Studies on establishment costs of fast-growing tree plantations on forest land

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Keywords

Hybrid poplar, plantation, site preparation, mounding, release, productivity, costs

Abstract

As part of its Transformative Technologies Program, FPInnovations is taking part in a research project on alternate sources of forest biomass to supply the emerging bio-industry. A series of studies was conducted on four different sites in Quebec to determine productivity, quality and cost of various treatments required to establish hybrid poplar plantations on forest land. The studies showed that site conditions and work organization had the most impact on the effectiveness and total cost of treatments.

INTRODUCTION

The study objective was to determine the costs of establishing forest plantations with fast-growing species. It addresses the effectiveness of preparing mounds, planting hybrid poplar cuttings on the mounds, and carrying out early stand tending on various site conditions.

Experience in Scandinavia and Quebec with seedlings planted on mounds showed increased survival rate and growth of seedlings, compared with those planted in trenches or depressions (Sutton 1993; Hallsby and Örlander 2004; Bilodeau-Gauthier et al. 2011). The main advantages of mineral soil mounds inverted over a humus layer are better drainage and higher soil temperature around seedlings. These conditions help seedlings take root better and grow faster, enabling them to thrive among competing vegetation.

In Canada, fast-growing tree plantations are normally established in marginal or abandoned farmland conditions (Larocque et al. 2013) and their establishment costs can be high. Currently in Quebec, a few forest companies have hybrid poplar plantation programs.

FPInnovations followed three studies with mounding, planting and early stand tending of hybrid poplar plantations in forest land conditions. The results are presented in this report.

DESCRIPTION OF STUDIES

The three studies to establish hybrid poplar plantations were conducted in Quebec in the Saguenay, Mauricie and Estrie regions. The activities included mounding in 2009, planting of hybrid poplars in 2010 and tending treatments in 2011. Activities were carried out by experienced contractors, operators and silviculture workers.

The studies included the following components: evaluation of site conditions before treatment, productivity studies of the operations and post-treatment surveys. A cost analysis was also performed for each study site.

DESCRIPTION OF STUDY SITES

The study sites in the Saguenay and Mauricie regions were established in a public forest following harvesting with protection of regeneration and soils in mixedwood forests. The Estrie site was established in a private woodlot, after a degraded hardwood forest was clear-cut in 2009 so that hybrid poplar could be planted. Terrain conditions and shrub vegetation characteristics of the study sites before treatment are provided in Tables 1 and 2.

The Saguenay site had dense hardwood vegetation conditions (Figure 1a). The soil was composed of a thin layer of humus on loamy sand with 28% stoniness. It was slightly rough with very few obstacles on the ground and an even slope of 9% with a steeper section of 16 to 22%.Vegetation density in stems/ha was 650 softwoods; 14,000 commercial hardwoods including trembling aspen and white birch; and 30,000 non-commercial hardwoods including pin cherry and willow with an average height of 2.5 m.

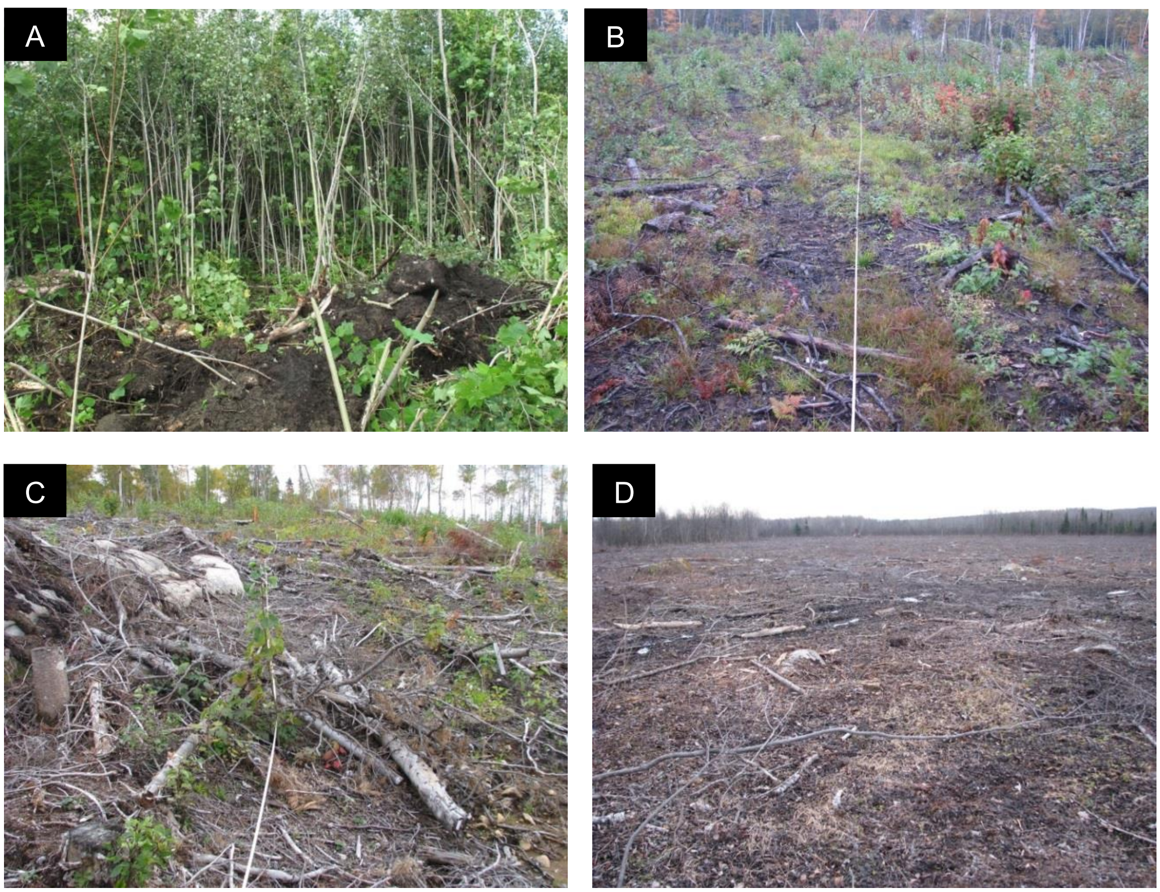

Figure 1. View of terrain conditions of study sites before treatment.

- **A. Dense hardwood vegetation at Saguenay site**
- **B. Relatively easy site conditions at Mauricie Site 1**
- **C. More difficult rough site conditions at Mauricie Site 2**
- **D. Private woodlot study site in Estrie region**

Two sites located west of La Tuque were part of the study in the Mauricie region. Site 1 had easier operational conditions than Site 2 because the terrain was less rough and stony (Figure 1b). Both sites had a similar type of soil and number of obstacles on the ground. Site 2 (Figure 1c) was different from Site 1 primarily because of its many rock outcrops. Both sites also had short hardwood vegetation of roughly 30,000 stems/ha with very little softwood.

The Estrie site, a private woodlot located north of Windsor was flat, moist, with deep sandy clay and few obstacles on the ground (Figure 1d). The natural hardwood regeneration density was under 4,000 stems/ha with an average height of less than 1 m. Bio solids and lime residues from the local paper mill had been spread to fertilize the site before site preparation.

Table 1. Terrain conditions of study sites before treatment

Study sites	**Saguenay**	**Mauricie 1**	**Mauricie 2**	**Estrie**
Terrain				
Humus thickness (cm)	6	5	4	5
Stoniness (%)	28	27	64	28
Average slope (%)	9	6	10	0
Drainage	Fresh	Fresh	Fresh	Moist
Soil	Loamy sand	Loamy sand	Loamy sand	Sandy clay
Debris on ground				
<5 cm*	12	49	47	27
>5 cm*	1	7	8	3
Volume (m^3/ha)	19	48	56	23
Stumps				
Number/ha	253	525	1,020	791
Average diameter (cm)	28	25	21	25
Average height (cm)	21	24	26	22

*Average of number of pieces over a 20-m line

Table 2. Characteristics of shrub vegetation at study sites before treatment

Study sites	Saguenay	Mauricie 1	Mauricie 2	Estrie
Density (stems/ha)				
Softwoods				
15 – 150 cm	265	1 623	577	0
150 – 400 cm	382	438	0	0
>400 cm	0	0	0	0
Total	647	2,061	577	0
Commercial hardwoods				
15 – 150 cm	3,794	27,975	28,987	341
150 – 400 cm	10,353	3,464	0	68
>400 cm	0	21	0	0
Total	14,147	31,460	28,987	409
Non-commercial hardwoods				
15 – 150 cm	15,559	980	838	2,386
150 – 400 cm	14,794	576	0	614
>400 cm	147	0	0	0
Total	30,500	1,556	838	3,000
Grand total	45,294	35,077	30,402	3,409

SITE PREPARATION

Description of machines

The site preparation was done by excavators equipped with a conventional bucket. The use of excavators for this one-time treatment allows considerable flexibility, particularly under difficult terrain conditions, such as poor drainage, heavy debris and stoniness with boulders. In the Saguenay and Estrie regions, 20-t excavators equipped with 1-m^3 buckets were used, whereas in the Mauricie region, an 11-t excavator equipped with a 0.5-m^3 bucket was used.

Method

The three sites were prepared by successive passes perpendicular to the road. Microsites were produced by digging into the soil with the bucket and turning over the mineral soil onto the humus to form a mound (Figure 2). If necessary, any slash, rocks or stumps were moved or removed before mounding. At the Saguenay site, operators had to flatten the high regeneration with the bucket to improve visibility and facilitate mounding.

Figure 2. View of mounding sequence with excavator.

At the Saguenay and Mauricie sites, the operator created mounds on each side of the excavator and behind it, in a semi-circle pattern. At the Estrie site, the treatment pattern was different in order to preserve access trails to the site for distributing the planting stock and performing future stand tending or spreading bio solids to fertilize the site. The operator only made mounds on each side of the machine, and none behind the excavator as it advanced. To leave trails relatively free of obstacles, the operator removed stumps and boulders in front of the machine and buried them in the holes where the soil had been removed to make the mounds. The operator manoeuvered the machine very efficiently minimizing excavator arm movements, cab rotations and machine travel.

Results

Productivity

Productivity results for mounding are given in Table 3. For all studies, productivity ranged from 142 to 276 mounds/productive machine hour (PMH) and the treatment intensity ranged from 900 to 1,200 mounds/ha. Productivity was lower at the Saguenay site and at Site 2 in the Mauricie region (142 mounds/PMH).

At the Saguenay site, the time spent clearing the dense vegetation accounted for 30% of total productive time whereas for the other study sites, it ranged from 8 to 15% and, consequently, more time was spent making mounds.

At Site 2 in the Mauricie region, the low productivity can be explained by more rough and stonier terrain, and thin soils. It took longer to produce each mound since the operator spent more time digging up enough mineral soil to form a good quality mound. The smaller bucket with half the capacity of those used at the Estrie and Saguenay sites, also impacted productivity at Site 1.

At the Estrie site, productivity was the highest (276 mounds/PMH). Two factors can explain the relative efficiency of the machine. Firstly, since the terrain was flat and had few obstacles and shrub vegetation and a deep mineral soil, operating conditions were easier than those of the two other sites. Secondly, the excavator's systematic operation was very efficient and made mounds rapidly.

Table 3. Summary of site preparation activities

Study sites	Saguenay	Mauricie 1	Mauricie 2	Estrie
Productivity				
ha/PMH	0.134	0.145	0.154	0.285
mounds/PMH	142	166	142	276
mounds/ha	1 052	1 148	924	970
Width of passes (m)	16.4	14.5	14.5	17.2
Distribution of time elements (% of productive time)				
Mounding	60	74	65	76
Clearing vegetation	30	8	15	13
Travel	7	15	19	11
Operational delays	3	3	1	0
Total	100	100	100	100

Treatment quality

The quality criteria for mounding are based on the number of mounds per hectare and a minimum thickness of mineral soil in the mound. The mounds must also be relatively stable and free from debris and rocks. Mound quality was ranked from 1 to 6 in decreasing order of quality (Appendix 1). Results for mounding quality for each study site are given in Table 4.

Treatment quality was higher at the Mauricie Site 1 and the Estrie site, mainly because the mineral soil was thick enough for planting the hybrid poplar cuttings. At these sites, over 90% of mounds were ranked from 1 to 3, the density of mounds was higher and over 97% were plantable. At the two Mauricie sites, mound size and volume were smaller because a smaller bucket was used. At the Saguenay site, mound volume was higher, but the average thickness of the mineral soil cap was only 25 cm. More difficult terrain conditions because of shrub vegetation in the Saguenay region and rocks at Site 2 in the Mauricie region were the main causes of a smaller number of plantable or good quality mounds.

Table 4. Evaluation of mounding quality

Study sites	Saguenay	Mauricie 1	Mauricie 2	Estrie
Mounds				
Height (cm)	49	49	46	56
Volume (m^3)	0.82	0.33	0.32	0.59
Thickness of mineral soil (cm)	25	44	42	48
Classification (%)				
Class 1	5	-	-	-
Class 2	27	79	47	78
Class 3	29	14	22	16
Class 4	12	6	15	4
Class 5	7	1	5	2
Class 6	20	-	11	-
Stable	92	100	92	96
Plantable	77	98	83	97
Density (mounds/ha)				
Plantable	810	1,125	767	941
Total	1,052	1,148	924	970

PLANTING OPERATION

Description of work

Hybrid poplars were planted at each of the study sites in the spring of 2010, one year after site preparation. The hybrid poplar cuttings were sizeable, over 1 m long and with a bare-root ball measuring between 10 and 15 cm. They were delivered in bundles of 50, with the root ball in a plastic bag containing damp peat moss. A variety of cuttings from different sources were planted at each of the study sites. At the Mauricie and Estrie sites, the bundles were evenly distributed (Figure 3) using a forwarder, whereas at the Saguenay site, the tree planters had to re-supply at roadside.

Most of the tree planters transported the long cuttings at their side, secured with a harness or belt, whereas others transported them by hand, holding the bundle or putting them in modified containers (Figure 4). They all used planting shovels to dig the slit-shaped hole in the mound (Figure 5). The basic quality criteria for planting hybrid poplar cuttings are as follows: the root ball must be buried at a minimum depth of 30 cm in the mineral soil; the soil must be well compacted around the cutting; and the cutting must be vertical.

Figure 3. Hybrid poplar cuttings at planting site.

Figure 4. Various methods used by tree planters to carry planting stock, including a container or harness.

Figure 5. View of slit made in the mound with shovel and planting of cutting.

Results

Productivity

The time study results are shown in Table 5. The productivity of tree planters ranged from 103 to 182 cuttings/productive hour (PH) for an average of 140 cuttings/PH for all sites combined. Tree planters were more productive at the Mauricie sites; they planted an average of 182 and 157 cuttings/PH at Sites 1 and 2 respectively. They were less productive at Site 2 because the terrain was rough, and there were fewer mounds, which were farther apart and of poorer quality than those at Site 1. It should be noted that the Mauricie tree planters spent 80% of the productive time planting hybrid poplar cuttings and only 2% moving around.

Table 5. Summary of planting work

Study sites	Saguenay	Mauricie 1	Mauricie 2	Estrie	Total
Productivity (cuttings/PH)	118	182	157	103	140
Distribution of productive time (%)					
Planting	72	80	81	73	76
Travel	6	2	3	6	4
Re-supply	12	13	9	12	12
Breaks <15 minutes	10	5	7	9	8
Total	100	100	100	100	100

At the Saguenay and Estrie sites, productivity was clearly lower, 118 and 103 cuttings/PH respectively. Despite rougher terrain at the Saguenay site than at the Estrie site and tree planters having to re-supply at roadside, they were more productive than planters at the Estrie site. At this site, however, the clay soil was harder than the loamy sand of the other sites and thus took more time to produce the planting hole. It was also noted that the Estrie tree planters spent as much time moving around to re-supply as planters in the Saguenay region, even if the cuttings were distributed in drop-off points around at the planting site.

Apart from sites in the Mauricie region, it is hard to directly compare the impact of the various site conditions on tree planter productivity since different planters worked in each region. Since sampling was limited and planting is an arduous manual activity, each person’s motivation and physical abilities often have more impact than site conditions on performance.

PLANTATION TENDING

Release cutting, using brush cutters, was done between July and mid-September 2011 in the hybrid poplar plantations in the Saguenay and Mauricie regions to manually release the poplars from the competing vegetation (Figure 6).

Figure 6. View of cleaning activity at Site 1 in the Mauricie region.

No productivity study was conducted during the release cutting, and no follow-up was done after the treatment. Regeneration surveys were carried out before the work to determine the characteristics of the competing vegetation (Table 6) and help estimate the cost of treatment. One year after planting in the Saguenay and Mauricie regions, the average height of the trees including the mound was 202 cm, whereas the height of the competing vegetation was 138 cm. The density of stems >15 cm in height at these sites was over 52,000 stems/ha.

At the Estrie site, the average height of trees was clearly higher at 351 cm, whereas the competing vegetation was only 106-cm tall. The competing vegetation was mainly composed of grasses and the density of stems >15 cm in height was 15,000 stems/ha. The difference in height of close to 2.5 m between the poplar and the competing vegetation was the main reason for not tending the Estrie site. The use and spreading of paper mill bio solids and lime residues on this site surely contributed to the strong growth of cuttings during the first year.


Figure 7. View of hybrid poplars at the Estrie site.

Table 6. Results of regeneration surveys

Study sites	Saguenay	Mauricie 1 and 2	Estrie
Height of poplars (cm)	183	164	313
Height of poplars including mound (cm)	211	192	351
Height of competing vegetation (cm)	146	129	106
Difference between poplars and competing vegetation (m)	65	63	245
Poplars over topped by competing vegetation (%)	10	6	0
Grass coverage (%)	4	2	36
RFF* coverage (%)	34	36	36
Density of stems >15 cm in height (stems/ha)	56,090	52,118	15,052

Includes raspberries, ferns and fireweed.

COST ANALYSIS

The cost analysis includes the costs of site preparation, planting (including the cost for the planting stock based on our studies), and an estimate for the release treatment (Table 7).

Site preparation

The cost for mounding was calculated according to the machine's productivity and hourly rate. This hourly rate, according to FPInnovations' standard formula for establishing cost was estimated at $162.20/PMH for the 20-t excavators and at $134.26/PMH for the 12-t excavator. The production cost for a mound made by an excavator ranged from $0.59 to $1.15 per mound. Since the treatment cost was based on the productivity achieved at the various sites, it was higher for sites where conditions were more difficult such as those in the Saguenay and Site 2 in the Mauricie region and lower in the Estrie region and Site 1 in the Mauricie region, where conditions were easier. The treatment cost ranged from $569 to $1,211/ha and was calculated based on the cost per mound and treatment intensity (mounds/ha). It should be noted that conditions at the Saguenay site were extreme for this type of treatment and the use of a smaller bucket probably contributed to lower productivity rates at the Mauricie sites.

Planting and cuttings

The planting cost was based on the productivity of tree planters and an hourly rate of $61.08/PH for planting. The hourly rate was based on historical data for costs and expenses associated with reforestation operations in Québec (Del Degan 2009).

The cost for planting the cuttings ranged from $0.34 to $0.59/cutting. At the Mauricie sites, the average planting cost was $0.36/cutting, whereas at the Saguenay and Estrie sites, it was $0.56/cutting. The lower planting cost in the Mauricie region was directly related to the higher productivity of the tree planters, compared with that of other sites. The cost for the cuttings, including nursery production and transport to the forest, was $1.17/cutting. The cost for the cuttings also ranged from $1,076 to $1,343/ha and was directly related to planting intensity.

Plantation tending

The treatment cost for the mechanical release of the regeneration was calculated according to a formula used by the Ministère des Ressources naturelles et de la Faune (MRNF) in public forests (MRNF 2011). It is based on the occupancy rate of raspberries, ferns and fireweed and the density of trees and shrubs >15 cm in height. It includes the mechanical treatment by workers equipped with brush cutters, and planning and follow-up costs. The cost of the release cutting at the Saguenay and Mauricie sites ranged from $849 to $857/ha. There was no tending cost for the Estrie site since the plantation could grow freely.

Total cost

The total establishment cost of hybrid poplar plantations for all study sites ranged from $2.35 to $3.65/cutting. Based on an average cost of $3.12/cutting and a density of 1,000 cuttings/ha, the average cost for establishing a plantation of hybrid poplars on forest land would be $3,120/ha. However, our trials have shown that properly choosing and preparing a site could avoid having to perform a release treatment and therefore considerably reduce costs.

Table 7. Cost analysis

Study sites	Saguenay	Mauricie 1	Mauricie 2	Estrie
Site preparation (2009)				
Production (mounds/ha)	1,053	1,148	920	968
Productivity				
ha/PMH	0.134	0.145	0.155	0.29
mounds/PMH	141	166	142	276
Hourly rate of machine ($/PMH)	162.20	134.26	134.26	162.20
Treatment cost				
($/ha)	**1,211**	**928**	**870**	**569**
($/mound)	**1.15**	**0.81**	**0.95**	**0.59**
Plantation (2010)				
Productivity (cuttings/PH)	118	182	157	103
Hourly rate of planting ($/PH)	61.08	61.08	61.08	61.08
Total planting cost				
($/ha)	**545**	**385**	**358**	**574**
($/cutting)	**0.52**	**0.34**	**0.39**	**0.59**
Planting stock (2010)				
Cost of planting stock ($/cutting)	1.17	1.17	1.17	1.17
Total cost of planting stock ($/ha)	**1,232**	**1,343**	**1,076**	**1,133**
Release (2011)				
Treatment cost				
($/ha)	**857**	**849**	**849**	
($/cutting)	**0.81**	**0.74**	**0.92**	
Total establishment cost				
($/ha)	**3,845**	**3,505**	**3,153**	**2,276**
($/cutting)	**3.65**	**3.05**	**3.43**	**2.35**

CONCLUSION

The studies showed that terrain conditions have an impact on the productivity of activities to prepare, plant and maintain the site and consequently on the total cost of establishing hybrid poplar plantations.

Site preparation effectiveness (mounding) was primarily influenced by obstacles on the ground, high-density regeneration and the availability of mineral soil for producing quality mounds. In addition, the work method of excavator operators also had an impact on mounding productivity. Despite the Estrie site being easier to treat than the other sites, the method and work pattern used for this study site were still clearly more effective than for the other sites.

The productivity of tree planters depended on their skills, motivation and physical fitness. A greater number of workers would be needed to draw conclusions on the impact of site conditions. For the same reasons, it is hard to compare the productivity of release treatments with the conditions of the study sites.

Terrain conditions had an indirect impact on the productivity of tree planters and reforestation costs. When the mounds were of lesser quality, tree planters had more difficulty and took more time preparing the planting holes. With more difficult terrain conditions, mounds were generally of lesser quality due to a lack of mineral soil, excess debris in the mounds and soil texture. However, it is difficult to exactly explain the difference in productivity among the tree planters, unless a subjective level of skills is associated to them during analyses.

The distribution of planting stock at the site to supply tree planters is strongly recommended. Hybrid poplar cuttings are big and tree planters cannot carry a large number while they work. In addition, the bundles do not contain that many cuttings and are relatively heavy to carry over long distances. By reducing the supply time by ensuring well-placed drop-off points for cuttings, tree planters have more time and energy to plant the cuttings rather than carry them around.

Release treatments were performed on natural regeneration in the year following the planting at the Saguenay and Mauricie sites, due to the slight difference in height of the planted cuttings and the competing vegetation. At the Estrie site, the cuttings' height was clearly higher so they did not need any treatment. A combination of several factors may have contributed to the fast establishment and growth of planted cuttings during the first year at this site, such as the quality of mounds and planting, the choice of clones, a more fertile soil and the addition of bio solids and lime residues.

The average total establishment cost of hybrid poplar plantations in forests, at a density of 1,000 cuttings/ha, was $3,120/ha. In the best conditions observed, the cost was $2,350/ha. Preliminary results on the follow-up of 10- to 15-year-old hybrid poplar plantations in forests in Quebec suggest a yield of 8 to 12 m3/ha/year or roughly 2.7 to 4.1odt[1] /ha/year[2].

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[1] Oven-dry tonne

[2] *Personal communication with Jean Ménétrier, Forest research branch, Quebec's Ministère des ressources naturelles (MRN).*

In agricultural areas, on marginal or abandoned farmland, the establishment cost of fast-growing plantations is roughly $5,430/ha, with an average yield of 6.3 odt/ha/year (Allen et al. 2013).

To compare the cost of wood at maturity according to two scenarios, the calculation considers the establishment cost of plantations, a discount rate of 2% per year and a harvest age of 20 years. The analysis shows that the cost of the wood at maturity on forest land based on an average yield of 3.4 odt/ha/year and an average cost of $3,120/ha was $66/odt. In better conditions, a yield of 4.1odt/ha/year could be expected for an establishment cost of $2,350/ha and therefore the wood at maturity would cost $42/odt. In agricultural areas, the cost would be $63/odt according to the average yield. Despite a higher cost for establishing fast growing tree plantations in agricultural areas, the cost of wood at maturity is lower than the wood produced with hybrid poplars on forest land when using the expected average yield for both scenarios. A good choice of site and establishment methods would however help achieve a lower production cost on forest land.

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APPENDIX 1: CLASSIFICATION OF MOUND QUALITY

Class 1 – Cap of mineral soil

Class 2 – Cap of mineral soil over humus or litter, with no debris

Class 3 – Cap of mineral soil over humus or litter, with some debris mixed in

Class 4 – Cap of mineral soil over humus or litter, with some debris protruding

Class 5 – Cap of mineral soil significantly distorted by protruding debris

Class 6 – Debris and other organic matter (no exposed mineral soil)

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