	2.20	83.33%	2.31	5.7292
	India (Bed 4)	2-Row Plot	N1	3.84	0.68	4.05	100.00%	2.27	10.5469
	India (Bed 4)	2-Row Plot	N10	3.84	0.50	3.00	100.00%	2.26	7.8125
	India (Bed 4)	2-Row Plot	N11	3.84	0.43	1.70	66.67%	2.20	4.4271
	India (Bed 4)	2-Row Plot	N12	3.84	0.53	3.20	100.00%	2.32	8.3333
	India (Bed 4)	2-Row Plot	N13	3.84	0.29	1.75	100.00%	1.76	4.5573
	India (Bed 4)	2-Row Plot	N2	3.84	0.65	3.90	100.00%	2.37	10.1563
	India (Bed 4)	2-Row Plot	N3	3.84	0.55	2.20	66.67%	2.28	5.7292
	India (Bed 4)	2-Row Plot	N4	3.84	1.08	5.40	83.33%	2.53	14.0625
	India (Bed 4)	2-Row Plot	N5	3.84	0.65	3.10	83.33%	2.38	8.0729
	India (Bed 4)	2-Row Plot	N6	3.84	0.45	2.20	83.33%	2.18	5.7292
	India (Bed 4)	2-Row Plot	N7	3.84	0.73	2.90	66.67%	2.36	7.5521
	India (Bed 4)	2-Row Plot	N8	3.84	0.70	2.80	66.67%	2.21	7.2917
	India (Bed 4)	2-Row Plot	N9	3.84	0.67	4.00	100.00%	2.32	10.4167
	India (Bed 4)	2-Row Plot	S1	3.84	0.52	2.70	83.33%	2.20	7.0313
	India (Bed 4)	2-Row Plot	S10	3.84	0.69	3.50	83.33%	2.42	9.1146
	India (Bed 4)	2-Row Plot	S11	3.84	0.64	3.40	83.33%	2.41	8.8542
	India (Bed 4)	2-Row Plot	S12	3.84	0.88	4.20	83.33%	2.61	10.9375
	India (Bed 4)	2-Row Plot	S13	3.84	1.10	4.80	66.67%	2.64	12.5000
	India (Bed 4)	2-Row Plot	S2	3.84	0.63	2.50	66.67%	2.22	6.5104
	India (Bed 4)	2-Row Plot	S3	3.84	0.42	1.90	83.33%	2.14	4.9479
	India (Bed 4)	2-Row Plot	S4	3.84	0.28	1.10	66.67%	1.91	2.8646

(Continued on p. 109)

(Continued from p. 108)

Map Legend Number	Clone	Plot Type	Row #	Plot Area	Avg Wet Wt per Plant (kg)	Sum Wet Wt per Row (kg)	Survival	Mean Max Ht (m)	Wet Wt/ha (Tonnes)
	India (Bed 4)	2-Row Plot	S5	3.84	0.57	3.40	100.00%	2.12	8.8542
	India (Bed 4)	2-Row Plot	S6	3.84	0.48	2.60	83.33%	2.05	6.7708
	India (Bed 4)	2-Row Plot	S7	3.84	0.48	2.30	66.67%	2.19	5.9896
	India (Bed 4)	2-Row Plot	S8	3.84	0.58	3.50	100.00%	2.46	9.1146
	India (Bed 4)	2-Row Plot	S9	3.84	0.60	2.40	66.67%	2.40	6.2500
	India (Bed 4)	3-Row Plot	C	5.76	0.49	4.10	88.89%	2.32	7.1181
	India (Bed 4)	3-Row Plot	N1	5.76	0.67	6.05	100.00%	2.29	10.5035
	India (Bed 4)	3-Row Plot	N2	5.76	0.58	4.10	77.78%	2.33	7.1181
	India (Bed 4)	3-Row Plot	N3	5.76	0.89	6.90	88.89%	2.49	11.9792
	India (Bed 4)	3-Row Plot	N4	5.76	0.57	3.80	77.78%	2.23	6.5972
	India (Bed 4)	3-Row Plot	N5	5.76	0.73	4.40	66.67%	2.29	7.6389
	India (Bed 4)	3-Row Plot	N6	5.76	0.66	5.30	88.89%	2.31	9.2014
	India (Bed 4)	3-Row Plot	N7	5.76	0.53	4.20	88.89%	2.22	7.2917
	India (Bed 4)	3-Row Plot	N8	5.76	0.44	3.70	88.89%	2.29	6.4236
	India (Bed 4)	3-Row Plot	S1	5.76	0.55	3.30	66.67%	2.16	5.7292
	India (Bed 4)	3-Row Plot	S2	5.76	0.38	2.50	77.78%	2.12	4.3403
	India (Bed 4)	3-Row Plot	S3	5.76	0.46	3.90	88.89%	1.98	6.7708
	India (Bed 4)	3-Row Plot	S4	5.76	0.54	4.60	88.89%	2.10	7.9861
	India (Bed 4)	3-Row Plot	S5	5.76	0.49	3.80	77.78%	2.36	6.5972
	India (Bed 4)	3-Row Plot	S6	5.76	0.64	4.60	77.78%	2.34	7.9861
	India (Bed 4)	3-Row Plot	S7	5.76	0.64	4.70	77.78%	2.48	8.1597
	India (Bed 4)	3-Row Plot	S8	5.76	1.02	8.10	88.89%	2.65	14.0625
	India (Bed 4)	4-Row Plot	C	7.68	0.47	4.90	83.33%	2.25	6.3802
	India (Bed 4)	4-Row Plot	N1	7.68	0.66	7.95	100.00%	2.32	10.3516
	India (Bed 4)	4-Row Plot	N2	7.68	0.82	7.60	75.00%	2.41	9.8958
	India (Bed 4)	4-Row Plot	N3	7.68	0.55	5.30	83.33%	2.28	6.9010
	India (Bed 4)	4-Row Plot	N4	7.68	0.71	5.70	66.67%	2.29	7.4219
	India (Bed 4)	4-Row Plot	N5	7.68	0.58	7.00	100.00%	2.29	9.1146
	India (Bed 4)	4-Row Plot	N6	7.68	0.48	4.90	83.33%	2.26	6.3802
	India (Bed 4)	4-Row Plot	S1	7.68	0.52	4.40	75.00%	2.18	5.7292
	India (Bed 4)	4-Row Plot	S2	7.68	0.42	4.50	83.33%	2.01	5.8594
	India (Bed 4)	4-Row Plot	S3	7.68	0.48	4.90	75.00%	2.12	6.3802
	India (Bed 4)	4-Row Plot	S4	7.68	0.59	5.90	83.33%	2.43	7.6823
	India (Bed 4)	4-Row Plot	S5	7.68	0.67	6.90	83.33%	2.42	8.9844
	India (Bed 4)	4-Row Plot	S6	7.68	0.99	9.00	75.00%	2.62	11.7188
	India (Bed 4)	5-Row Plot	C	9.60	0.52	7.10	86.67%	2.27	7.3958
	India (Bed 4)	5-Row Plot	N1	9.60	0.60	7.95	86.67%	2.30	8.2813
	India (Bed 4)	5-Row Plot	N2	9.60	0.79	9.50	80.00%	2.43	9.8958

(Continued on p. 110)

(Continued from p. 109)

Map Legend Number	Clone	Plot Type	Row #	Plot Area	Avg Wet Wt per Plant (kg)	Sum Wet Wt per Row (kg)	Survival	Mean Max Ht (m)	Wet Wt/ha (Tonnes)
	India (Bed 4)	5-Row Plot	N3	9.60	0.65	6.90	73.33%	2.23	7.1875
	India (Bed 4)	5-Row Plot	N4	9.60	0.59	8.20	93.33%	2.26	8.5417
	India (Bed 4)	5-Row Plot	N5	9.60	0.38	5.45	93.33%	2.08	5.6771
	India (Bed 4)	5-Row Plot	S1	9.60	0.48	5.00	73.33%	2.16	5.2083
	India (Bed 4)	5-Row Plot	S2	9.60	0.47	6.50	86.67%	2.01	6.7708
	India (Bed 4)	5-Row Plot	S3	9.60	0.55	7.60	86.67%	2.34	7.9167
	India (Bed 4)	5-Row Plot	S4	9.60	0.65	7.50	73.33%	2.41	7.8125
	India (Bed 4)	Single Row +10 Row Survival	C	1.92	0.53	1.60	87.88%	2.42	8.3333
	India (Bed 4)	Single Row +10 Row Survival	N1	1.92	0.40	1.20	78.79%	2.03	6.2500
	India (Bed 4)	Single Row +10 Row Survival	S1	1.92	0.67	2.00	81.82%	2.20	10.4167
	India (Bed 4)	Single Row +10 Row Survival (Avg Wt/Plant Method)	N1	1.92	0.40	1.20	82.54%	2.03	5.1587
	India (Bed 4)	Single Row +10 Row Survival (Avg Wt/Plant Method)	S1	1.92	0.67	2.00	80.95%	2.20	8.4325

Table A22. Summary of 2012-13 detailed sampling and plot scenarios of single year's growth of Bed #4 at Ellerslie Short-Rotation Woody Crops Technical Development Site.

Clone	Plot Type	Plot Data	Plot Area (m^2)	# of Plots	Avg Wet Wt per Plant (kg)	Total Wet Wt per Plot (kg)	Survival	Mean Max Ht (m)	Wet Wt/ha (Plot) (Tonnes)	Difference To Actual
India (Bed 4)	Site (100% Sample)	1	103.68	1	0.5991	80.70	82.72%	2.28	7.784	N/A
India (Bed 4)	Single Row Plot	Min	1.92	54	0.2333	0.30	33.33%	1.55	1.563	-79.93%
India (Bed 4)	Single Row Plot	Mean	1.92	54	0.5991	1.49	82.72%	2.28	7.784	N/A
India (Bed 4)	Single Row Plot	Max	1.92	54	1.3000	3.90	100.00%	2.74	20.313	160.97%
India (Bed 4)	2-Row Plot	Min	3.84	27	0.2750	1.10	66.67%	1.76	2.865	-63.20%
India (Bed 4)	2-Row Plot	Mean	3.84	27	0.5991	2.99	82.72%	2.28	7.784	N/A
India (Bed 4)	2-Row Plot	Max	3.84	27	1.1000	5.40	100.00%	2.64	14.063	80.67%
India (Bed 4)	3-Row Plot	Min	5.76	17	0.3778	2.50	66.67%	1.98	4.340	-44.24%
India (Bed 4)	3-Row Plot	Mean	5.76	17	0.6052	4.59	83.01%	2.29	7.971	2.41%
India (Bed 4)	3-Row Plot	Max	5.76	17	1.0222	8.10	100.00%	2.65	14.063	80.67%
India (Bed 4)	4-Row Plot	Min	7.68	13	0.4208	4.40	66.67%	2.01	5.729	-26.39%
India (Bed 4)	4-Row Plot	Mean	7.68	13	0.6109	6.07	82.05%	2.30	7.908	1.59%
India (Bed 4)	4-Row Plot	Max	7.68	13	0.9917	9.00	100.00%	2.62	11.719	50.56%
India (Bed 4)	5-Row Plot	Min	9.6	10	0.3800	5.00	73.33%	2.01	5.208	-33.09%
India (Bed 4)	5-Row Plot	Mean	9.6	10	0.5677	7.17	83.33%	2.25	7.469	-4.04%
India (Bed 4)	5-Row Plot	Max	9.6	10	0.7933	9.50	93.33%	2.43	9.896	27.14%
India (Bed 4)	Single Row +10 Row Survival	Min	1.92	3	0.4000	1.20	78.79%	2.03	6.250	-36.74%
India (Bed 4)	Single Row +10 Row Survival	Mean	1.92	3	1.6000	1.60	82.83%	2.22	8.333	-11.05%
India (Bed 4)	Single Row +10 Row Survival	Max	1.92	3	0.6667	2.00	87.88%	2.42	10.417	9.50%
India (Bed 4)	Single Row +10 Row Survival (Avg Wt/ Plant Method)	Min	1.92	2	0.4000	1.20	80.95%	2.03	5.159	-33.72%
India (Bed 4)	Single Row +10 Row Survival (Avg Wt/ Plant Method)	Mean	1.92	2	0.5333	1.60	81.75%	2.12	6.812	-12.48%
India (Bed 4)	Single Row +10 Row Survival (Avg Wt/ Plant Method)	Max	1.92	2	0.6667	2.00	82.54%	2.20	8.433	8.34%

Appendix IX

History of Soil Assessment and Analysis Information

Table A23. Soil composition summary of samples collected between 2003 and 2010 at Ellerslie Short-Rotation Woody Crops Technical Development Site.

Map Legend Number	Year	Sample	Sand (%)	Clay (%)	Silt (%)	pH	Total Org C (%)
4	2003	3-3	22	36	42	6.37	8.51
4	2003	3-4	23	36	41	6.44	7.46
24	2003	4-3	30	32	38	6.36	6.23
24	2003	4-4	28	30	42	6.62	6.63
24	2003	5-3	28	32	40	6.04	7.74
24	2003	5-4	26	30	44	6.36	6.78
24	2003	6-3	8	31	61	6.27	7.38
24	2003	6-4	26	31	43	6.51	5.72
15	2005	1-3	6	32	62	7.08	6.8
15	2005	1-4	24	34	42	6.45	5.93
16	2005	2-3	25	31	43	6.16	6.99
16	2005	2-4	25	31	44	5.92	7.11
25	2005	7-3	23	35	41	5.94	6.86
25	2005	7-4	24	33	43	6.03	6.97
25	2005	8-3	33	30	37	5.78	7.29
25	2005	8-4	30	28	42	5.96	6.5
25	2005	9-3	30	32	37	5.75	6.32
25	2005	9-4	29	29	41	5.84	6.05
27	2005	10-3	29	32	39	6.08	8.84
27	2005	10-4	27	33	39	5.94	7.37
31	2005	11-3	30	29	41	6.81	8.64
31	2005	11-4	31	31	38	5.99	6.15
49	2010	12-3	32	31	37	5.65	6.72
49	2010	12-4	28	36	36	5.73	5.06

Table A24. Soil analysis summary of samples collected between 2003 and 2010 at Ellerslie Short-Rotation Woody Crops Technical Development Site.

Map Legend Number	Year	Sample	Ca (mg kg^{-1})	K (mg kg^{-1})	Mg (mg kg^{-1})	Na (mg kg^{-1})	P (mg kg^{-1})	NO3-N (mg kg^{-1})	NH4-N (mg kg^{-1})
4	2003	3-3	5847	330	635	6.39	9.52	12.5	44.3
4	2003	3-4	378	84.3	164	349	7.56	38.0	113.0
24	2003	4-3	350	103	146	410	13.7	17.3	34.6
24	2003	4-4	310	65.8	194	379	7.05	16.0	45.6
24	2003	5-3	362	146	129	355	6.3	28.1	67.9
24	2003	5-4	342	37.1	175	345	4.32	46.2	44.3
24	2003	6-3	369	54.0	140	348	4.16	47.2	43.0
24	2003	6-4	374	25.3	196	323	4.29	19.0	52.9
15	2005	1-3	5869	479	560	< 0.605	4.98	20.6	23.0
15	2005	1-4	318	153	135	417	7.85	22.1	29.3
16	2005	2-3	5545	219	528	4.08	6.76	23.3	36.2
16	2005	2-4	368	281	156	387	11.5	32.5	31.1
25	2005	7-3	394	104	120	347	4.75	26.2	31.2
25	2005	7-4	433	60.5	153	377	4.55	32.1	115.0
25	2005	8-3	376	87.3	126	331	4.89	83.7	75.7
25	2005	8-4	404	43.6	151	367	4.66	38.6	58.3
25	2005	9-3	375	87.1	137	376	5.45	92.2	47.8
25	2005	9-4	466	37.7	174	347	4.93	119.0	113
27	2005	10-3	423	77.3	120	348	6.13	129.0	56.8
27	2005	10-4	362	52.2	135	331	5.88	79.4	75.0
31	2005	11-3	239	170.0	150	296	8.64	150.0	36.4
31	2005	11-4	349	45.9	141	279	5.24	150.0	41.4
49	2009	12-3	345	131.0	105	274	8.19	369.0	174
49	2009	12-4	360	44.5	133	278	6.04	333.0	70.0

Table A25. Summary of 2003 soil sampling completed at Ellerslie Short-Rotation Woody Crops Technical Development Site.

Map Legend Number	Location	Row	Tree	pH $CaCl_2$	E.C. mmhos^{-cm}	Total C %
4	Adjacent Field	1	6	6.0	0.50	8.0
	Adjacent Field	1	20	6.0	0.38	8.2
	Adjacent Field	2	6	5.7	0.44	7.8
	Adjacent Field	2	20	5.6	0.38	7.6
	Adjacent Field	3	6	5.6	0.48	7.7
	Adjacent Field	3	20	5.6	0.36	7.0
	Undisturbed Microsite Between Rows	3	2	5.9	0.78	8.4
	Undisturbed Microsite Between Rows	3	11	6.0	0.44	8.1
	Undisturbed Microsite Between Rows	3	18	6.1	0.68	8.0
	Undisturbed Microsite Between Rows	8	3	6.0	0.70	8.5
	Undisturbed Microsite Between Rows	8	11	5.8	0.60	8.1
	Undisturbed Microsite Between Rows	8	18	6.0	0.76	8.1
	Undisturbed Microsite Between Rows	13	3	5.9	0.60	8.4
	Undisturbed Microsite Between Rows	13	11	5.9	0.56	8.5
	Undisturbed Microsite Between Rows	13	11 (b)	6.0	0.60	8.4
	Undisturbed Microsite Between Rows	13	19	5.7	0.52	8.0
	Undisturbed Microsite Between Rows	13	19 (b)	6.0	0.68	8.1
	Undisturbed Microsite Between Rows	18	3	5.9	0.50	7.9
	Undisturbed Microsite Between Rows	18	11	5.9	0.62	8.0
	Undisturbed Microsite Between Rows	18	19	6.1	0.60	7.8
	Elevated Microsite Between Trees	3	2	5.9	0.86	8.2
	Elevated Microsite Between Trees	3	11	6.0	0.90	8.2
	Elevated Microsite Between Trees	3	11 (b)	6.0	0.94	8.1
	Elevated Microsite Between Trees	3	18	6.1	0.48	8.7
	Elevated Microsite Between Trees	3	18 (b)	6.1	0.48	8.6
	Elevated Microsite Between Trees	8	3	5.8	0.92	8.7
	Elevated Microsite Between Trees	8	11	6.0	1.40	8.3
	Elevated Microsite Between Trees	8	18	5.9	0.72	8.1
	Elevated Microsite Between Trees	13	3	6.0	0.42	8.5
	Elevated Microsite Between Trees	13	11	6.0	0.48	8.3
	Elevated Microsite Between Trees	13	11 (b)	6.0	0.48	8.4
	Elevated Microsite Between Trees	13	19	5.9	1.06	8.1
	Elevated Microsite Between Trees	18	3	5.9	0.56	8.2
	Elevated Microsite Between Trees	18	11	5.9	0.50	8.1
	Elevated Microsite Between Trees	18	19	6.0	0.48	8.2
	Elevated Microsite Beneath Trees	3	2	5.9	1.10	8.5
	Elevated Microsite Beneath Trees	3	11	6.0	0.94	8.2
	Elevated Microsite Beneath Trees	3	18	6.1	0.54	8.1
	Elevated Microsite Beneath Trees	8	3	5.9	0.70	8.3
	Elevated Microsite Beneath Trees	8	11	6.0	0.54	8.0
	Elevated Microsite Beneath Trees	8	18	6.0	0.90	8.1
	Elevated Microsite Beneath Trees	13	3	5.9	0.48	8.3
	Elevated Microsite Beneath Trees	13	11	6.0	0.38	8.4
	Elevated Microsite Beneath Trees	13	19	5.9	0.42	8.1
	Elevated Microsite Beneath Trees	18	3	5.9	0.54	7.9
	Elevated Microsite Beneath Trees	18	11	6.0	0.46	7.7
	Elevated Microsite Beneath Trees	18	19	5.9	0.46	7.9

Table A26. Full rotation Forest 2020 soil carbon assessments completed at Ellerslie Short-Rotation Woody Crops Technical Development Site.

Map Legend Number	Year	Sample ID	Total Carbon (%)	Total Inorganic Carbon (%)	0-15cm Bulk Density (g.cm^{-3})
26	2019	Walker-Grab-25 East	5.70	0.565	
26	2019	Walker-Grab-25-Center	5.85	0.601	1.064444
26	2019	Walker-Grab-25-West	5.95	2.020	
26	2019	Walker-Grab-45-East	5.94	0.485	
26	2019	Walker-Grab-45-Center	5.77	2.670	1.082222
26	2019	Walker-Grab-45-West	5.67	0.575	
26	2019	Walker-Grab-65-East	5.78	2.570	
26	2019	Walker-Grab-65-Center	6.18	1.150	0.910000
26	2019	Walker-Grab-65-West	6.26	0.884	
26	2019	Walker-Grab-85-East	5.96	1.730	
26	2019	Walker-Grab-85-Center	5.78	0.525	1.070000
26	2019	Walker-Grab-85-West	5.52	0.768	
25	2019	Assiniboine-Grab-25-East	5.97	0.568	
25	2019	Assiniboine-Grab-25-Center	6.58	1.010	1.096667
25	2019	Assiniboine-Grab-25-West	6.10	1.430	
25	2019	Assiniboine-Grab-45-East	5.02	0.663	
25	2019	Assiniboine-Grab-45-Center	5.81	0.659	1.077778
25	2019	Assiniboine-Grab-45-West	5.60	0.483	
25	2019	Assiniboine-Grab-65-East	5.70	0.481	
25	2019	Assiniboine-Grab-65-Center	5.77	1.020	1.117778
25	2019	Assiniboine-Grab-65-West	5.66	0.507	
25	2019	Assiniboine-Grab-85-East	5.50	0.864	
25	2019	Assiniboine-Grab-85-Center	4.77	0.495	1.110000
25	2019	Assiniboine-Grab-85-West	5.27	1.880	
24	2019	Hill-Grab-25-East	5.60	0.623	
24	2019	Hill-Grab-25-Center	5.39	0.702	1.181111
24	2019	Hill-Grab-25-West	5.19	1.420	
24	2019	Hill-Grab-45-East	5.43	0.723	
24	2019	Hill-Grab-45-Center	5.26	0.475	1.148889
24	2019	Hill-Grab-45-West	5.30	1.290	
24	2019	Hill-Grab-65-East	5.41	0.658	
24	2019	Hill-Grab-65-Center	5.74	0.624	1.006667
24	2019	Hill-Grab-65-West	4.79	0.575	
24	2019	Hill-Grab-85-East	5.40	1.340	
24	2019	Hill-Grab-85-Center	4.37	0.703	1.056667
24	2019	Hill-Grab-85-West	4.83	1.510	

Appendix X

Methodologies used for conducting physical and chemical wood fibre characterization (Supplied by Uy, 2007, Grunet, 2007, Huntley, 2008 and Huntley et al., 2011, FPInnovations)

Methodology

Each sample was analyzed for extractives content, carbohydrate composition and total lignin content. For wood chemistry, samples were analyzed in duplicate and the averages of these values were reported. Separate analyses were performed for knots wood and clear wood for the wood chemistry portion of this work. The physical properties (density and microfibril angle) were determined with SilviScan. Fibre length and coarseness were evaluated with the Fiber Quality Analyzer (FQA) in triplicate. Calorific values were reported for knots wood only and were performed in duplicate. SilviScan and FQA analyses were performed on clear wood only.

Sample Preparation

The samples were debarked upon receipt and then frozen (-10 °C). All frozen, debarked samples were segmented with a band saw. In climate-controlled conditions, 20 °C and 40% relative humidity (RH) wood segments were partitioned (by hand) into knots wood and clear wood. Band sawn segments were visually evaluated for knots, where possible. Clear wood was excised from segments containing knots. Visible reaction wood zones surrounding the knots were included as knots wood. For wood chemistry and calorific values, these sections were ground with a Whiley mill to pass through a 40-mesh screen.

Calorific Values

Calorific values were determined from bark-free, oven-dried, wood meal via direct calorimetry (PAPTAC testing method J.19P). Values were the average of duplicate experiments and recorded as the total energy (MJ) per oven-dried (OD) kg wood meal.

Extractives

Wood extractives content was determined according to the standard TAPPI method T280 pm-99. A 1 g portion of wood was used for moisture content determination and 3.5 g of conditioned wood meal was Soxhlet extracted with acetone for 6 hours. The acetone was removed by warming samples (35 °C) under a stream of nitrogen; followed by freeze-drying. The freeze-dried extractive weight was reported as a percentage of OD wood.

Klason Lignin & Carbohydrates

Lignin content was determined with a modified Klason lignin method (TAPPI method T222 om-98). Approximately 200 mg of extracted, oven-dried wood meal was weighed in a test tube before reaction with 3 mL of 72% sulphuric acid. The mixture was diluted to 3% sulphuric acid, hydrolyzed at 120 °C for 1 hour, and filtered through a pre-washed and weighed glass microfiber filter. Acid insoluble lignin content was determined gravimetrically. Acid soluble lignin was determined spectrophotometrically (TAPPI UM-250) by the absorbance of the filtered hydrolyzate at 205 nm. The filtered hydrolyzate was analyzed for six wood monosaccharides: arabanan, rhamnan, galactan, glucan, xylan and mannan. This was accomplished directly via high performance anion exchange chromatography with pulsed amperometric detection (HPAEC-PAD). The process used a Dionex ICS-3000 HPLC, equipped with a GP50 gradient pump, an ED40 electrochemical detector, an AS40 auto-sampler and a pneumatic controller for the 500 mM NaOH post-column addition solution. The column was a Dionex CarboPac PA10 (4 x 250 mm) preceded by a CarboPac PA10 guard column (4 x 50 mm). Samples were run in duplicate.

SilviScan Sample Preparation

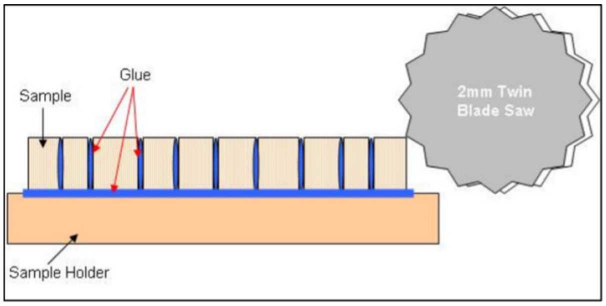

Figure 70. Sample prepared for 2 mm twin blade cutting. (Image supplied by FPInnovations)

A disc, free of visible knots, was sectioned from each de-barked wood stem. A 1 cm x 1 cm, bark-to-bark sample was sectioned with a band saw, with the pith included. The samples were conditioned in a climate-controlled room, 20 °C and 40% RH, for 2 weeks. Conditioned samples were cut into lengths of approximately 10 mm and glued to an MDF sample holder (Figure 70). The sides of the samples were also glued together to increase rigidity and decrease the chance of samples dislodging from the sample holder while cutting. The samples were cut in the 7 mm twin blade to give the final dimensions required for the SilviScan analysis of 2 mm thickness x 7 mm height. The basic density of each sample was obtained using the conditioned weight (g) and physical dimensions (mm): length, thickness and height (measured with a digital caliper). The values were encoded in the SilviScan database. The prepared samples were scanned from bark-to-bark across the pith, with both the x-ray densitometer and the x-ray diffractometer. The results from the densitometer and diffractometer were processed using the SilviScan's "wood" processing software. This was done to align the results from both components and compute the Modulus of Elasticity (MOE, GPa). The results were then exported as a CSV file. Density data was obtained every 25 µm; MFA and MOE were measured in 0.2 mm intervals.

Appendix XI

Physical and Chemical Characterization Results

Table A27. Summary of chemical composition (all values are a percentage of the oven-dried wood mass) evaluated in 2007 at Ellerslie Short-Rotation Woody Crops Technical Development Site.

Map Legend Number	Clone / Species	Total Extractives (Acetone Solvent)	Acid Soluble Lignin	Acid Insoluble Lignin	Total Lignin	Total Carbohydrates	Total
5	SV1	1.07	3.23	18.23	21.46	59.72	81.18
5	Viminalis	0.71	3.23	22.43	25.66	58.94	84.6
49	India	0.76	2.39	21.79	24.18	57.55	81.73
50	Pseudo	0.88	3.09	17.36	20.45	61.84	82.29
51	Hotel	1.02	2.42	28.89	31.31	54.01	85.32
57	SX67	1.58	3.02	22.32	25.34	60.03	85.37
57	SX64	1.54	2.77	21.47	24.24	58.08	82.32
57	SX61	1.31	2.46	28.62	31.08	55.43	86.51
73	Juliet	1.19	3.08	26.32	29.4	56.08	85.48
N/A	*Salix Discolor*	0.85	2.64	27.24	29.88	56.31	86.19
N/A	SA 2	0.71	2.51	25.33	27.84	56.71	84.55

Table A28. Carbohydrate composition as a percentage of oven-dried, extractive free wood evaluated in 2007 at Ellerslie Short-Rotation Woody Crops Technical Development Site.

Map Legend Number	Clone / Species	Arabinan	Galactan	Glucan	Xylan	Mannan	Total
5	SV1	0.27	0.74	44.28	13.61	0.82	59.72
5	Viminalis	0.26	0.84	42.39	13.37	2.08	58.94
49	India	0.34	0.74	41.76	13.97	0.74	57.55
50	Pseudo	0.24	0.68	48.30	12.25	0.38	61.84
51	Hotel	0.26	0.68	39.13	13.08	0.87	54.01
57	SX67	0.35	0.77	42.97	14.19	1.74	60.03
57	SX64	0.37	0.82	43.56	12.72	0.60	58.08
57	SX61	0.31	0.66	40.72	12.43	1.31	55.43
73	Juliet	0.18	0.72	42.3	11.82	1.06	56.08
N/A	*Salix Discolor*	0.37	0.81	39.6	13.67	1.86	56.31
N/A	SA 2	0.23	0.63	43.53	11.27	1.05	56.71

2007-08 physical and chemical characterization work completed in conjunction with FPInnovations for knot and clear wood.

Table A29. Percentage of Knots and Clear Wood for Hybrid Poplar and Salix Clones Evaluated in 2007-08 at Ellerslie Short-Rotation Woody Crops Technical Development Site.

Map Legend Number	Clone/Species	Species	Knots %	Clear %	Calorific Value (MJ/ODKG)
N/A	FFC-1	Hybrid Poplar	29.6	70.4	19.231
55	Charlie	Salix	43.4	56.6	19.313
49	India	Salix	48.4	51.6	19.122
N/A	DN-136	Hybrid Poplar	43.0	57.0	19.196
2	DN-34	Hybrid Poplar	28.9	71.1	19.601
50	Pseudo	Salix	26.9	73.1	19.238
54	NM-6	Hybrid Poplar	62.4	37.6	19.213
48	Viminalis (MBG)	Salix	42.1	57.9	21.071
5	Tristis	Hybrid Poplar	72.6	27.4	19.615
45	Brooks 1	Hybrid Poplar	50.9	49.1	19.627
24	Hill	Hybrid Poplar	71.7	28.3	19.722
52	Alpha	Salix	100.0	0.0	19.566
5	SV-1	Salix	65.1	34.9	19.194
N/A	Hyb Aspen (CFS)	Hybrid Aspen	63.8	36.2	19.443
16	Hyb Aspen (ELL)	Hybrid Aspen	48.7	51.3	19.662
5	Q-1150	Hybrid Poplar	59.0	41.0	19.713
51	Hotel	Salix	100.0	0.0	19.534
57	SX-64	Salix	100.0	0.0	19.741

Table A30. Summary of the physical properties for hybrid poplar and Salix clones (values are the average of multiple bark-to-bark measurements) evaluated in 2007–08 at Ellerslie Short-Rotation Woody Crops Technical Development Site.

Map Legend Number	Clone	Species	Diameter* (mm)	Density (kg/m^3)	Maceration Yield (%)	MFA (°)	Weighted Average Fibre Length (mm)	Average Fibre Coarseness (mg^{-m})
N/A	FFC-1	Hybrid Poplar	45.5	380.56	58.78	24.26	0.462	0.083
55	Charlie	Salix	23.4	386.24	46.04	23.06	0.383	0.081
49	India	Salix	24.6	494.69	55.29	28.12	0.537	0.066
N/A	DN-136	Hybrid Poplar	28.9	441.24	54.42	22.20	0.531	0.087
2	DN-34	Hybrid Poplar	27.8	482.00	51.59	26.81	0.527	0.091
50	Pseudo	Salix	19.9	343.91	52.09	22.74	0.489	0.059
54	NM-6	Hybrid Poplar	18.8	415.08	52.97	16.42	0.468	0.063
48	Viminalis	Salix	17.4	482.80	56.18	18.60	0.403	0.055
5	Tristis	Hybrid Poplar	18.7	446.13	56.19	24.44	0.418	0.084
45	Brooks 1	Hybrid Poplar	23.3	370.83	52.55	17.41	0.484	0.064
24	Hill	Hybrid Poplar	25.0	453.30	54.20	29.29	0.422	0.074
52	Alpha	Salix	9.5	408.61	50.82	24.62	0.315	0.048
5	SV-1	Salix	21.4	634.73	62.09	17.94	0.512	0.059
N/A	HA (CFS)	Hybrid Aspen	32.8	459.26	56.67	13.60	0.562	0.067
16	HA (ELL)	Hybrid Aspen	86.9	414.17	60.52	20.32	0.568	0.080
5	Q-1150	Hybrid Poplar	21.2	413.05	56.48	23.66	0.502	0.074
51	Hotel	Salix	8.6	543.07	51.33	23.53	0.334	0.046
57	SX-64	Salix	14.6	426.05	55.10	25.14	0.458	0.065

* Note that the diameter recorded here is for the segment evaluated with SilviScan, which was obtained from a location along the stem having approximately 2 cm of clear wood.

Table A31. Summary of knot wood chemical composition (all values are a percentage of the oven-dried wood mass) evaluated in 2007–08 at Ellerslie Short-Rotation Woody Crops Technical Development Site.

Map Legend Number	Clone	Species	Acid Insoluble Lignin	Acid Soluable Lignin	Extractives	Ash	Carbohydrates	Total
N/A	2293-19	Hybrid Poplar	22.23	2.82	1.65	0.70	60.44	87.85
55	Charlie	Salix	20.76	3.53	1.28	0.66	59.04	85.27
49	India	Salix	19.60	2.95	1.95	0.51	62.00	87.00
N/A	DN-136	Hybrid Poplar	23.13	3.13	2.40	0.63	58.80	88.09
2	DN-34	Hybrid Poplar	23.58	2.74	3.51	0.66	57.95	88.44
50	Pseudo	Salix	21.04	3.84	1.13	0.51	57.56	84.09
54	NM-6	Hybrid Poplar	19.37	3.59	1.84	0.53	59.65	84.98
48	Viminalis	Salix	19.85	3.66	1.49	0.55	60.83	86.40
5	Tristis	Hybrid Poplar	21.83	3.30	2.64	0.58	59.24	87.58
45	Brooks 1	Hybrid Poplar	22.28	3.60	2.04	0.58	59.84	88.35
24	Hill	Hybrid Poplar	23.12	3.06	2.30	0.52	57.38	86.38
52	Alpha	Salix	21.74	3.47	1.99	0.83	57.49	85.51
5	SV-1	Salix	17.64	3.76	1.26	0.49	66.38	89.54
N/A	HA (CFS)	Hybrid Aspen	18.02	3.85	3.88	0.45	64.47	90.68
16	HA (ELL)	Hybrid Aspen	17.17	3.63	2.91	0.27	65.00	88.98
5	Q-1150	Hybrid Poplar	22.20	3.22	2.86	0.54	59.56	88.37
51	Hotel	Salix	24.80	3.10	2.79	0.54	56.91	88.14
57	SX-64	Salix	21.99	3.56	2.34	0.33	60.32	88.53

Table A32. Summary of knot wood carbohydrate composition (all values are a percentage of the oven-dried extractive-free knot wood mass) evaluated in 2007–08 at Ellerslie Short-Rotation Woody Crops Technical Development Site.

Map Legend Number	Clone	Species	Arabinan	Rhamnan	Galactan	Total Glucan	Xylan	Mannan	Hemicellulose Glucan*
N/A	2293-19	Hybrid Poplar	0.51	0.71	0.71	41.11	15.08	2.32	2.70
55	Charlie	Salix	0.28	0.87	0.87	40.07	15.77	1.18	2.20
49	India	Salix	0.43	0.73	0.73	42.78	15.42	1.91	2.50
N/A	DN-136	Hybrid Poplar	0.57	0.68	0.68	38.85	15.74	2.30	2.70
2	DN-34	Hybrid Poplar	0.50	0.63	0.63	37.29	16.03	2.87	3.00
50	Pseudo	Salix	0.23	0.72	0.72	40.60	14.20	1.10	2.00
54	NM-6	Hybrid Poplar	0.45	0.61	0.61	40.84	14.45	2.68	2.80
48	Viminalis	Salix	0.33	0.73	0.73	41.21	15.78	2.06	2.60
5	Tristis	Hybrid Poplar	0.63	0.63	0.63	40.38	14.24	2.73	2.80
45	Brooks 1	Hybrid Poplar	0.51	0.56	0.56	41.13	14.39	2.68	2.80
24	Hill	Hybrid Poplar	0.48	0.57	0.58	38.57	14.65	2.54	2.70
52	Alpha	Salix	0.55	0.78	0.78	38.48	15.22	1.67	2.40
5	SV-1	Salix	0.14	0.62	0.62	47.78	15.58	1.65	2.40
N/A	HA (CFS)	Hybrid Aspen	0.21	0.38	0.38	45.55	15.60	2.37	2.70
16	HA (ELL)	Hybrid Aspen	0.22	0.41	0.41	44.53	17.38	2.05	2.80
5	Q-1150	Hybrid Poplar	0.34	0.44	0.44	40.04	15.59	2.72	2.90
51	Hotel	Salix	0.27	0.64	0.64	39.99	14.66	0.72	1.80
57	SX-64	Salix	0.11	0.57	0.57	40.96	17.04	1.07	2.20

* Hemicellulose glucan content is the estimated portion of the total glucan content that originates from methylglucuronoxylan (Me-GluU) and glucomannan.

Table A33. Summary of clear wood chemical composition (all values are a percentage of the oven-dried wood mass) evaluated in 2007–08 at Ellerslie Short-Rotation Woody Crops Technical Development Site.

Map Legend Number	Clone	Species	Acid Insoluble Lignin	Acid Soluable Lignin	Extractives	Ash	Carbohydrates	Total
N/A	2293-19	Hybrid Poplar	22.70	2.95	1.62	0.56	56.38	84.21
55	Charlie	Salix	20.76	3.60	1.24	0.57	55.49	81.67
49	India	Salix	19.69	3.04	1.75	0.54	58.02	83.04
N/A	DN-136	Hybrid Poplar	22.90	3.10	2.51	0.66	54.68	83.85
2	DN-34	Hybrid Poplar	23.11	2.93	3.40	0.58	56.08	86.10
50	Pseudo	Salix	20.91	4.14	1.51	0.54	55.01	82.09
54	NM-6	Hybrid Poplar	20.27	3.44	1.84	0.60	58.71	84.86
48	Viminalis	Salix	19.57	3.61	1.93	0.68	58.20	83.99
5	Tristis	Hybrid Poplar	21.84	3.47	2.19	0.73	60.48	88.70
45	Brooks 1	Hybrid Poplar	22.26	3.49	2.07	0.69	60.18	88.69
24	Hill	Hybrid Poplar	23.20	3.19	2.14	0.59	57.59	86.72
52	Alpha	Salix	ND	ND	ND	ND	ND	ND
5	SV-1	Salix	17.60	3.82	1.24	0.49	66.37	89.52
N/A	HA (CFS)	Hybrid Aspen	17.27	4.04	2.91	0.51	60.05	84.78
16	HA (ELL)	Hybrid Aspen	16.60	3.81	2.72	0.47	61.78	85.38
5	Q-1150	Hybrid Poplar	21.88	3.14	2.69	0.66	55.19	83.55
51	Hotel	Salix	ND	ND	ND	ND	ND	ND
57	SX-64	Salix	ND	ND	ND	ND	ND	ND

(ND: No Data)

Table A34. Summary of clear wood carbohydrate composition (all values are a percentage of the oven-dried extractive-free clear wood mass) evaluated in 2007–08 at Ellerslie Short-Rotation Woody Crops Technical Development Site.

Map Legend Number	Clone	Species	Arabinose	Rhamnose	Galactose	Glucose	Xylose	Mannose	Hemicellulose glucan*
N/A	FFC-1	Hybrid Poplar	0.53	0.73	0.73	38.80	13.47	2.13	2.41
55	Charlie	Salix	0.34	0.88	0.88	37.93	14.28	1.18	2.02
49	India	Salix	0.45	0.74	0.74	40.34	13.89	1.85	2.32
N/A	DN-136	Hybrid Poplar	0.58	0.70	0.70	36.45	14.11	2.14	2.48
2	DN-34	Hybrid Poplar	0.56	0.69	0.69	36.26	15.05	2.82	2.92
50	Pseudo	Salix	0.30	0.75	0.75	38.80	13.29	1.13	1.89
54	NM-6	Hybrid Poplar	0.14	0.36	0.36	40.57	14.71	2.57	2.76
48	Viminalis	Salix	0.06	0.46	0.46	39.52	15.95	1.76	2.48
5	Tristis	Hybrid Poplar	0.45	0.41	0.41	40.92	15.49	2.80	2.95
45	Brooks 1	Hybrid Poplar	0.29	0.34	0.34	41.53	15.12	2.56	2.79
24	Hill	Hybrid Poplar	0.23	0.31	0.31	38.52	15.71	2.52	2.83
52	Alpha	Salix	ND	ND	ND	ND	ND	ND	ND
5	SV-1	Salix	0.11	0.54	0.54	47.67	15.88	1.63	2.40
N/A	HA (CFS)	Hybrid Aspen	0.11	0.25	0.25	42.32	14.72	2.40	2.67
16	HA (ELL)	Hybrid Aspen	0.15	0.33	0.33	42.30	16.67	1.99	2.66
5	Q-1150	Hybrid Poplar	0.24	0.34	0.34	37.19	14.54	2.54	2.72
51	Hotel	Salix	ND	ND	ND	ND	ND	ND	ND
57	SX-64	Salix	ND	ND	ND	ND	ND	ND	ND

* Hemicellulose glucan content is the estimated portion of the total glucan content that originates from methylglucuronoxylan (Me-GluU) and glucomannan. (ND: No Data)

2008 destructive sampling physical characterization, chipping analysis, chemical characterization and pulping evaluation work completed in conjunction with FPInnovations. Kraft pulping was completed in bombs (45 g, oven-dried charge) within a B-K micro-digester assembly. All the pulps were washed, screened through a 0.008", oven-dried and weighed to determine pulp yield. The kappa numbers of the pulp were determined using TAPPI standard method T236 om-99. The black liquor residual effective alkali was determined by barium carbonate precipitation and potentiometric titration with hydrochloric acid to pH 8.3.

Table A35. Summary of the physical properties of hybrid poplar and hybrid aspen evaluated in 2008 at Ellerslie Short-Rotation Woody Crops Technical Development Site.

		Density (kg/m³)			MFA (degrees)			MOE (Gpa)		
Clone / Species	Basic Density*	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Hybrid Aspen	345	403.2	402.7	403.6	14.4	15.2	13.5	11.1	10.2	12.0
Green Giant	353.6	414.1	407.0	421.3	30.5	33.5	27.5	6.6	6.2	7.0
Walker 2002	359.7	421.9	419.6	424.2	18.9	20.8	17.1	9.0	8.3	9.6
Northwest	359.7	421.9	411.0	432.9	23.7	22.5	24.9	8.0	7.9	8.0
Assiniboine	388	458.1	440.8	475.5	19.6	18.8	20.3	9.4	9.2	9.6
Walker 2004	353	413.3	402.5	424.1	22.2	20.0	24.4	7.9	8.2	7.6
HA-Pulping	375.6	442.1	420.9	463.4	15.6	16.7	14.5	11.9	9.8	14.0
NW-Pulping	377.7	444.9	424.8	465.0	23.1	28.5	17.6	8.8	7.9	9.7
W-Pulping	386.5	456.2	420.1	492.3	23.2	17.6	28.8	8.6	9.5	7.6

*Basic density was calculated from the average SilviScan value for 8% moisture content.

Table A36. Summary of fibril length (mm) by diameter class of the physical properties of hybrid poplar and hybrid aspen evaluated in 2008 at Ellerslie Short-Rotation Woody Crops Technical Development Site.

Clone		Age (years)	0-3 (mm)	4-6 (mm)	7+ (mm)	Area-weighted Core Mean (mm)
Hybrid Aspen	Min		0.525	0.669		0.560
	Mean	7	0.575	0.744	0.858	0.667
	Max		0.613	0.808		0.728
Green Giant	Min		0.592	0.731		0.689
	Mean	8	0.652	0.845	0.957	0.789
	Max		0.739	0.945		0.839
Walker 2002	Min		0.490	0.612	0.718	0.613
	Mean	7	0.574	0.715	0.726	0.672
	Max		0.620	0.814	0.734	0.760
Northwest	Min		0.490	0.605	0.747	0.596
	Mean	9	0.560	0.685	0.780	0.673
	Max		0.598	0.747	0.813	0.741
Assiniboine	Min		0.482	0.606		0.529
	Mean	6	0.535	0.714		0.605
	Max		0.614	0.841		0.690
Walker 2004	Min		0.521	0.607		0.565
	Mean	6	0.549	0.717		0.609
	Max		0.577	0.825		0.687

Table A37. Summary of the physical chip properties in preparation for pulping of hybrid poplar and hybrid aspen evaluated in 2008 at Ellerslie Short-Rotation Woody Crops Technical Development Site.

	Hybrid Aspen	Northwest HP	Walker HP
Chip Properties			
Moisture % (received)	47.5	49.1	47.4
Accepts Knots %	6.8	4.4	5.6
Bulk Density (kg/m^3)	171.0	189.0	188.0
Basic Density (kg/m^3)	337.0	364.0	370.0
Percentage (rounded to 0.1) of Screened Fractions Determined with a Gradex Chip Classifier			
Fines	1.0	1.0	0.5
3 mm Holes	2.7	1.0	1.2
Accept 7 mm Holes	77.4	66.3	71.6
Over Thick 8 mm-bars	6.1	7.9	4.9
Over Thick 10 mm-bars	10.8	13.8	17.2
Over Long 45 mm	2.1	10.0	4.6

Table A38. Summary of the chemical, extractive and carbohydrate properties of chips in preparation for pulping of hybrid poplar and hybrid aspen evaluated in 2008 at Ellerslie Short-Rotation Woody Crops Technical Development Site.

	Hybrid Aspen	Northwest HP	Walker HP
Chemical Properties (%)			
Ash	0.50	0.62	0.52
Acid Insoluble Lignin	18.78	20.06	20.83
Acid Soluble Lignin	3.04	2.83	2.76
Total Lignin	21.82	22.90	23.59
Total Extractives (Acetone Solvent)	2.50	2.25	2.27
Extractives Group (%)			
Fatty acids	21.82	22.02	21.00
Monoglycerides	1.21	0.76	1.02
Sterols	3.87	4.58	4.29
Wax esters	0.61	0.59	0.65
Diglycerides	5.53	2.67	4.01
Steryl esters	14.88	20.84	16.47
Triglycerides	17.10	9.24	13.49
Identified, total	65.01	60.69	60.92
Unidentified, total	34.99	39.32	39.08
Carbohydrates (%)			
Glucan	47.26	49.60	47.90
Xylan	17.79	17.07	17.36
Rhamnan	0.46	0.51	0.47
Galactan	0.69	0.79	0.69
Arabinan	0.38	0.47	0.42
Mannan	2.43	2.45	2.73
Total recovery	93.84	96.65	95.95

2009–10 University of British Columbia analysis of wood pellets produced from various hybrid poplar and Salix clones from Ellerslie.

Table A39. Physical properties of wood pellets produced from SRWC in 2009-10 at Ellerslie Short-Rotation Woody Crops Technical Development Site.

Map Legend Number	Sample	Heating Value (MJ/kg)	Durability (%)	Moisture Content (%)	Mean Ash Content (%)	Mean Bulk Density (kg/m^3)	Mean Particle Density (kg/m^3)
2	DN-34	18.5	82.4	8.8	2.1	672	1213
10	DN-182	17.8	86.6	10.7	1.8	648	1207
54	NM-6	17.6	72.2	10.6	2.3	587	1164
57	SX-61	18.6	83.7	13.3	2.0	627	1164
57	SX-64	18.0	86.7	13.2	2.1	557	1137
57	SX-67	17.7	86.6	11.1	2.1	595	1128
49	India 3 Yr	17.7	91.1	12.2	1.4	645	1149
49	India 2 Yr	18.2	89.7	10.1	1.4	651	1202
N/A	Salix Mix	18.7	74.9	7.3	2.3	701	1239
N/A	Hybrid Poplar Mix	19.6	89.2	6.7	1.0	637	1206

Table A40. Physical dimensions of wood pellets (n=25) produced from SRWC in 2009-10 at Ellerslie Short-Rotation Woody Crops Technical Development Site.

Map Legend Number	Sample	Average Mass (g)	Average Length (mm)	Average Diamete (mm)	Number of pellets per 100 g	Darkness (grade)
2	DN-34	1.0	21.0	6.4	81	1
10	DN-182	1.0	26.1	6.4	101	1
54	NM-6	1.0	26.3	6.5	100	1
57	SX-61	1.0	26.3	6.4	99	2
57	SX-64	0.9	25.2	6.5	93	2
57	SX-67	1.0	25.9	6.5	96	2
49	India 3 Yr	0.8	20.4	6.4	76	4
49	India 2 Yr	0.9	24.3	6.4	94	4
N/A	Salix Mix	0.9	23.6	6.4	94	4
N/A	Hybrid Poplar Mix	1.0	26.0	6.4	102	3

Appendix XII

Operational information associated with 2019 Woody Biomass Compaction Prototype Trial.

1" Screens

The entire contents of the 21 BioBaler produced bales totalled 6775 kg. The bales were processed by the Haybuster tub grinder, equipped with 1" screens. They were processed through the Biomass Innovations Compaction Unit prototype, which produced 8 bales and averaged 725.8 kg/bale (Table 44). The bulk density of the baled biomass increased from 226.21 kg/m^3 of the original BioBaler bales to 526 kg/m^3 for the compacted bales. The compaction process for the 1" screen material was completed in a gross trial time of 2:14:10 (hh:mm:ss). This included 00:04:24 for repairs, breaks and other non-operational stoppages unrelated to the compacting operations. The gross operating time for this portion of the compacting prototype assessment was 2:09:46, equating to a production rate of 2684 kg per gross operating hour.

Table A41. Biomass Innovations Compaction Unit prototype operational summary at Ellerslie Short-Rotation Woody Crops Technical Development Site.

Processed Size	1" Screens	2" Screens	3" Screens	5" Screens	All
Bales	**8**	**9**	**9**	**11**	**37**
Productive	1:30:57	1:30:43	1:44:22	2:03:10	6:49:12
Productive Idle	0:34:42	0:16:39	0:40:28	0:11:20	1:43:09
Scheduled Machine Hours (SMH)	2:05:39	1:47:22	2:24:50	2:14:30	8:32:21
Non-Productive Idle	0:04:07	0:18:26	0:35:42	0:28:59	1:27:14
Gross Operating	2:09:46	2:05:48	3:00:32	2:43:29	9:59:35
Total Mass (kg)	5806	5265	5012	4447	20530
Gross Productivity (kg/hr)	2684.51	2511.13	1665.73	1631.98	2054.40
Productivity / SMH (kg/hr)	2772.46	2942.25	1924.61	1983.66	2351.78
Net Productivity (kg/hr)	3830.24	3482.27	2881.38	2166.19	3010.22
Total Mass (ODKG)	3405	3209	3055	3292	12961
Productivity / SMH (ODKG/hr)	1626.18	1793.33	1173.06	1468.55	1484.79
Net Productivity (ODKG/hr)	2246.61	2122.47	1756.22	1603.68	1900.50
Productive Per Bale Summary					
Net Operating / Bale	0:15:42	0:11:56	0:16:06	0:12:14	0:13:51
Compacting	0:09:31	0:08:25	0:09:35	0:08:30	0:08:58

(Continued on p. 130)

(Continued from p. 129)

Processed Size	1" Screens	2" Screens	3" Screens	5" Screens	All
Bales	**8**	**9**	**9**	**11**	**37**
Wrapping Bale	0:00:41	0:00:39	0:00:47	0:01:20	0:00:54
Ejecting Bale	0:00:47	0:00:34	0:00:50	0:00:53	0:00:46
Closing Door	0:00:24	0:00:26	0:00:23	0:00:30	0:00:26
Clean/Check	0:04:20	0:01:51	0:04:30	0:01:02	0:02:47
Moisture Content	41.35%	39.05%	39.05%	25.97%	36.35%
Average Mass/Bale (kg)	725.75	585.00	556.89	404.25	554.86
Average Mass/Bale (ODKG)	**425.69**	**356.56**	**339.43**	**299.27**	**353.15**

This included 00:04:07 of non-operating time related to biomass related issues. These issues included the "bridging" of material within the hopper and the "jamming" of biomass entering the baler, resulting in 2:05:39 scheduled machine hours (SMH) or 2772 kg per SMH. Idle time was identified as 27.62% of the SMH operating time, or 0:34:42. The nature of the trial required the testing of a prototype, and therefore more frequent checks of the machine. The trial resulted in a net productive operating time of 1:30:57, equating to a production rate of 3830 kg per productive machine hour (PMH). The productive operating time can be further divided into 83.67% or 1:16:06 attributed to biomass processing, 5.97% or 0:05:26 attributed to bale wrapping, 6.87% or 0:06:15 attributed to ejecting the bale, and 3.48% or 0:03:10 attributed to closing the baler door.

2" Screens

The entire contents of the 21 BioBaler produced bales, totalled 5810 kg. The bales were processed by the Haybuster tub grinder, equipped with 2" screens. They were processed through the Biomass Innovations Compaction Unit prototype, which produced 9 bales and averaged 585 kg/bale. The bulk density of the baled biomass increased from 193.89 kg/m^3 of the original BioBaler bales to 424 kg/m^3 for the compacted bales. The compaction process for the 2" screen material was completed in a gross trial time of 2:20:00. This included 00:14:12 for repairs, breaks and other non-operational stoppages unrelated to the compacting operations. The gross operating time for this portion of the compacting prototype assessment was 2:05:48, equating to a production rate of 2511 kg per gross operating hour. This included 00:18:26 of non-operating time related to biomass related issues. These issues included the "bridging" of material within the hopper and the "jamming" of biomass entering the baler, resulting in 1:47:22 scheduled machine hours (SMH) or 2942 kg per SMH. Idle time was identified as 15.51% of the SMH operating time, or 0:16:39. The nature of the trial required the testing of a prototype, and therefore more frequent checks of the machine. The trial resulted in a net productive operating time of 1:30:43, equating to a production rate of 3482 kg per productive machine hour (PMH). The productive operating time can be further divided into 83.54% or 1:15:47 attributed to biomass processing, 6.50% or 0:05:54 attributed to bale wrapping, 5.59% or 0:05:04 attributed to ejecting the bale, and 4.37% or 0:03:58 attributed to closing the baler door.

3" Screens

The entire contents of the 19 BioBaler produced bales, totalled 6219 kg. The bales were processed by the Haybuster tub grinder, equipped with 3" screens. They were processed through the Biomass Innovations Compaction Unit prototype, which produced 9 bales and averaged g 557 kg/bale. The bulk density of the baled biomass increased from 229.50 kg/m^3 of the original BioBaler bales to 403.7 kg/m^3 for the compacted bales. The compaction process for the 3" screen material was completed in a gross trial time of 3:53:35. This included 00:53:03 for repairs, breaks and other non-operational stoppages unrelated to the compacting operations. The gross operating time for this portion of the compacting prototype assessment was 3:00:32, equating to a production rate of 1666 kg per gross operating hour. This included 00:35:42 of non-operating time related to biomass related issues. These issues included the "bridging" of material within the hopper and the "jamming" of biomass entering the baler, resulting in 2:24:50 scheduled machine hours (SMH) or 1925 kg per SMH. Idle time was identified as 25.90% of the SMH operating time, or 0:40:28. The nature of the trial required the testing of a prototype, and therefore more frequent checks of the machine. The trial resulted in a net productive operating time of 1:44:22, equating to a production rate of 2881 kg per productive machine hour (PMH). The productive operating time can be further divided into 82.69% or 1:26:18 attributed to biomass processing, 6.79% or 0:07:05 attributed to bale wrapping, 7.20% or 0:07:31 attributed to ejecting the bale, and 3.32% or 0:03:28 attributed to closing the baler door.

5" Screens

The entire contents of the 20 BioBaler produced bales, totalled 5533 kg. The bales were processed by the Haybuster tub grinder, equipped with 5" screens. They were processed through the Biomass Innovations Compaction Unit prototype, which produced 11 bales and averaged 404 kg/bale. The bulk density of the baled biomass increased from 194.0 kg/m^3 of the original BioBaler bales to 293.1 kg/m^3 for the compacted bales. The compaction process for the 5" screen material was completed in a gross trial time of 3:02:05. This included 00:18:36 for repairs, breaks and other non-operational stoppages unrelated to the compacting operations. The gross operating time for this portion of the compacting prototype assessment was 2:43:29, equating to a production rate of 1632 kg per gross operating hour. This included 00:28:59 of non-operating time related to biomass related issues. These issues included the "bridging" of material within the hopper and the "jamming" of biomass entering the baler, resulting in 2:14:30 scheduled machine hours (SMH) or 1984 kg per SMH. Idle time was identified as 8.43% of the SMH operating time, or 0:11:20. The nature of the trial required the testing of a prototype, and therefore more frequent checks of the machine. The trial resulted in a net productive operating time of 2:03:10, equating to a production rate of 2166 kg per productive machine hour (PMH). The productive operating time can be further divided into 75.85% or 1:33:25 attributed to biomass processing, 11.85% or 0:14:36 attributed to bale wrapping, 7.85% or 0:09:40 attributed to ejecting the bale, and 4.45% or 0:05:29 attributed to closing the baler door.

Trial Summary

The entire contents of the 81 BioBaler produced bales averaged 300.4 kg/bale or 162.4 ODKG/bale, totalling 24,336 kg. The bales were processed by the Haybuster tub grinder, equipped with 1", 2", 3" and 5" screens. They were processed through the Biomass Innovations Compaction Unit prototype, producing 37 bales averaging 555 kg/bale, or 353.1 ODKG/bale, including 584 grams of wrapping. The bulk density of the baled biomass increased from 210.7 kg/m^3 of the original BioBaler bales to 402.2 kg/m^3 for the compacted bales. The compaction process was completed in a gross trial time of 11:29:50, including 01:30:15 for repairs, breaks and other non-operational stoppages unrelated to the compacting operations. The gross operating time for this portion of the compacting prototype assessment was 9:59:35, equating to a production rate of 2054 kg per gross operating hour. This included 01:27:14 of non-operating time related to biomass related issues. These issues included the "bridging" of material within the hopper and the "jamming" of biomass entering the baler, resulting in 8:32:21 scheduled machine hours (SMH) or 2352 kg per SMH. Idle time was identified as 19.69% of the SMH operating time, or 1:43:09. The nature of the trial required the testing of a prototype, and therefore more frequent checks of the machine. The trial resulted in a net productive operating time of 6:49:12, equating to a production rate of 3010 kg per productive machine hour (PMH). The productive operating time can be further divided into 81.04% or 5:31:36 attributed to biomass processing, 8.07% or 0:33:01 attributed to bale wrapping, 6.96% or 0:28:30 attributed to ejecting the bale, and 3.93% or 0:16:05 attributed to closing the baler door.