CROP DENSITY FOR HYBRID POPLAR IN THE PRAIRIE PROVINCES

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Prepared for:

Saskatchewan Forest Centre
Prince Albert, SK

Prepared by:

Cees ("*Case*") van Oosten, M.Sc.F., R.P.F.
SilviConsult Woody Crops Technology Inc.
2356 York Crescent
Nanaimo, British Columbia
Canada V9T 4N3

Phone: (00)1 250 758 8230
Fax: (00)1 250 758 8251
Email: silviconsult@telus.net

SUMMARY REPORT - CROP DENSITY FOR HYBRID POPLAR IN THE PRAIRIE PROVINCES

There is considerable interest in the Prairie region to plant fast-growing tree species on suitable farmland. As hybrid poplar is the fastest growing tree species in the northern hemisphere, it is a prime candidate to meet this growing interest. To determine potential end uses for the wood, besides fibre for the pulp and paper industry, Forintek Canada Corp. has undertaken several studies, under contract with the Saskatchewan Forest Centre in Prince Albert (SK), to test the suitability of Prairie-grown hybrid poplar for various end uses in solid and composite or engineered wood products. The results have been encouraging and point to a potentially bright future for this wood, provided a sustainable supply of sufficient quantity and quality can be grown.

Private landowners need to realize the maximum net value from their land, whatever the crop. To realize this with an SRIC[I] hybrid poplar crop, the maximum amount of merchantable wood needs to be grown in the shortest possible time to produce the highest net value per hectare. The amount of high value merchantable wood that can be grown depends, among others, on the crop density. The choice of crop density and rotation length (crop cycle) depends on the crop development and rate of growth, and on financial considerations.

❖ Crop development and rate of crop growth

Biomass and pulpwood crops are typically planted in excess of 1000 stems per hectare (spha) at rotation ages varying from four to seven years for biomass crops, and seven to 12 years for pulpwood crops. On the opposite end of the scale are the crops to produce solid wood (saw and veneer logs); these are grown at very low densities of 156-200 spha, mainly in western Europe and South America. Densities between 400 and 1200 spha are still relatively unexplored.

The following conclusions were drawn from a review and analysis of existing short and long term hybrid poplar crop density data from trials in southwestern British Columbia, Oregon, Minnesota and France, where annual measurement data were collected. The long term crop densities cover a range of 202 to 1347 spha, roughly in increments of 100 to 150 spha; the oldest common age is 13 years.

- Differentiation of growth rates between trees in the same crop starts at age two to four years; the more dominant trees continue to grow at a higher rate than the more suppressed trees for the rest of the crop rotation;
- Differentiation of growth rates is independent of the crop density and is likely caused by factors, such as:
  - Slight differences in soil conditions;
  - Differences in stock size (small caliper vs. large caliper stock, etc.);
  - Differences in weed competition;

[I] SRIC stands for short-rotation-intensive-culture.

- Diameter[I] (DBH) growth peaks at age three to four in most trials and this is independent of crop density;
- The rate of DBH growth depends on crop density; trees grown at lower densities have a better and more sustained growth in their DBH and thus volume per tree, than those planted at higher densities;
- Annual DBH growth rapidly declines after peaking, regardless of density.

The main conclusion is that the success of an SRIC hybrid poplar crop is determined by the choice of crop density and by its early establishment success, which is influenced by the intensity of crop management.

❖ Financial considerations

No long term crop density data exist for the Prairie region and the three existing density trials located in Saskatchewan are not old enough yet and lack annual measurement data. Growth for the 13 year old trials from British Columbia and Oregon is assumed possible in the Prairie region in double the time; a 25 year rotation was used. Table 1 lists the crop density scenarios that were used; Table 2 contains the associated mean annual increments[II] (MAI) that were analyzed for a 25 year rotation.

Table 1

Crop Density (metric)	
spha	Spacing
1077	3.05 x 3.05 m
897	3.66 x 3.05 m
770	3.6 x 3.6 m
657	3.9 x 3.9 m
567	4.2 x 4.2 m
494	4.5 x 4.5 m
434	4.8 x 4.8 m

Table 2

Volume information	1077 spha	897 spha	770 spha	657 spha	567 spha	494 spha	434 spha
Volume/ha (m^3)	351	368	381	372	315	286	273
Prairie region – 25 Yrs – MAI m^3/ha/yr	14.0	14.8	15.2	14.9	12.6	11.4	10.9

Forintek Canada Corp. conducted simulations to provide potential lumber and veneer recoveries from a range of tree sizes; however, only the lumber recovery simulations were used in further analysis. Although more scenarios were simulated by Forintek, the number used for analysis was restricted to reflect a more conservative lumber recovery. Trees were 'pruned' to a height of 6.7 m (22 ft.) and 'cut' into saw log lengths of 2.44 m (8 ft.) and/or 3.05 m (10 ft.); this allowed for two logs with clear wood of 3.05 m in length, including trim, with knotty cores of 10 and 14 cm respectively. Each log was assumed to have a taper of 1.0 cm per meter of length. The lumber prices (Table 3) that were used were based on estimated prices from an

Table 3

Grade	Lumber prices for 4/4 lumber per '000' fbm
Select & Better	US$980
#1 Shop	US$610
#2 Shop	US$455

[I] The diameter of a tree is measured at 1.30 m (4.3 ft.) height, which is a convenient height for most people. It is about at breast height, hence it is called 'diameter at breast height' or simply DBH. The measurement of the DBH always includes the bark.
[II] MAI is mean annual increment. This is the total volume divided by the age; it is expressed as m^3 per ha per year (m^3/ha/yr).

emerging US hybrid poplar lumber market; an exchange rate of 85¢ US per CAD was used. Discount rates[I] of 2, 4, 6, 8 and 10% were used for the analysis.

In the future, log prices should be based on the true quality of the wood, supported by well documented pruning records. It is assumed that a sliding scale for log prices for pruned hybrid poplar can be based on the lumber value that can be generated from each saw log. The saw log price (delivered to the mill) per m^3 is assumed to be equal to 50% of the lumber value per m^3 of saw log for each crop density. Lumber values for unpruned trees (i.e. 100% knotty core) are assumed to be at the #2 Shop level of US$455 per thousand fbm[II], regardless of density. The pulpwood portion for each tree was valued at $30 per m^3. Table 4 shows the weighted average log prices per m^3 for each density.

Table 4

Weighted average log price/m^3	1077 spha	897 spha	770 spha	657 spha	567 spha	494 spha	434 spha
No pruning – 100% knotty core	$50	$54	$57	$59	$58	$60	$61
Pruning to a 14 cm knotty core	$63	$71	$78	$84	$82	$87	$91
Pruning to a 10 cm knotty core	$72	$82	$90	$95	$94	$98	$101

The discounted cash flow method calculates the present values of costs and revenues realized at some point in the future; e.g. one dollar at age 10 is worth 82¢ today when discounted at a 2% discount rate (68¢ at 4%, 56¢ at 6% etc.). When the present value of the costs is subtracted from the present value of the revenues, the result is called net present value or NPV. The best net return comes from the scenario(s) with the most positive NPV.

All scenarios are evaluated against an unpruned crop at the 1077 spha density, called the 'Base Case'; it is the crop valued at $50/$m^3$ in Table 4. For each of the discount rates, the NPV is calculated for each 'Base Case' and is subtracted from the each of corresponding NPVs for all other scenarios. This difference is called the incremental NPV; a positive incremental NPV indicates that the scenario is superior to the 'Base Case'.

Table 5

Comparison to 'Base Case' – Incremental NPV	1077 spha	897 spha	770 spha	657 spha	567 spha	494 spha	434 spha
No pruning – 100% knotty core	'Base Case'	+	+	+	+	+	+
Pruning to a 14 cm knotty core	+ (@2-4%)	+	+	+	+	+	+
Pruning to a 10 cm knotty core	+ (@2-6%)	+	+	+	+	+	+

Table 5 shows that all densities of 897 spha and lower have a positive incremental NPV cf. the 'Base Case'; they are superior to the 'Base Case' at any of the five discount rates, regardless of pruning. Pruning of 1077 spha is a marginal investment.

[I] These are real discount rates, which are interest rates, net of inflation, at which costs and revenues are discounted to the present.
[II] Foot board measure (fbm) is a unit of cubic measure for lumber, equal to one foot square by one inch thick. Lumber mills still sell lumber in imperial units.

– Sensitivity analysis

A sensitivity analysis was carried out to determine the impact of a reduction in saw log price to 50% of the original for all pruned scenarios. For the unpruned scenarios, the log value was based on a uniform price of US$455 per '000' fbm for lumber, which resulted in a price level barely above that for pulpwood ($30-33/m^3) for all densities. Pruning to a 10 cm knotty core only makes sense for densities of 770 spha and lower, at the 2-6% discount rates.

A second sensitivity analysis reduced pruning productivity to 54% of original (150 cf. 275 trees per manday), but used full saw log prices. The resulting increase in pruning costs of almost 85% did not have as significant an impact as a 50% reduction in log prices. Pruning makes sense for densities of 770 spha and lower at the 2-8% discount rates for both 10 and 14 cm knotty cores.

❖ Conclusions

- Pruning appears to be a good investment at any of the discount rates for crop densities of 897 spha and lower;
- In order for the land owner or farmer to realize a sufficient return on a pruning investment, the market price for a saw log needs to be tied to its lumber value recovery. This in turn needs to be supported by well documented pruning records;
- For unpruned crops, there is still potential to capture lumber value, but at a greatly reduced rate per m^3. The best returns for unpruned crops are in the 657-897 spha crop density range;
- For pruned crops with either 10 cm or 14 cm knotty cores, the best returns are in the 434-770 spha crop density range;
- If a land owner or farmer does not want to commit to pruning, the optimum crop densities will be 657-770 spha.
- All scenarios are based on the premise that a land owner needs to maximize his net return per hectare. Therefore the production of a 100% pulpwood crop has not been considered.
- The sensitivity analysis for the price reduction to 50% of saw log value for the unpruned scenarios indicates that 1077 spha may be too dense, even for a pulp wood crop.

❖ Recommendations

In light of the absence of specific long term density data for the Prairie region, the following recommendations are made for high value saw log and veneer log crops:

1. Consider planting at approximately 816 spha or a 3.5 x 3.5 m spacing;
2. Consider planting a portion at densities down to 625 spha or a 4 x 4 m spacing;
3. Create incentives for land owners to own (a portion of) the sawmill in order to capture more of the incremental value of clear lumber recovery.

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Organization	Contacts
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REPORT - PART I

1 Introduction

The most cost-effective means to increase the value of short-rotation-intensive-culture hybrid poplar crops ('SRIC hybrid poplar', or simply 'SRIC crop') is by choosing an optimal crop density at time of planting. Too often density is determined by operational factors, such as allowing for enough room for a tractor and implement to carry out crop maintenance. There is little information on which to base a decision on crop density.

2 Objectives

a) To determine the range of crop densities that yield the best opportunity for good net returns to the private owner.
b) To provide crop density guidelines for short-rotation-intensive-culture (SRIC) hybrid poplar crops for the Prairie Provinces.

It is important for independent land owners and farmers to maximize the net value of their crop. Most non-industrial SRIC poplar crops in the world are in private ownership, with sizes varying from as less than one hectare to many hundreds of hectares. Most private owners have one purpose in common and that is to derive maximum value from their land. This can be generated from a high volume at a relatively low unit price in a short time frame (rotation), or a lower volume at a relatively high unit price in a longer time frame. To help the landowner make a decision what density to plant, it is necessary to link crop density to end use to ensure the owner derives the best net value from his land.

To ensure some income is derived early in the rotation from poplar crops, farmers have been using intercropping in countries such as France, northern Italy, Chili, Argentina and India, followed sometimes by cattle grazing when the trees are older (Chili and Argentina). The recommendations in this report do not consider the benefits from intercropping.

3 Approach used

❖ Report - Part II

- Literature review to determine what relevant information exists in support of the objectives;
- Field visits to various companies and organizations;
- Various companies and organizations (see Appendix A) made their data or information available for analysis;
- Data and information analysis;
- Reviews with an expert review group (see Appendix B).

- Report - Part III

– A joint project with Forintek Canada Corp. in Vancouver, B.C. to simulate lumber and veneer recovery to enable valuation of various options.

4 Background

Biomass and pulpwood crops are typically planted in excess of 1000 stems per hectare (spha)[I] at rotation ages varying from four to seven years for biomass crops, and seven to 12 years for pulpwood crops in areas where these crops have been grown for some time. Biomass crops are harvested periodically with new crops coppicing from cut stumps; pulpwood crops are replanted with new stock. On the opposite end of the scale are the crops to produce solid wood (saw and veneer logs) and these have traditionally been grown at very low densities of 156-200 spha, mainly in western Europe and South America; in Northern Italy crop densities are as high as 400 spha on the best soils. These crops are replanted with new stock.

Densities between 400 and 1200 spha are still relatively unexplored. In fairly recent developments in Washington and Oregon States, several companies have been changing crop densities from pulpwood to solid wood production. The need to change was driven by the need to increase net returns per hectare. This is a general trend in private forestland ownership in North America and has started to affect established SRIC poplar farms. The continuation and success of these farms depend on being able to generate a better net return per hectare, and this is driving the conversion to lower crop densities. In the province of British Columbia (BC), and Oregon (OR) and Washington (WA) States there is a limit on the rotation length when SRIC poplar is grown as a farm crop. These shorter rotations are not conducive to the very low crop densities used in Europe and an intermediate range of crop densities is needed. The Prairie Provinces do not have such restrictions.

AFOCEL[II] in France is investigating yield potential of poplar planted at higher densities than the traditionally used 156-200 spha. This organization has established a network of trials to test crop densities ranging from 200 to 400 spha (some at 500 spha) to determine the optimum density for the production of trees that meet the standards for the veneer industry. Although this organization mostly serves the pulp and paper industry in France, the vast majority of hybrid poplar crops are in small private ownership and the owners have traditionally produced wood for the veneer industry, from crops planted at low densities. There appears to be little incentive to switch to pulpwood production, but there is interest in generating more income and fibre from these crops. The density trials were established to determine at which density it is still possible to produce veneer logs, while at the same time producing a better volume per hectare.

[I] Most information in this report is in metric units.
[II] AFOCEL – Association Forêt-Cellulose, a research and development organization of the forest industry (primarily pulp and paper, but also solid wood and veneer products) in France, in partnership with several government departments and other research organizations.

REPORT - PART II

1 Literature review

There are a number of research reports available on high crop densities for biomass crops, but fewer for pulpwood production and even less for solid wood production for lumber and veneer. Information on biomass and high density short rotation woody crop production covers various species (including *Populus* - poplar). Collection of annual or even periodic growth data in long term poplar trials is often irregular and uncertain.

There are several key publications[I] that shed light on long term stand development and these, together with short and long term measurement data, form the basis of the findings, conclusions and recommendations in this report.

2 Data and information sources

Most of the data of the density trials that were used for this project consists of measurements for the first three to five years only; most are continuous. A few trials contain annual DBH[II] data for up to 17 years. Measurement data collected on an irregular basis help determine the potential yield, but do not allow a good understanding of crop development.

3 Field visits and cooperating companies and organizations

Field visits were made to various companies and organizations in Canada, the US-PNW and one visit to AFOCEL[III] in France to review various density trials. Several organizations were able to make information or data available; others provided financial support.

Access to data was granted on the condition that the data remain proprietary and confidential. The resulting analysis and conclusions are reported in this report.

4 Data analysis

This section summarizes the approach of the data analysis. Some of the long term trials (up to 13 years) in Oregon for the higher crop densities are replicated; the long term trials (up to 17 years) from BC are not. The only data were for DBH; height data were not complete, with the exception of several trails from BC. For these reasons the analysis is not based on the rigorous standards of a statistical analysis, but rather on a descriptive analysis.

[I] See the literature list at the end of the Appendices (pages 51-54) – critical reports are highlighted in grey.
[II] DBH is the diameter at breast height, measured including the bark (diameter outside bark, or dob). Breast height is at 1.3 m.
[III] The visit was made in April 2005 to AFOCEL - North East Division near Dijon, France. This visit was in combination with a private visit to Europe.

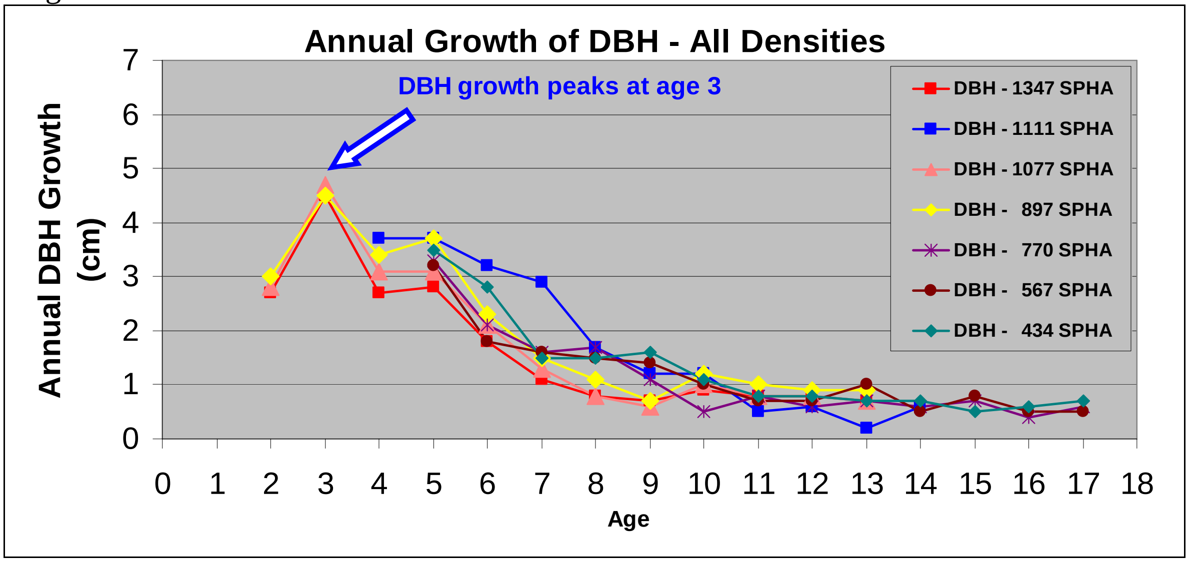
4.1 Diameter at breast height - DBH

4.1.1 Peak of annual DBH growth

Krinard and Johnson (1984)[I] reported that the peak of DBH growth is independent of crop density in long term density trials of eastern cottonwood established in the southeast US and occurs in the third or fourth growing season.

In long term trials in Oregon in crop densities from 897, 1077 and 1347 spha, DBH [II] growth peaks in the third growing season (Figure 1). A yield plot at 1111 spha on Vancouver Island (BC) lacks growth data for the third growing season, but DBH growth peaks no later than age four. Data measurements for three trials in BC at 434, 567 and 770 spha did not start till the end of the fifth growing season. For these BC trials DBH growth decreases after age five.

Figure 1



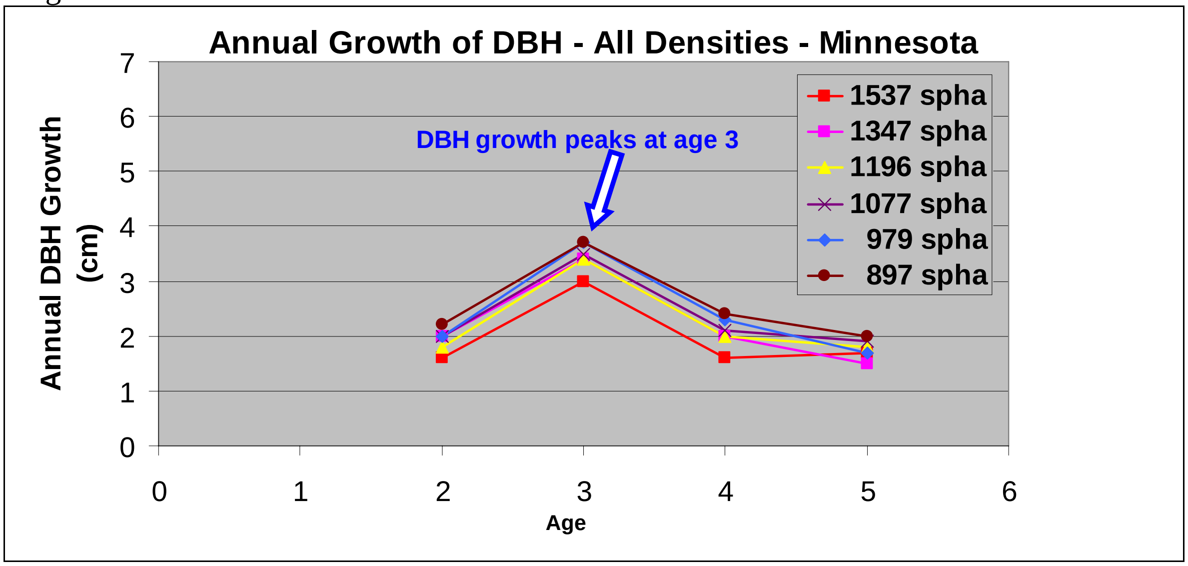
Five year growth data for a non-irrigated Minnesota density trial with a different hybrid type[III] in a continental climate also shows that DBH growth peaks in the third growing season and is independent of crop density (Figure 2).

[I] For literature citations such as Krinard and Johnson (1984), please refer to the literature list at the end of the Appendices (pages 51-54).

[II] In the remainder of this section DBH is the quadratic mean diameter (QMD) at breast height. It is the diameter at breast height of a tree with the average basal area (see also http://sres.anu.edu.au/associated/mensuration/s_diam.htm).

[III] The clone used for this trial is DN34, with a small amount of DN5.

Figure 2



Plot data from another density trial on Vancouver Island for 1111, 816 and 625 spha also show this peak in the third growing season. Growth rates of irrigated poplar in the Columbia basin in northeast Oregon are among the fastest in the world due to a favourable growing climate and the irrigation and fertilization regimes. Data for density trials in this region show that peak DBH growth is independent of crop density; it occurs in the third and fourth growing seasons.

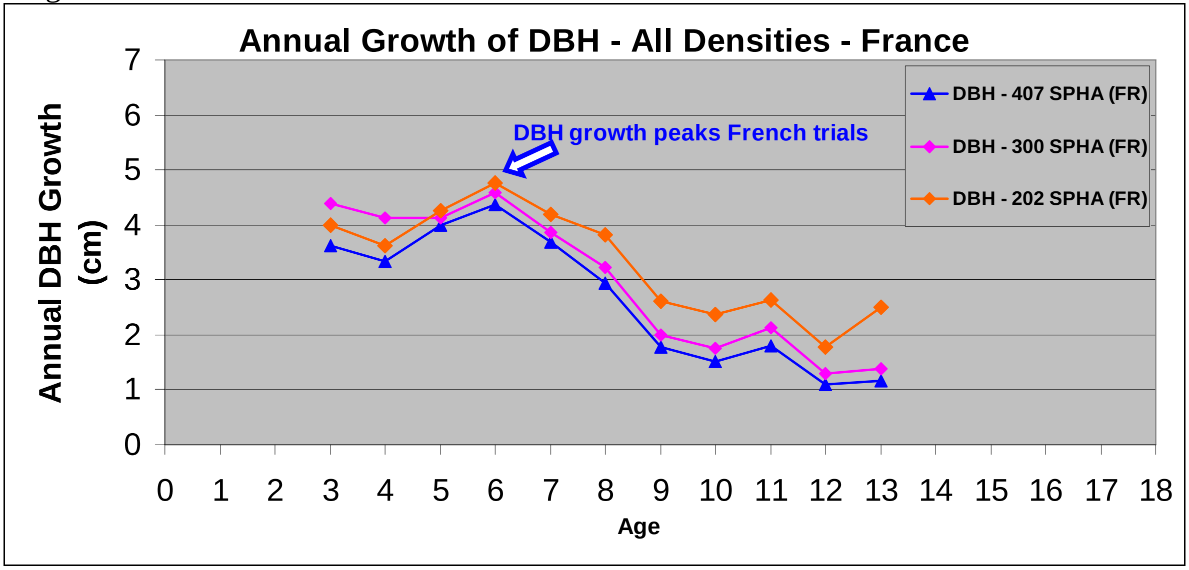
The long term (16 years) trials in Ontario were not measured every year, making data analysis less meaningful. The data in years one through three for one dataset and one through four for the second dataset also indicated peak DBH growth in the third to fourth (maybe fifth) growing seasons. These trials were planted at 420 and 332 spha.

Three AFOCEL trials[I], which are planted at densities of 200, 300 and 400 spha, peak DBH growth in the sixth growing season. It is of interest that they also show coming off a peak in the third growing season, followed by a decline ('valley') in the fourth growing season and the subsequent increase to the peak in the sixth growing season (Figure 3).

A similar secondary peak has also occurred for the three Oregon trials in the 5th year and again in the 10th year (Figure 1). Other trials in BC show a similar phenomenon. For several yield trials of different ages located in the same geographical area on North Vancouver Island these valleys, followed by peaks in the DBH growth rate, occurred in the same calendar years. The conclusion was that they probably resulted from unfavourable weather events, such as a severe drought or a very cool and wet summer.

[I] No data were provided for these trials, but AFOCEL was kind enough to provide compilations of the data in a format that was used for this report.

Figure 3



Leaf diseases or insect problems could also result in periodic growth losses; however, these were absent in this area and could not have been the cause.

- **Conclusions**

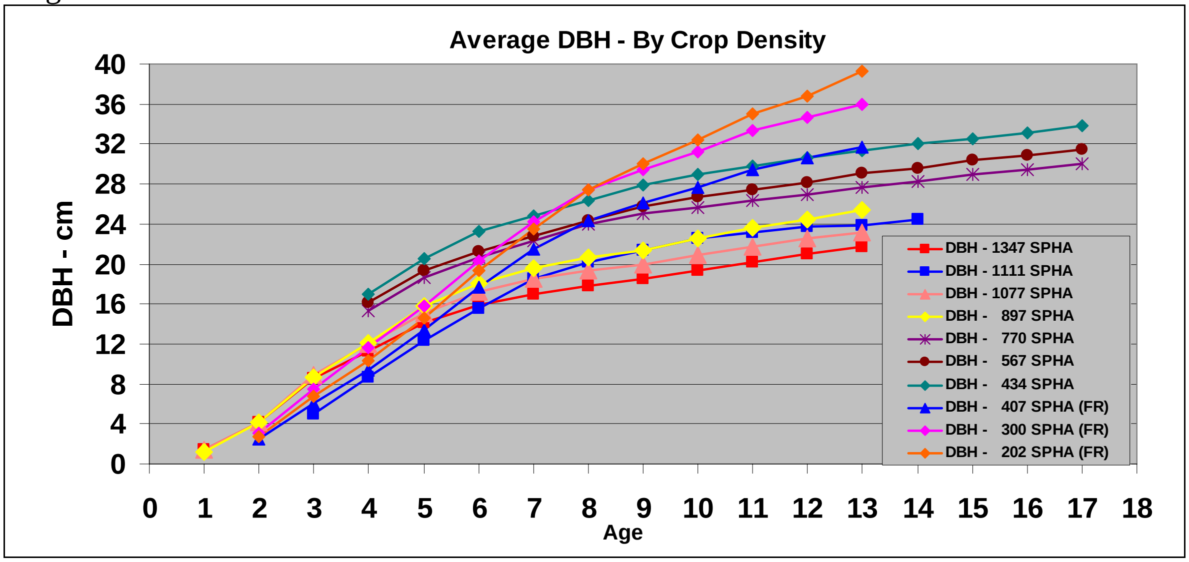
- Peak of DBH growth is independent of crop density;
- Annual DBH growth rapidly declines after peaking;
- Although the decline is gradual, intermittent peaking or plateau-ing does occur;
- Annual DBH growth appears to stabilize after 10 to 12 years to a growth rate of less than 1.0 cm per year for all (Figure 1) but the lowest three densities in the AFOCEL plots (Figure 3).

4.1.2 DBH & density

Although peaking of DBH growth is independent of crop density, the rate of DBH growth is not. Figure 4 shows this relationship with different clones in different geographical areas.

This relationship between a lower crop density and an increased DBH is as expected.

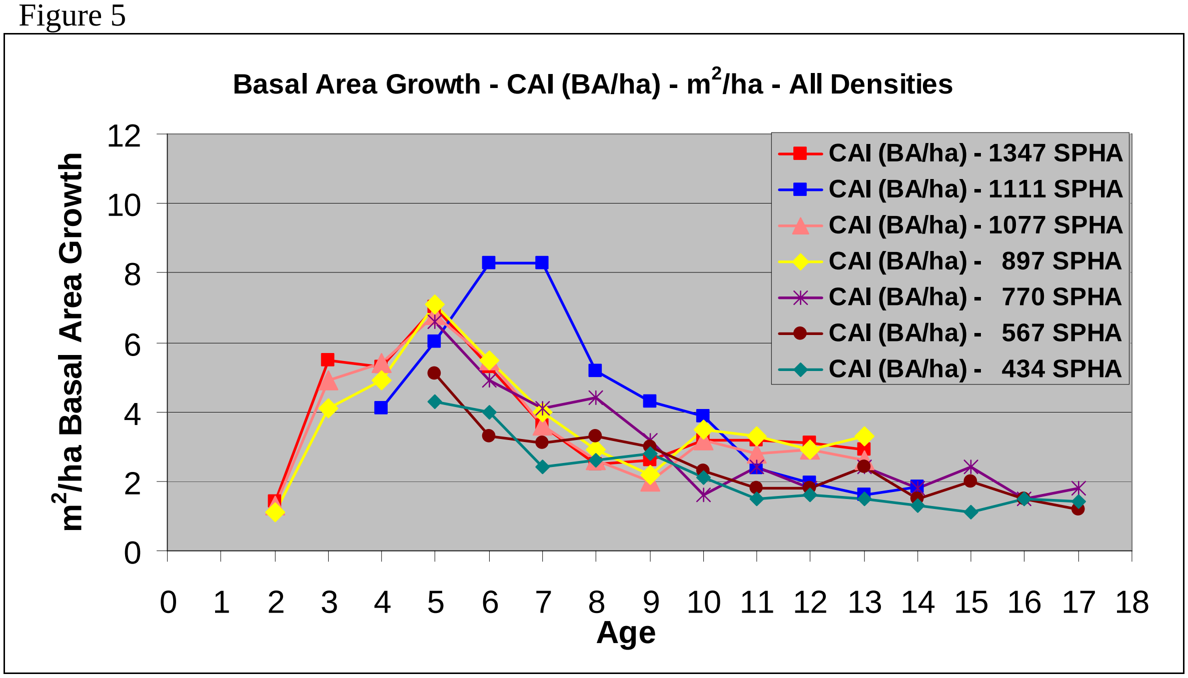
Figure 4



4.1.3 Basal area growth

The basal area (BA) is the surface area of the cross section of a tree at breast height (1.3 m above ground level). The total BA per hectare is the sum of the basal areas for all trees on one hectare; it is expressed as m^2/ha. Basal area per tree is calculated as the surface of a circle (πr^2, where r is the radius of the circle, which is equal to half the DBH). Any variations in the DBH growth rate are expressed exponentially in the growth of the basal area.

Figure 5



Year-over-year BA growth is referred to as the current annual increment of the basal area per hectare, or CAI (BA/ha). It also peaks early in the crop's life (Figure 5), in general two (to three) years following the peaking of the DBH growth. From field observations, this peak of basal area growth per hectare occurs when the crop closes its canopy. This is the start of a period of accelerated crop growth when it develops its maximum leaf area per hectare and shades out competing vegetation.

The rate of basal area growth per hectare depends on the previous year's DBH and on the crop density. It is negatively correlated with density.

- **Conclusions**

- Peak of CAI (BA/ha) appears independent of crop density;
- It follows the peak DBH growth by two (to three) years;
- CAI (BA/ha) rapidly declines after peaking;
- Although the decline is gradual, intermittent peaking or plateau-ing occurs;
- As with DBH growth, CAI (BA/ha) appears to stabilize after 10 to 12 years.

4.1.4 Basal area growth – source of variability

In order to make recommendations on crop density, it was important to understand the dynamics of crop development over time. When does crop differentiation occur that leads to a wide range of tree sizes? What are the likely causes of crop differentiation? Can the onset of intertree competition in a crop be identified and how is it linked to crop density?

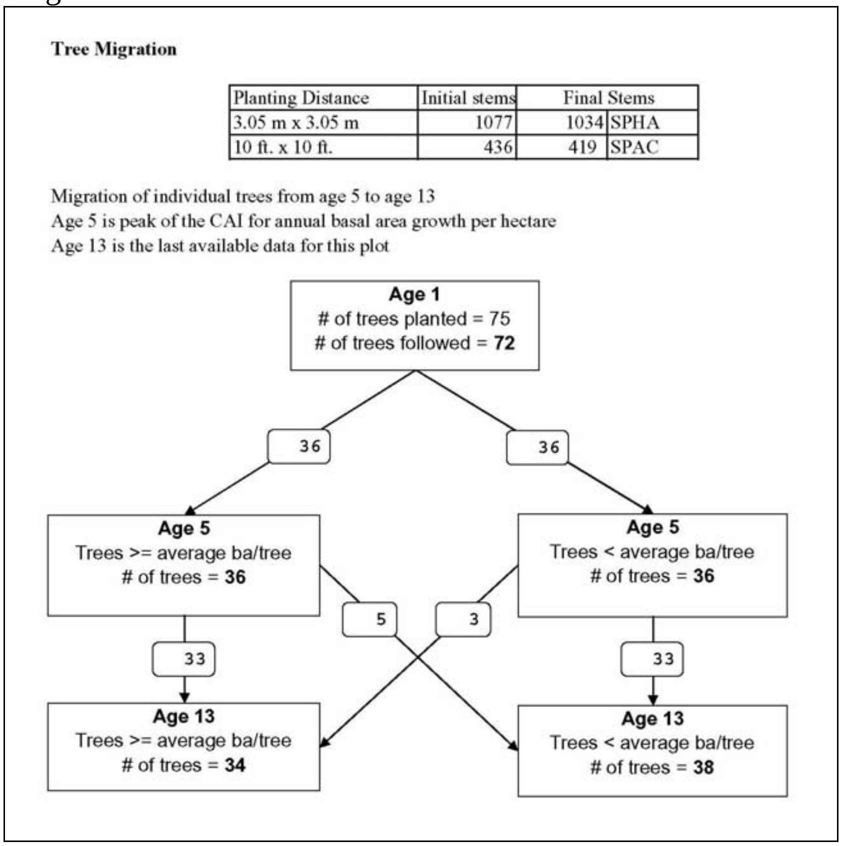
The intermittent peaks and valleys in basal area growth over time (Figure 5) were thought to be linked to the process of differentiation, i.e. some trees would start to gain on others and exert dominance. This led to the decision to look at variability of basal area growth over time for the dominant/co-dominant and the more suppressed trees.

Where sufficient plot data existed, data were split into:

- Trees with a basal area greater than or equal (>=) to the average basal area per tree at the time of the peak of CAI (BA/ha). These trees are called 'TOP'; and
- Trees with basal area smaller than (<) the average basal area per tree at the time of the peak of CAI (BA/ha). These trees are called 'BOTTOM'.

The 36 TOP and 36 BOTTOM trees were tracked from the year of peak CAI (BA/ha) to the last recorded age, which in this case was from age five to age 13. As Figure 6 shows, the vast majority of the TOP and BOTTOM trees remained in the TOP and BOTTOM categories when they reached age 13. Five trees 'migrated' from 'TOP' to 'BOTTOM' and three from 'BOTTOM' to 'TOP' and most of these cross-over trees were at or near the average basal area per tree at age five. At age 13 the 'TOP' had 34 trees and the 'BOTTOM' 38 trees.

Figure 6[I]



This example for a crop planted at 1077 spha (3.05 x 3.05 m or 10 x 10 ft.) shows there is little migration of trees from a dominant/co-dominant position at age five to a suppressed position ate age 13, and vice versa. The same was found for all other densities.

Figure 7

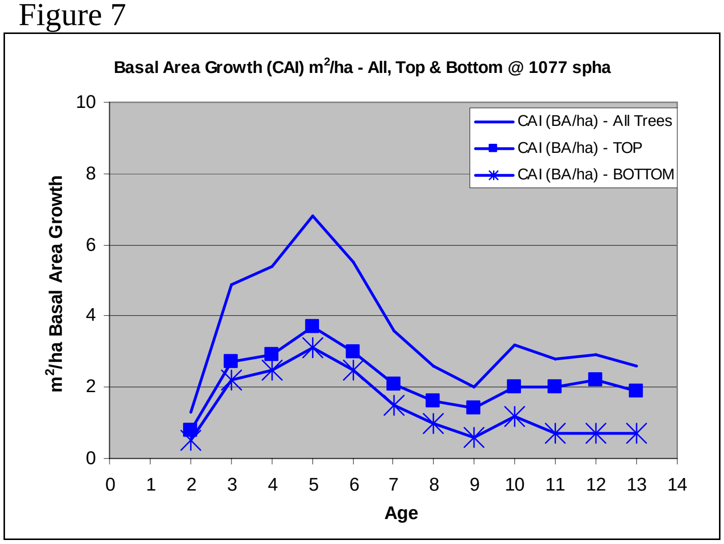
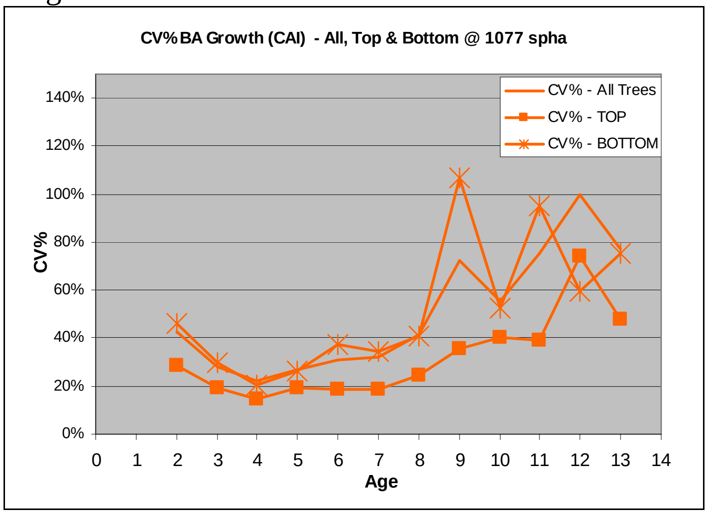


Figure 7 shows the split of basal area growth per hectare for the 'TOP' and BOTTOM' categories, in relation to the total 'All Trees'. Differentiation between the more dominant ('TOP') and the more suppressed ('BOTTOM') trees has already occurred at age two to three. The dominant/co-dominant trees remain so, whereas the more suppressed trees remain in the more suppressed 'BOTTOM' category. This is a consistent pattern for all other crop

[I] In this figure, SPAC means 'stems per acre' densities as well. The curves in Figure 7 show the intermittent peaks and valleys (see 4.1.3) for both 'TOP' and 'BOTTOM', indicating that all trees experience variability in their CAI (BA/ha). To determine where most of the variability occurs in the CAI (BA/ha), the percent coefficient of variation (CV%)[I] was determined for 'All Trees', 'TOP' and 'BOTTOM' (Figure 8).

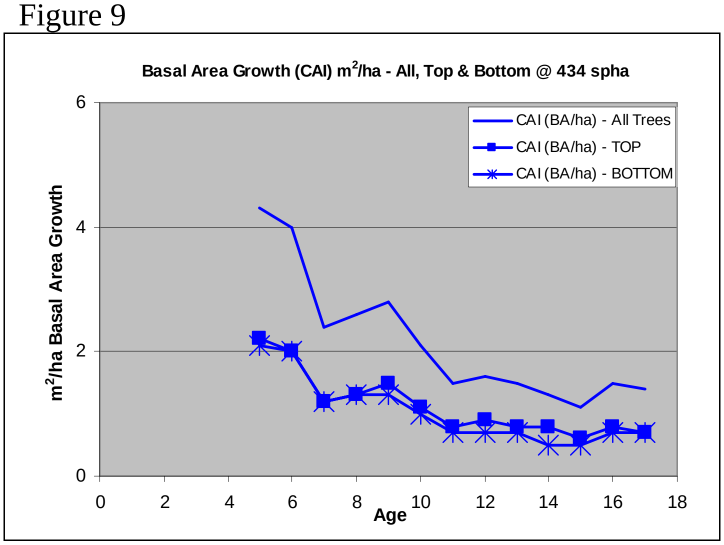
The CV% is relatively low and steady for the first part of the rotation, but starts to show spikes after age eight. Most variability occurs in the 'BOTTOM' trees. Although these swings in CV% differ from trial to trial, the pattern is similar; most variability occurs in the 'BOTTOM' trees and takes place later in the rotation, around age seven to eight. This could indicate that the 'BOTTOM' trees are affected much more than the 'TOP' trees by events that trigger the peaks and valleys in DBH and basal area growth.

Figure 8



Appendix C (7 pages) contains the charts for all the densities reported in Figures 1 and 5. It is of interest to note that the curves for the 'TOP' and 'BOTTOM' for the lowest two densities at 567 and 434 spha are very close (Appendix C, pages 6 & 7).

Figure 9



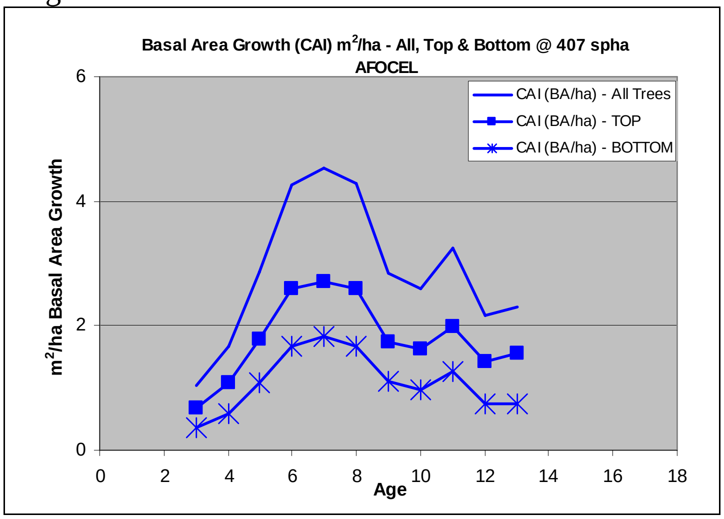
The 'TOP' and 'BOTTOM' curves for 567 spha have been closer together than for higher densities. The same curves for 434 spha are almost identical (Figure 9). This indicates extremely homogeneous crops with little variation in DBH.

To check whether this is the norm for low density crops, a comparison was made with the same curves for the AFOCEL

[I] CV% or Coefficient of Variation (%) is the standard deviation of a sample, divided by its mean.

density trials. The AFOCEL curves for the 'TOP' and 'BOTTOM' trees planted at 407 spha shows much more divergence (Figure 10). The AFOCEL curves for 300 and 200 spha show a similar divergence as for 407 spha.

Figure 10



From this AFOCEL information it is clear that differentiation between trees into dominant/co-dominant and more suppressed categories occurred well before age five. The extreme uniformity of the trees in the trial planted at 434 spha (Figure 9) cannot be explained satisfactorily. Even at age 5, there was hardly any difference between 'TOP' and 'BOTTOM' trees, as opposed to the densities of 567, 770 spha (Appendix C, pages 5 & 6) that were grown on the same trial site and all the other densities in trials grown elsewhere.

❖ Conclusions

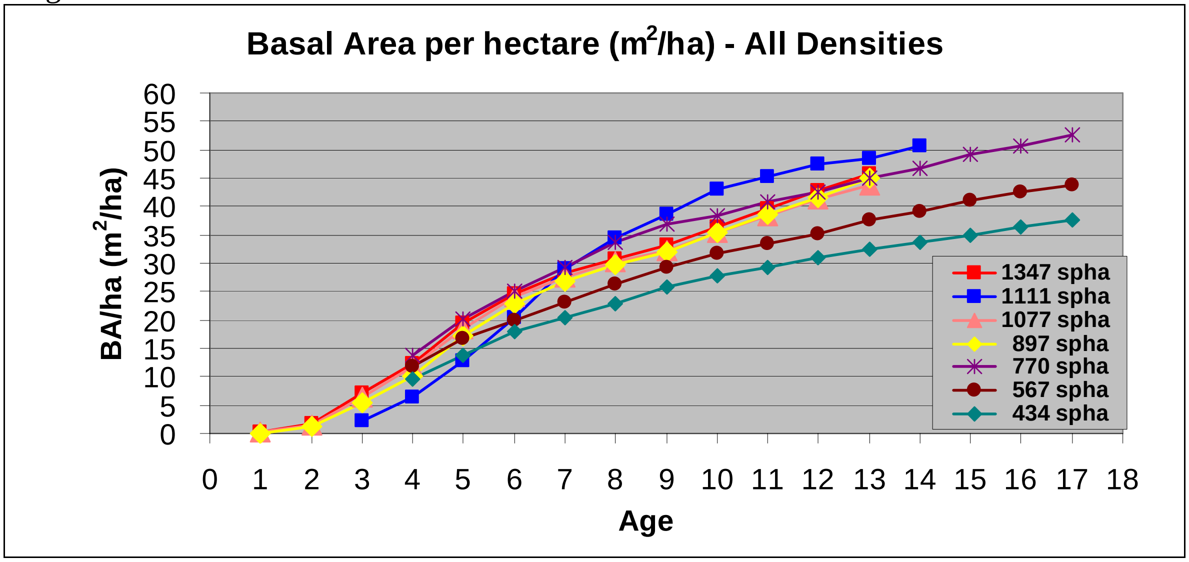
- Differentiation of growth rates between trees starts at a very young age and dominant/co-dominant trees continue to grow at a higher rate than the more suppressed trees;
- Differentiation is independent of crop density, since it starts at a very young age;
- Differentiation is likely caused by factors, such as:
    - Slight differences in soil conditions;
    - Differences in stock size (small caliper vs. large caliper cutting, etc.);
    - Differences in weed competition.
- It is uncertain if a lower crop density could impact the relative rate of basal area growth of dominant/co-dominant vs. more suppressed trees; i.e. would a lower density lead to a more uniform crop?
- Peaks and valleys in basal area growth show more variability in the 'BOTTOM' than in the 'TOP' trees, indicating more stress to suppressed trees than to dominant/co-dominant trees.

4.1.5 Basal area per hectare and density

The relationship between total basal area per hectare (BA/ha - m^2/ha) is displayed in Figure 11. The trial with 1111 spha is located on North Vancouver Island and was planted to a clone that was different from the other trials. The trials with 1347, 1077 and 897 spha are located on the same site in Oregon and were planted with a clone suited to that site; they show remarkable homogeneity and very similar BA/ha. The trials with

770, 567 and 434 spha are located on the same trial site in southwestern British Columbia and were planted with yet another clone that proved suitable to that area.

Figure 11



Of interest is that the Oregon trial with the 1347, 1077 and 897 spha does not show much difference in BA/ha after 13 years. It should be noted that the site in southwestern British Columbia is on very good and well-drained farmland that had grown agricultural crops prior to being planted to poplar.

❖ Conclusions

- Basal area per hectare increases with crop density for a given length of time.
- Crops grown at lower densities have a better and more sustained growth in DBH and thus basal area (and thus volume) per tree than trees planted at higher densities;
- It has yet to be determined if crops grown in a certain range of densities (e.g. 500-800 spha) can achieve the same average growth rate per year in basal area per hectare when rotations are increased with decreasing density, for instance:
  - A crop grown at 500 spha might grow 50 m^2/ha in 20 years, for an average of 2.5 m^2/ha/yr. Would a crop at 800 spha grow at the same average rate for 15 years grow to a total of 37.5 m^2/ha?

REPORT - PART III

1 Introduction

In order to determine the range of crop densities that yield the highest net return to the private landowner who plans to grow an SRIC poplar crop, he needs to know the potential value of the end product. The dilemma with this new crop is that there is not yet enough of a sustainable and concentrated supply of consistent quality to attract a processing industry. There will be no market until a sufficient supply is ready.

As a private landowner, there is the need to produce a crop with as high a value as possible within the time limit the owner has in mind. The question then arises if producing the highest value possible in 30 years for example is a better deal than a lower value in 20 years.

2 Simulations by Forintek Canada Corp.

Forintek Canada Corp. is one of the sponsors (Appendix A) of this project and has conducted simulations to provide potential lumber and veneer recoveries from a range of tree sizes. Forintek has been contracted by the Saskatchewan Forest Centre to investigate the suitability of the wood characteristics of existing hybrid poplar grown in the Prairie region for various uses, including veneer, OSB and solid wood products. The results are very encouraging and confirm that the wood is very suitable for a number of uses, including appearance grades of lumber and possibly veneer.

3 Methods used

During a meeting with the Expert Review Group (Appendix B) in November 2005, criteria were set for the simulations at Forintek.

3.1 Simulation criteria

Fifteen DBH classes were selected (Table 6).

Although log markets in Canada buy and trade logs in metric units (tonnes, cubic meters), most mills in the industry still use imperial units to define log sizes and grades and lumber output. Sawmills also use the foot board measure (fbm), or simply called board foot or board feet; it is a unit of cubic measure for lumber, equal to one foot square by one inch thick. The following tables are all expressed in metric with the imperial measurement unit in brackets. Lumber output is still expressed in fbm.

Table 6

DBH Class	Range	
cm	cm	cm
16.0	15.1	17.0
18.0	17.1	19.0
20.0	19.1	21.0
22.0	21.1	23.0
24.0	23.1	25.0
26.0	25.1	27.0
28.0	27.1	29.0
30.0	29.1	31.0
32.0	31.1	33.0
34.0	33.1	35.0
36.0	35.1	37.0
38.0	37.1	39.0
40.0	39.1	41.0
42.0	41.1	43.0
44.0	43.1	45.0

- Three stem lengths were used with different bucking lengths (Table 7).

Table 7

Stem length	Bucking length (not including trim)			
	Log 1	Log 2	Log 3	Log 4
8.4 m (27.5 ft.)	3.05 m (10 ft.)	2.44 m (8 ft.)	Rest	
9.9 m (32.5 ft.)	3.05 m (10 ft.)	3.05 m (10 ft.)	Rest	
11.4 m (37.5 ft.)	3.05 m (10 ft.)	2.44 m (8 ft.)	2.44 m (8 ft.)	Rest

- Pruning height was set at 6.7 m (22 ft.), which includes trim (Figure 12);
- Three knotty cores were set at:
  - 10 cm (4 in.)
  - 12 cm (4.7 in.), and
  - 14 cm (5.5 in.).
- Taper was set at:
  - 0.6 cm per 1.0 m of log length (0.75 in. per 10 ft.)
  - 0.8 cm per 1.0 m of log length (1.0 in. per 10 ft.)
  - 1.0 cm per 1.0 m of log length (1.25 in. per 10 ft.)
- Only one thickness of lumber output was simulated: 4/4 lumber (called four quarter, which is 1.19 in. thick).
- Stem sweep was ignored to limit the number of simulations.

Lumber simulations were carried out using a simulation model 'OPTITEK', which was developed by Forintek Canada Corp. The grades in Table 8 were used for lumber output.

Table 8

Optitek Grades	Upper limit of knotty core volume as a proportion of lumber
Grade 1	16.7% (1/6th)
Grade 2	33.3% (1/3rd)
Grade 3	100%

The prices per thousand board feet are in US dollars and were based on market estimates in the US Pacific Northwest (Table 9).

Table 9

Grade	Lumber prices for 4/4 lumber per '000' fbm
Select & Better	US$980
#1 Shop	US$610
#2 Shop	US$455

Figure 12 shows a schematic of a stem with its knotty core. Figure 13 is a typical sawing pattern centered around the knotty core.

Figure 12

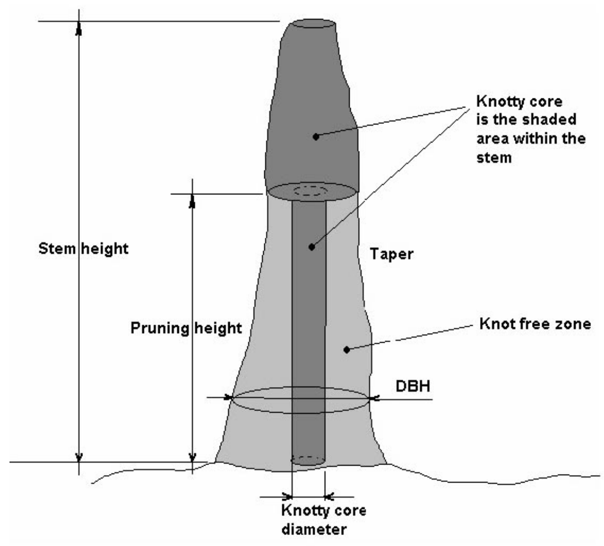


Figure 13

4 Simulation output

Simulation output was converted to fit typical DBH distributions for each density.

Lumber products included 4/4 (1.19”) thick lumber, with 4, 5, 6, 7 and 8 inch widths and 6, 7, 8, 9, 10 and 12 ft nominal lengths. Piece values are listed in Appendix D and were calculated based on the prices in Table 9.

5 Analysis

The analysis required conversion of the output data to fit each of the 15 DBH classes (Table 6).

For the analysis only the following simulation output was used:

- Two knotty core sizes:
  - 10 cm (4 in.)
  - 14 cm (5.5 in.)

- One taper class:
  - 1.0 cm per 1.0 m of log length (1.25 in. per 10 ft.)

Results for the intermediate knotty core size of 12 cm (4.7 in.) were also intermediate. The highest taper was selected to be on the conservative side of estimating value output. A lower taper would result in a higher lumber recovery and thus value.

The number of simulated logs per stem as shown in Table 7 was adjusted for trees in the lower DBH ranges; second and third logs did not have sufficient top diameter to make a saw log. For the 11.4 m (37.5 ft.) stem length the lumber recovery and values for the fourth log were also removed from the data.

5.1 Choice of trial data for analysis

The tree data in Table 10 were used to complete the analysis.

Table 10

Crop Density (metric)		Crop Density (Imperial)	
spha	Spacing	spac	Spacing
1077	3.05 x 3.05 m	436	10 x 10 ft.
897	3.66 x 3.05 m	363	12 x 10 ft.
770	3.6 x 3.6 m	312	11.8 x 11.8 ft.
657	3.9 x 3.9 m	266	12.8 x 12.8 ft.
567	4.2 x 4.2 m	229	13.8 x 13.8 ft.
494	4.5 x 4.5 m	200	14.8 x 14.8 ft.
434	4.8 x 4.8 m	176	15.7 x 15.7 ft.

These data were selected from the trials reviewed in Report - Part II and augmented with two densities not presented earlier; they were chosen to reflect a full range of crop densities. Two are from northwest Oregon (1077 and 897 spha; the 897 spha is almost equivalent to 3.3 x 3.3 m spacing) and five are from southwestern British Columbia. Growing conditions are considered similar and many clones grown in northwest Oregon have also done well in southwestern British Columbia.

All analysis output is for age 13 years. This is the oldest common age for these trials.

5.2 Tree heights

Most tree data were for DBH only and only inconsistent height data were included for a few of the trials. To assign a height to each DBH class, a height-diameter curve was used from a trial on North Vancouver Island with a crop planted at 4 x 4 m spacing, with a density of 625 spha (Appendix E). All trials used for the analysis (Table 10) were assigned the same heights per DBH class.

5.3 Volume calculations

Volumes were calculated with a taper and volume equation developed for North Vancouver Island hybrid poplar (unpublished) and further developed by SilviConsult Inc.

for easy data input. The taper and volume equation for North Vancouver Island fits the height and DBH values for the trials used in this analysis.

For future use in the Prairie Provinces, the Quebec table and formula in Appendix F are a good choice till local volume tables can be developed. In fact volumes derived from this table and the associated formula proved a reasonably good fit cf. the taper and volume equation for North Vancouver Island.

6 Results

For each of the trials listed in Table 10, the tree volume per hectare inside bark was calculated using the taper and volume equation for North Vancouver Island. Saw log volume and pulpwood volumes were derived from the Forintek simulation data and adjusted for input values as described in section 5 'Analysis' of Report - Part III.

6.1 Saw log values vs. lumber values

The analysis output provides comparative lumber values per hectare, based on the Select & Better, #1 Shop and #2 Shop values of Table 9 (see also Appendix G). These values are based on trees that were pruned to 6.7 m (22 ft.), which includes the first two logs for each tree with a DBH of 22 cm and over; trees with a DBH of 16 - 20 cm only have one log considered to be large enough for a saw log. For unpruned logs (100% knotty core), the equivalent lumber value was assumed to be US$455 per '000' fbm, which is #2 Shop grade.

There is an established market for red alder (*Alnus rubra*) hardwood saw logs in British Columbia and the Northwest US states. Hybrid poplar is considered a suitable substitute for this species and although an emerging market for hybrid poplar saw logs is developing in Oregon, there are no reliable prices yet with which to value log output of hybrid poplar crops.

For the private land owner who grows pruned hybrid poplar trees, the log price he fetches in the future will have to be based on the true quality of the wood, supported by well documented pruning records. Once there is a sufficient hybrid poplar supply coming on line, land owners and farmers should consider investing in a sawmill to process and market their own wood. This way a portion of the incremental value generated from pruning flows back to the producers.

6.2 Residual chip and pulpwood values

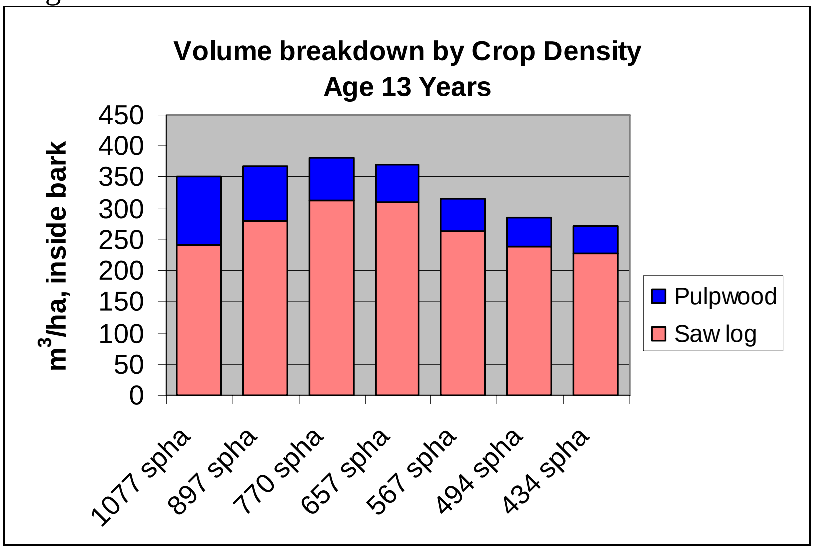
The sawmilling process generates a substantial amount of residual chips from each saw log (Appendix G). The value of residual chips is not considered in this analysis.

Pulpwood is everything that is not a saw log and constitutes the mostly unpruned top portion of the tree. Pulpwood price is assumed to be $30 per m^3 (delivered). The value of sawdust is ignored.

6.3 Volumes per hectare

The volume (inside bark) per hectare varies with density (Figure 14). Higher densities tend to support higher total volumes per hectare till age 13. Lower crop densities can reach merchantable volumes close to those of higher crop densities due to an increased individual tree size.

Figure 14



For instance, the total volume per hectare for 1077 spha is 351 m^3, vs. 286 m^3 for 494 spha, yet the saw log volume of 1077 spha is about the same as for 494 spha (241 m^3 vs. 239 m^3 – see Appendix G). Although this example illustrates these trends well, it should be noted that the data used originates from two different regions and clones.

As density decreases, total volume per hectare decreases; however, an increasing proportion is saw log. For 1077 spha the pulpwood portion is as high as 31%; for 434 spha it is only 16% of total volume per hectare. For analysis purposes, the top portion is considered pulpwood, even though some of this wood could be suitable for OSB manufacture.

6.4 Lumber value vs. log value per hectare (gross)

Not only do lower crop densities catch up in merchantable volume per hectare to the higher densities, value-wise the lower densities move up even more due to larger tree sizes. An increased tree size translates into better lumber recovery per tree, which increases the value per '000' fbm (Appendix G).

An argument was made in 6.1 for the log prices to be based on the true quality of the wood, supported by well documented pruning records. A premium red alder log fetches \$80/m^3 delivered to the mill, even though there are no records to substantiate its quality; it is an unmanaged log and it is valued on its appearance. Therefore it is reasonable to propose a sliding scale for log prices for pruned hybrid poplar, based on the lumber value that can be generated. For this analysis, the log price (delivered to the mill) per m^3 is assumed to be equal to 50% of the lumber value per m^3 of saw log for each crop density (Appendix H). Lumber values for unpruned trees (i.e. 100% knotty core) are assumed to be at the #2 Shop level of US\$455 per '000'fbm (Table 9 and Table 11), regardless of density.

Table 11

Weighted average log price/m^3	1077 spha	897 spha	770 spha	657 spha	567 spha	494 spha	434 spha
No pruning – 100% knotty core	$50	$54	$57	$59	$58	$60	$61
Pruning to a 14 cm knotty core	$63	$71	$78	$84	$82	$87	$91
Pruning to a 10 cm knotty core	$72	$82	$90	$95	$94	$98	$101

6.5 Gross revenue per hectare

Figure 15

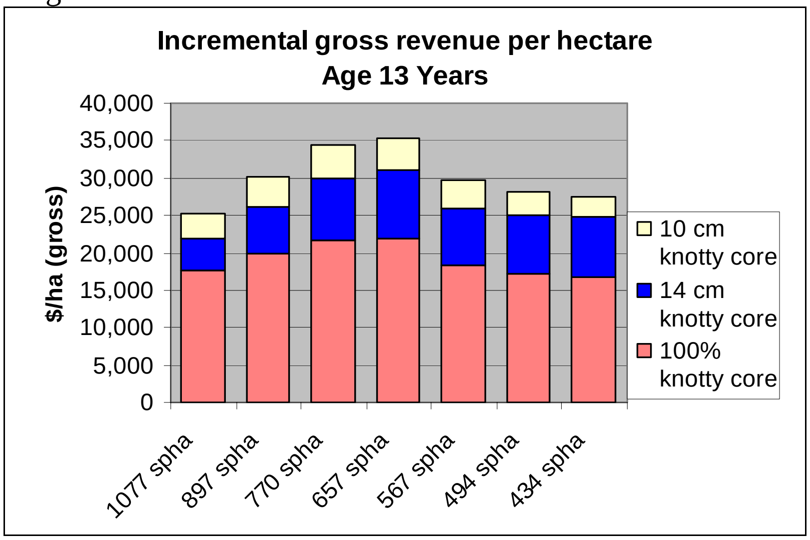


Figure 15 displays the total gross revenue per hectare of saw logs and pulpwood for the unpruned – 100% knotty core – and the incremental increases of gross revenue that can be generated when pruning to a 14 or 10 cm knotty core respectively.

As expected, pruning in the 1077 and 897 spha densities does not increase revenue as much as pruning in the lower densities. Labour costs for pruning are proportional to the spha and pruning costs for 1077 spha would be almost 30% higher than for 770 spha for instance.

Pruning to a 10 cm knotty core in the lower crop densities of 434 and 494 spha does not appear to increase revenue per hectare as much as for the medium densities. This may in part be due to fewer trees and larger tree sizes in the lowest two densities, where a decrease in knotty core size from 14 to 10 cm will not have as much impact on value recovery as in the smaller trees at medium crop densities. Since pruning costs are considered the same whether pruning to a 10 cm knotty core or a 14 cm knotty core, pruning might as well be done as early as possible to capture the incremental revenue.

7 Costs

Several crop management costs are influenced by crop density. Table 12 lists the main activities and how their costs are likely to decrease or increase with a lowering of crop density.

Table 12

Cost/ha decreases	Cost/ha increases
Planting	Weed control
Planting stock	
Shaping or singling	
Pruning	(Pruning vs. no pruning)
Harvest & transport?	Harvest & transport?

Planting and planting stock costs will decrease with a decrease in crop density. Shaping or singling is to improve the shape and form of the trees during the establishment period; with fewer trees planted, the cost per hectare will be lower.

Cost increases will be incurred in weed control as fewer trees per hectare delay canopy closure of the crop. If the decision is made to prune for quality and value enhancement, pruning costs will be incurred two to four times during the crop rotation, depending on location. Harvest and transport costs are based on a per m^3 basis and fluctuate with the volume per hectare and are only influenced by crop density; they could either increase or decrease on a per hectare basis.

8 Cost/Benefit analysis

The cost/benefit analysis is done for incremental activities that have associated costs and benefits as a result of a change in density and/or a decision to prune. Since all seven density scenarios are 13 years old, direct comparisons can be made. A discounted cash flow analysis is used to account for the time element, as this is a multi-year crop. Five discount rates (interest rates) are used: 2, 4, 6, 8 and 10% (Appendix I). These are based on real rates[I], which are net of an inflation rate (see also Appendix J). The 'Base Case', to which all scenarios are compared, is an unpruned (i.e. 100% knotty core) crop planted at 1077 spha.

8.1 The 13-year old trials

Table 13 contains a sample of the net present value (NPV) of the crop density 1077 spha,

Table 13

	Net present value (NPV) - $/ha – **Base Case, 1077 spha, unpruned, 100% knotty core**	Net present value (NPV) - $/ha – **1077 spha, pruned to 14 cm knotty core**	**Increase/Decrease over Base Case – NPV $/ha**
2%	$7,378	$8,947	**$1,569**
4%	$5,496	$6,480	**$983**
6%	$4,061	$4,605	**$543**
8%	$2,957	$3,181	**$224**
10%	$2,086	$2,079	**$7**

[I] The real discount rate or RDR is the interest rate, net of inflation, at which costs and revenues are discounted to the present.

pruned to a 14 cm knotty core (third column), as compared to the NPV of 'Base Case' 1077 spha, unpruned (100% knotty core). The increase or decrease at a given discount rate in NPV for the 1077 spha, pruned to a 14 cm knotty core is listed in the right-hand column. The details of this information can be found in Appendix K (2 pages).

In all but one cases, pruning the 1077 spha to a 14 cm knotty core shows a positive incremental NPV due to the benefit of the increased value of clear lumber cf. the 'Base Case'. At a 10% real discount rate, there is a -$7/ha NPV, which indicates a slight advantage of the 'Base Case' over the pruned scenario; however, it is so close than it is considered a break even. The full results can be seen in Table 14.

In Table 14 the net present value of the 'Base Case' (unpruned - 100% knotty core) crop is set at $0/ha for each of the discount rates. The values for each pruned crop represent the incremental NPV generated by the extra revenue from the saw logs, minus any incremental costs (Table 12) to grow and improve this crop (Appendix K for details).

Table 14

Increase or decrease over Base Case Net Present Value ($/ha) of Incremental Management Activities over base case							
Discount Rate	**1077 spha**	**897 spha**	**770 spha**	**657 spha**	**567 spha**	**494 spha**	**434 spha**
	Base Case Unpruned	**Unpruned**	**Unpruned**	**Unpruned**	**Unpruned**	**Unpruned**	**Unpruned**
2%	**$0**	$1,610	$2,806	$3,170	$1,207	$675	$550
4%	**$0**	$1,285	$2,209	$2,512	$973	$570	$483
6%	**$0**	$1,036	$1,753	$2,009	$794	$491	$433
8%	**$0**	$845	$1,405	$1,625	$662	$435	$399
10%	**$0**	$691	$1,125	$1,315	$555	$389	$370
	14 cm core	**14 cm core**	**14 cm core**	**14 cm core**	**14 cm core**	**14 cm core**	**14 cm core**
2%	$1,569	$4,945	$7,822	$9,206	$6,034	$5,876	$6,133
4%	$983	$3,685	$5,947	$7,070	$4,608	$4,513	$4,737
6%	$543	$2,727	$4,519	$5,441	$3,522	$3,476	$3,674
8%	$224	$2,007	$3,437	$4,203	$2,702	$2,691	$2,868
10%	$7	$1,449	$2,587	$3,224	$2,058	$2,073	$2,231
	10 cm core	**10 cm core**	**10 cm core**	**10 cm core**	**10 cm core**	**10 cm core**	**10 cm core**
2%	$4,042	$8,018	$11,365	$12,434	$8,884	$8,272	$8,188
4%	$2,865	$6,042	$8,675	$9,557	$6,805	$6,360	$6,320
6%	$1,983	$4,544	$6,632	$7,368	$5,225	$4,906	$4,900
8%	$1,320	$3,406	$5,073	$5,697	$4,023	$3,800	$3,818
10%	$808	$2,509	$3,838	$4,369	$3,070	$2,922	$2,959

Under all circumstances and crop densities, pruning to either a 10 cm or 14 cm knotty core makes financial sense for each of the discount rates. At the break even point (-$7/ha NPV) for 1077 spha and a 14 cm knotty core and the 10% discount rate, pruning creates an internal rate of return[I] of almost 10%; all other scenarios have an internal rate of return in excess of 10%. Pruning does make financial sense.

For unpruned crops, the 657 spha (3.9 x 3.9 m spacing) and 770 spha (3.6 x 3.6 m spacing) are clearly superior to any other crop density at age 13. Both densities maintain their superior position in the pruning scenarios.

8.2 <u>Sensitivity to changed costs or revenues</u>

The sensitivity analysis included a reduction in saw log value to 50% of the original analysis or a reduction in pruning productivity at full saw log prices.

8.2.1 Saw log value at 50% of original

To test the sensitivity of a change in revenue, saw log prices were reduced to 50% of the saw log value per m^3. For the 'Base Case' 1077 spha (100% knotty core), the saw log price would have dropped below the pulpwood price of $30/$m^3$ and its price was adjusted to be equal to the pulpwood price. For all unpruned scenarios, the log value was based on a uniform price of US$455 per '000' fbm for lumber, which resulted in a price level barely above that for pulpwood ($30-33/$m^3$) for all unpruned densities. The results can be viewed in Appendix L - part A.

For all crops with densities of 897 spha or lower, pruning to either a 10 cm or 14 cm knotty core still makes financial sense for each of the discount rates; all scenarios have an internal rate of return in excess of 10%. Pruning of 1077 spha neither pays at any of the discount rates for a 14 cm knotty core, nor at 8% or higher for the 10 cm knotty core.

8.2.2 Pruning productivity at 54% of original

With saw log prices back to the original level (see 6.4) and pruning productivity at 54% of the original analysis (150 trees vs. 275 trees per manday), pruning 1077 spha to a 14 cm knotty core results in a loss at all but the 2% discount rates. For the 10 cm knotty core only the 10% discount rate shows a negative NPV (Appendix L – part B).

8.3 <u>Changes from age 13 to 17 years</u>

Only for the trials in southwestern British Columbia data exist up to and including age 17 years (Figure 16). The relative positions of volume per hectare between the densities (Figure 15 cf. Figure 16) have not changed appreciably in four growing seasons. Increases in volume for all densities range from 16-20%, with increases in value from 25-29%, based on logs with a 10 cm knotfree core. The question is whether or not to let the crop grow till age 17 years.

[I] Internal rate of return or IRR is the interest rate at which the net present value is zero. It is considered a 'project earning' rate.

Figure 15

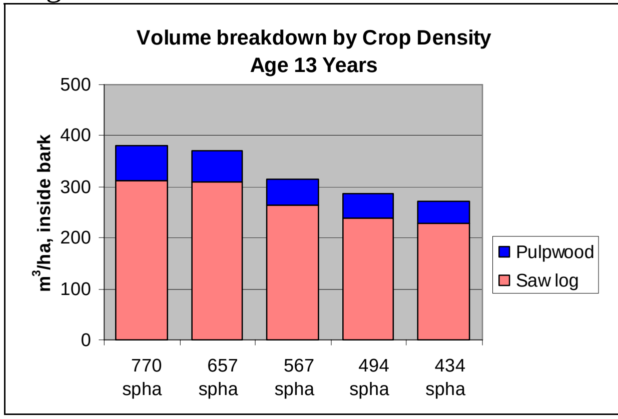
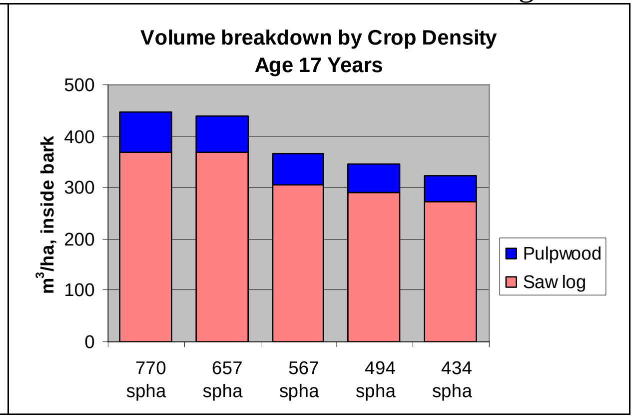


Figure 16



Keeping the crop growing till age 17 only makes economic sense at a 2% and possibly a 4% discount rate[I]. At discount rates higher than 4% the NPV of the 17 year old crop is lower than that for the 13-year old crop (Table 15). Note that the NPV values have not been reduced with the values of the 'Base Case' 1077 spha, as no 17 year old data exists for that trial.

The results in Table 15 demonstrate the impact of increasing discount rates and the element of time. Even though the crops in all cases are still increasing in volume per hectare (Figures 15 & 16) from age 13 to 17 years and still show a substantial increase in value per hectare, the higher discount rates and the extra four years reduce these values over 17 years to a lower NPV level than those for 13 years.

Table 15

Net Present Value comparisons between crops at ages 13 and 17 years						
Age	Discount Rate	770 spha & pruned 10 cm core	657 spha & pruned 10 cm core	567 spha & pruned 10 cm core	494 spha & pruned 10 cm core	434 spha & pruned 10 cm core
13 years	2%	$18,744	$19,812	$16,263	$15,651	$15,566
	4%	$14,171	$15,053	$12,301	$11,856	$11,816
	6%	$10,693	$11,430	$9,287	$8,968	$8,961
	8%	$8,030	$8,654	$6,980	$6,757	$6,775
	10%	$5,925	$6,455	$5,157	$5,009	$5,045
17 years	2%	$20,912	$22,461	$17,945	$18,022	$17,498
	4%	$14,433	$15,612	$12,384	$12,483	$12,142
	6%	$9,923	$10,841	$8,515	$8,626	$8,412
	8%	$6,721	$7,450	$5,768	$5,888	$5,763
	10%	$4,515	$5,107	$3,877	$4,000	$3,935

[I] This is before an adjustment necessary to reflect a re-investment return of the net revenue at age 13 years for an additional four years for the 13 year old crop.

9 Relevance to the Prairie region

It is recognized that the results (section 6) and cost/benefit analysis (section 8) apply to crops that have grown on the west coast and extrapolating results to crops that grow in the Prairie region is difficult at best. However, since no long term data are available for hybrid poplar crops in the region, results derived elsewhere could apply in general terms.

9.1 Growth rate

Growth rates in the Prairie region are unknown, but a mean annual increment (MAI)[I] of 16 m^3 per hectare per year on a 20 year rotation and at a crop density of 1100 spha (3 x 3 m spacing), is considered possible on the best sites. It is assumed that a rotation takes almost twice as long in the Prairie region as it does on the coast. Instead of using 13 years to generate the volumes of the previous analysis, it is assumed it will take 25 years in the Prairie region (Table 16).

Table 16

Volume information	**1077 spha**	**897 spha**	**770 spha**	**657 spha**	**567 spha**	**494 spha**	**434 spha**
Volume/ha (m^3)	351	368	381	372	315	286	273
Coast – 13 Years – MAI m^3/ha/yr	27.0	28.3	29.3	28.6	24.2	22.0	21.0
Prairie region – 25 Yrs – MAI m^3/ha/yr	**14.0**	**14.8**	**15.2**	**14.9**	**12.6**	**11.4**	**10.9**

9.2 Cost/Benefit analysis – Prairie region

The cost/benefit analysis is similar to the coastal analysis, except that all seven density scenarios are now 25 years old. Pruning takes place in later years and additional weed control is required (Appendix M). For example, the NPV of the crop density 1077 spha, pruned to a 14 cm knotty core (third column, Table 17) is compared to the NPV of ‘Base Case’ of 1077 spha, unpruned (100% knotty core). The increase or decrease at a given discount rate in NPV for the 1077 spha, pruned to a 14 cm knotty core is listed in the right-hand column. The details of this information can be found in Appendix M (2 pages).

Table 17

	Net present value (NPV) - $/ha – **Base Case, 1077 spha, unpruned, 100% knotty core**	Net present value (NPV) - $/ha – **1077 spha, pruned to 14 cm knotty core**	**Increase/Decrease over Base Case – NPV $/ha**
2%	$5,384	$6,391	**$1,007**
4%	$2,835	$3,084	**$248**
6%	$1,185	$984	**$201**
8%	$317	$47	**$364**
10%	$319	$807	**$488**

[I] MAI is mean annual increment. This is the total volume divided by the age; it is expressed as m^3 per ha per year (m^3/ha/yr).

Pruning of 1077 spha to a 14 cm knotty core shows a positive incremental NPV only at 2-4% discount rates over 'Base Case'. The full results can be seen in Table 18.

Table 18

Increase or decrease over Base Case for the Prairie region – 25 year rotation Net Present Value ($/ha) of Incremental Management Activities over base case							
Discount Rate	**1077 spha**	**897 spha**	**770 spha**	**657 spha**	**567 spha**	**494 spha**	**434 spha**
	Base Case Unpruned	**Unpruned**	**Unpruned**	**Unpruned**	**Unpruned**	**Unpruned**	**Unpruned**
2%	**$0**	$1,308	$2,243	$2,552	$979	$570	$482
4%	**$0**	$870	$1,438	$1,665	$663	$431	$395
6%	**$0**	$584	$914	$1,087	$460	$343	$340
8%	**$0**	$430	$638	$782	$361	$304	$319
10%	**$0**	**$314**	$431	$552	**$287**	**$275**	**$303**
	14 cm core	**14 cm core**	**14 cm core**	**14 cm core**	**14 cm core**	**14 cm core**	**14 cm core**
2%	$1,007	$3,754	$6,049	$7,191	$4,678	$4,582	$4,810
4%	$248	$2,078	$3,538	$4,324	$2,768	$2,756	$2,938
6%	$201	$1,023	$1,934	$2,482	$1,550	$1,589	$1,738
8%	$364	$523	$1,136	$1,550	$949	$1,011	$1,137
10%	$488	**$144**	$537	$848	$497	$575	$684
	10 cm core	**10 cm core**	**10 cm core**	**10 cm core**	**10 cm core**	**10 cm core**	**10 cm core**
2%	$2,922	$6,151	$8,824	$9,720	$6,913	$6,460	$6,420
4%	$1,376	$3,517	$5,220	$5,860	$4,126	$3,896	$3,914
6%	$400	$1,826	$2,893	$3,362	$2,328	$2,242	$2,296
8%	$52	$979	$1,705	$2,074	$1,414	$1,399	$1,468
10%	$382	$351	$821	$1,114	$734	$772	$851

For unpruned crops, the 657 spha (3.9 x 3.9 m spacing) and 770 spha (3.6 x 3.6 m spacing) are clearly superior to any other crop density at age 25.

Pruning in the 1077 spha crop only makes sense at the lower discount rates of 2-4% for the 14 cm knotty core and at 2-6% for the 10 cm knotty core. The positive values in **blue font** for several scenarios in Table 18 are not sufficiently high to compensate for the negative NPV of -$319 per hectare of the 'Base Case' at the 10% discount rate (see Table 17). It indicates that these scenarios have an internal rate of return that is lower than 10%. All other scenarios for densities of 897 spha and lower have an internal rate of return of in excess of 10%. Pruning makes financial sense for this 25 year rotation.

9.3 Sensitivity to changed costs or revenues

The sensitivity analysis included a reduction in saw log value to 50% of the original analysis or a reduction in pruning productivity at full saw log prices.

9.3.1 Saw log value at 50% of original

To test the sensitivity of a change in revenue, saw log prices were reduced to 50% of the saw log value per m^3. For the 'Base Case' 1077 spha (100% knotty core), the saw log price would have dropped below the pulpwood price of $30/$m^3$ and its price was adjusted to be equal to the pulpwood price. For all unpruned scenarios, the log value was based on a uniform price of US$455 per '000' fbm for lumber, which resulted in a price level barely above that for pulpwood ($30-33/$m^3$) for all unpruned densities. The results can be viewed in Appendix N - Part A.

Pruning of 1077 spha does not pay at any of the discount rates for a 14 cm knotty core. For the 10 cm knotty core, pruning only pays at the 2% discount rate.

For all crops with densities of 897 spha or lower, pruning to either a 10 cm or 14 cm knotty core still makes financial sense at the 2 and 4% discount rates, as well as for a 10 cm knotty core at 770 spha and lower and a 6% discount rate.

The price reduction for all unpruned scenarios resulted in a saw log price at or just above pulpwood price, which was assumed to be $30/$m^3$. At this level, all wood could therefore be considered pulpwood. Appendix N – Part A shows that the NPV for all densities of 897 spha and lower is greater than that for 1077 spha at all discount rates.

9.3.2 Pruning productivity at 54% of original

With saw log prices back to the original level (see 6.4) and pruning productivity at 54% of the original analysis (150 trees vs. 275 trees per manday), pruning 1077 spha to a 14 cm knotty core results in a loss at any of the discount rates. Pruning to a 10 cm knotty core results in a loss at the 6-8% discount rates (appendix N – part B).

Pruning pays for all other densities at the 2-6% discount rates for both 10 and 14 cm knotty cores. At 8% and a 14 cm knotty core, pruning densities of 770 spha and lower pays; for the 10 cm knotty core pruning all densities of 897 and lower pay at the 8% rate. At the 10% rate, only pruning of 657 and 434 spha pays at a 10% rate for both 10 and 14 cm knotty cores and so does pruning of 494 spha to a 10 cm knotty core (appendix N – part B).

❖ Conclusions

- Pruning appears to be a good investment at any of the discount rates for crop densities of 897 spha and lower;
- In order for the land owner or farmer to realize a sufficient return on a pruning investment, the market price for a saw log needs to be tied to its lumber value recovery. This in turn needs to be supported by well documented pruning records;
- For unpruned crops, there is still potential to capture lumber value, but at a greatly reduced rate per m^3. The best returns for unpruned crops are in the 657-897 spha crop density range, with increasing NPVs as follows:
    - 657 spha = 770 spha > 897 spha;
- For pruned crops with either 10 cm or 14 cm knotty cores, the best returns are in the 434-770 spha crop density range, with increasing NPVs as follows:
    - 657 spha > 770 spha > 567 spha >= 494 spha >= 434 spha
- If a land owner or farmer does not want to commit to do pruning, the optimum crop densities will be 657 to 770 spha.
- All scenarios are based on the premise that a land owner or farmer needs to maximize his net return per hectare. The production of a 100% pulpwood crop has not been considered.
- The sensitivity analysis for the price reduction to 50% of saw log value for the unpruned scenarios (see 9.3 and Appendix N, Part A) indicates that 1077 spha may even be too dense for a pulp wood crop.

Appendix A – Companies and organizations providing data, information and support

Organization	Data (D) or information/report (I)	
AFOCEL – Association Forêt-Cellulose – France	Long term data results – compiled	I
GreenWood Resources – Oregon	Several short and long term datasets	D
Forintek Canada Corp.	Simulations for recovery of lumber and veneer	I
Ontario Forest Research Institute (OFRI) – Ontario	Long term datasets	D
Potlatch Corporation – Oregon	Several short and long term datasets	D
Scott Paper Limited – British Columbia	Long term datasets	D
SilviConsult Woody Crops Technology Inc – British Columbia	Long term datasets & internal report	D I
University of Minnesota - Minnesota	Short term dataset	D
University of Saskatchewan – Saskatchewan	BSc. Thesis on three density trials in Saskatchewan.	I

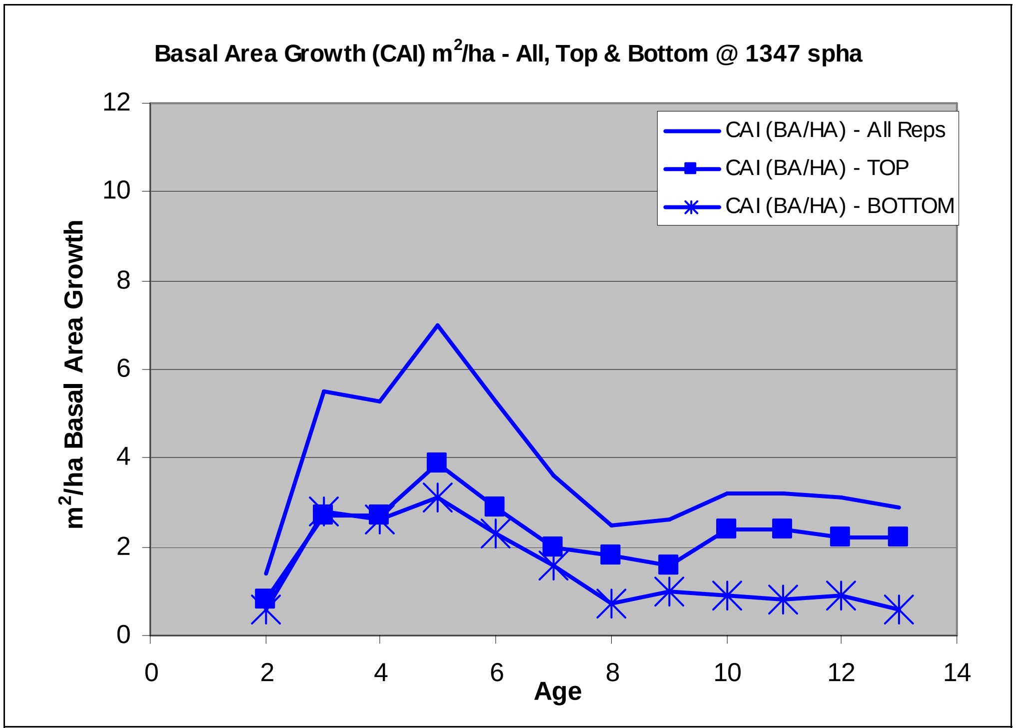
Appendix B – Expert Review Group

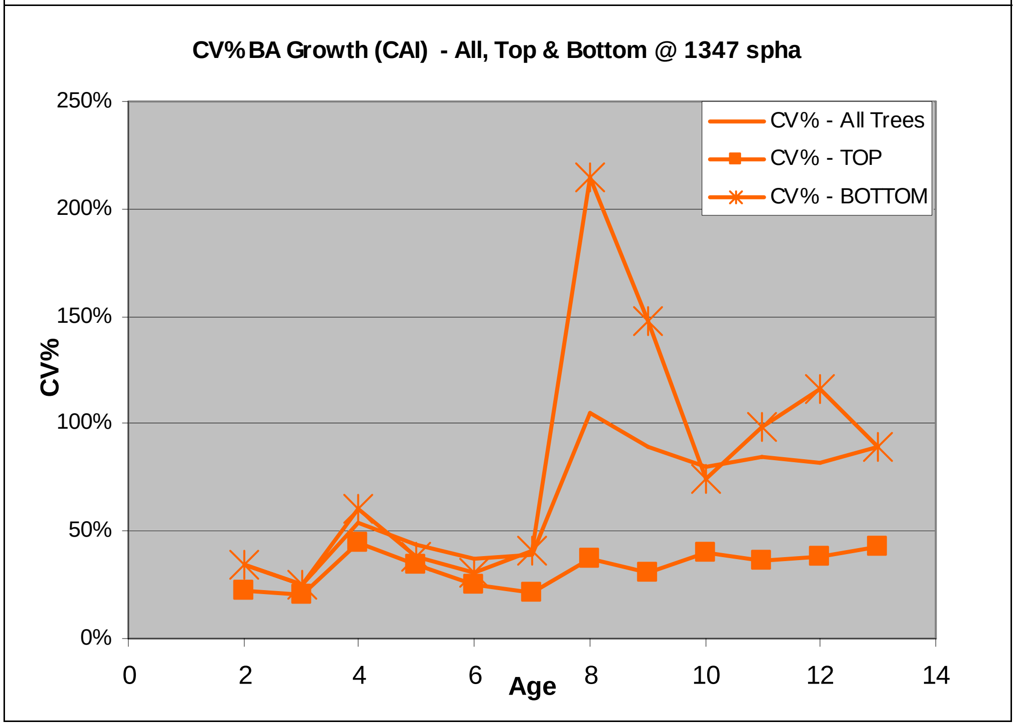
The Expert Review Group consisted of representatives of the companies that made long term density data available. The first meeting was hosted by Washington State University in Puyallup (WA) in November 2005. The second review meeting was held in March and was hosted by Forintek Canada Corporation in Vancouver (B.C.).

Members	Affiliation
Brian Stanton	GreenWood Resources
Jake Eaton	Potlatch Corporation
Dan Carson	Scott Paper Canada Ltd.
Jon Johnson	Washington State University

Appendix C – Basal Area growth and CV% of Basal Area growth – Page 1 of 7

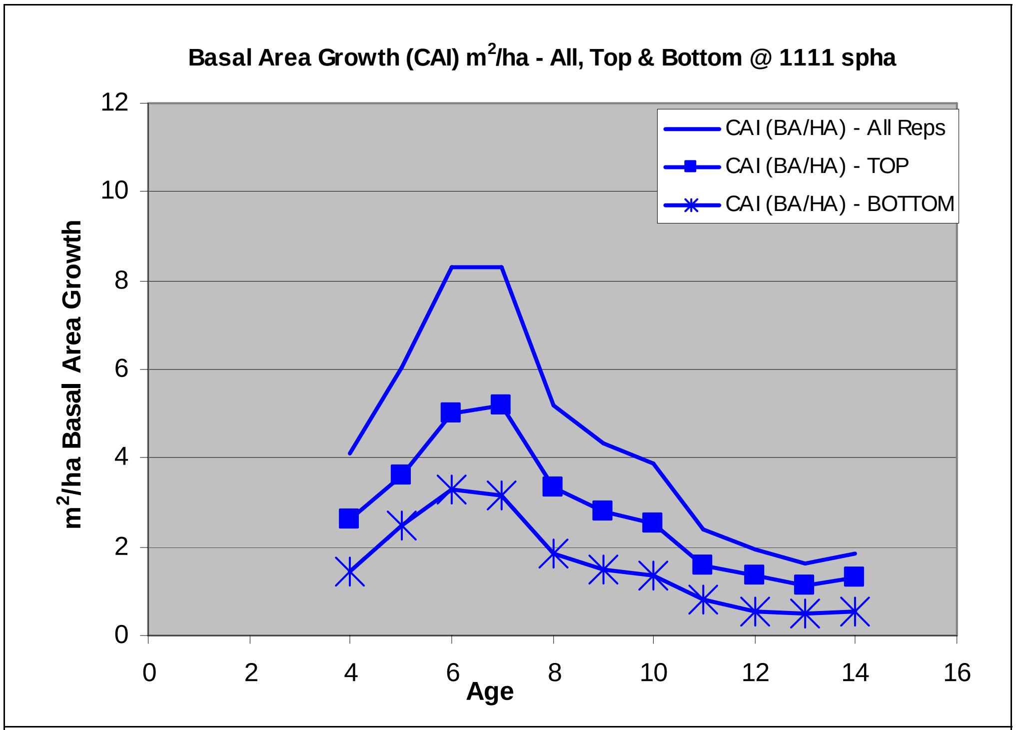
1347 spha – 3.05 x 2.44 m (10 x 8 ft.)

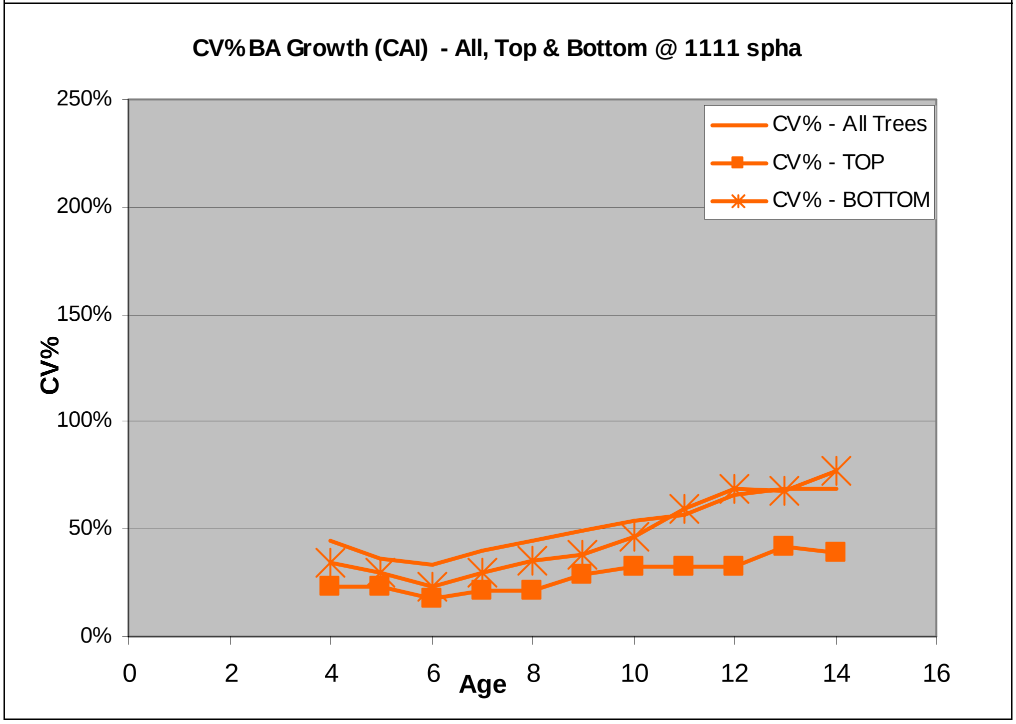




<u>Appendix C</u> – Basal Area growth and CV% of Basal Area growth – Page 2 of 7

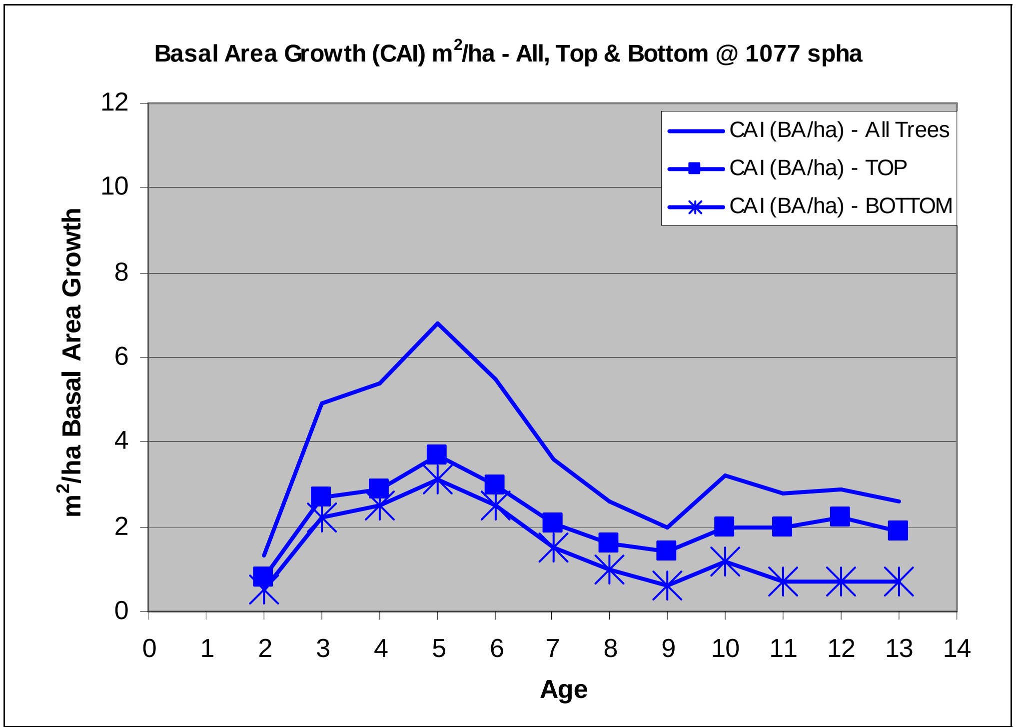
1111 spha – 3 x 3 m (9.8 x 9.8 ft.)

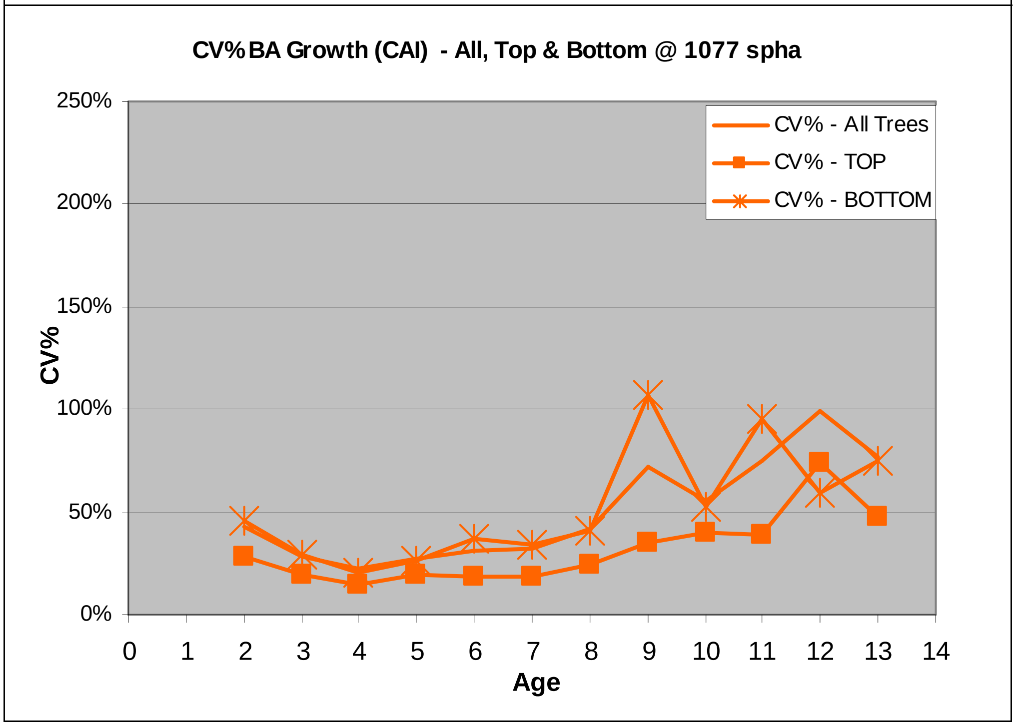




Appendix C – Basal Area growth and CV% of Basal Area growth – Page 3 of 7

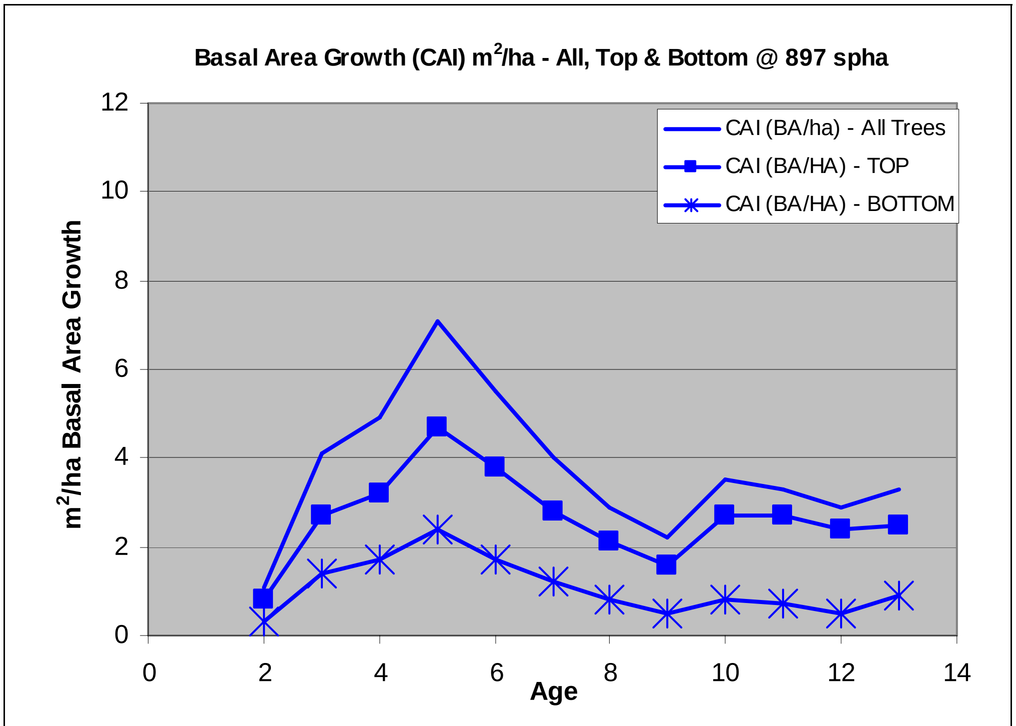
1077 spha – 3.05 x 3.05 m spacing (10 x 10 ft.)

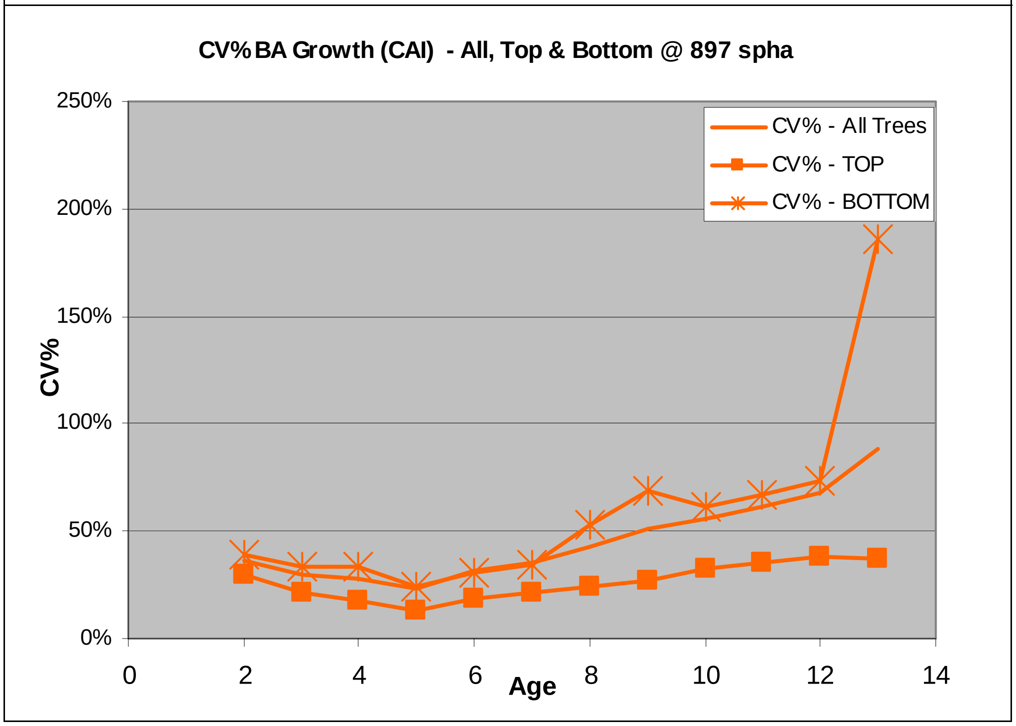




Appendix C – Basal Area growth and CV% of Basal Area growth – Page 4 of 7

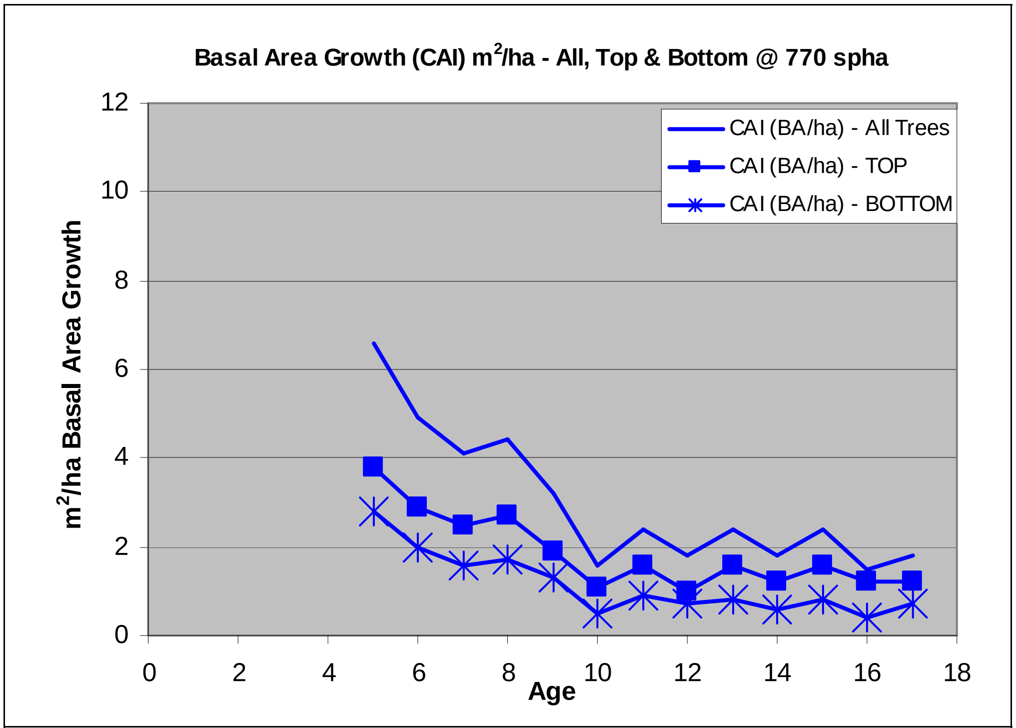
897 spha – 3.05 x 3.66 m spacing (10 x 12 ft.)

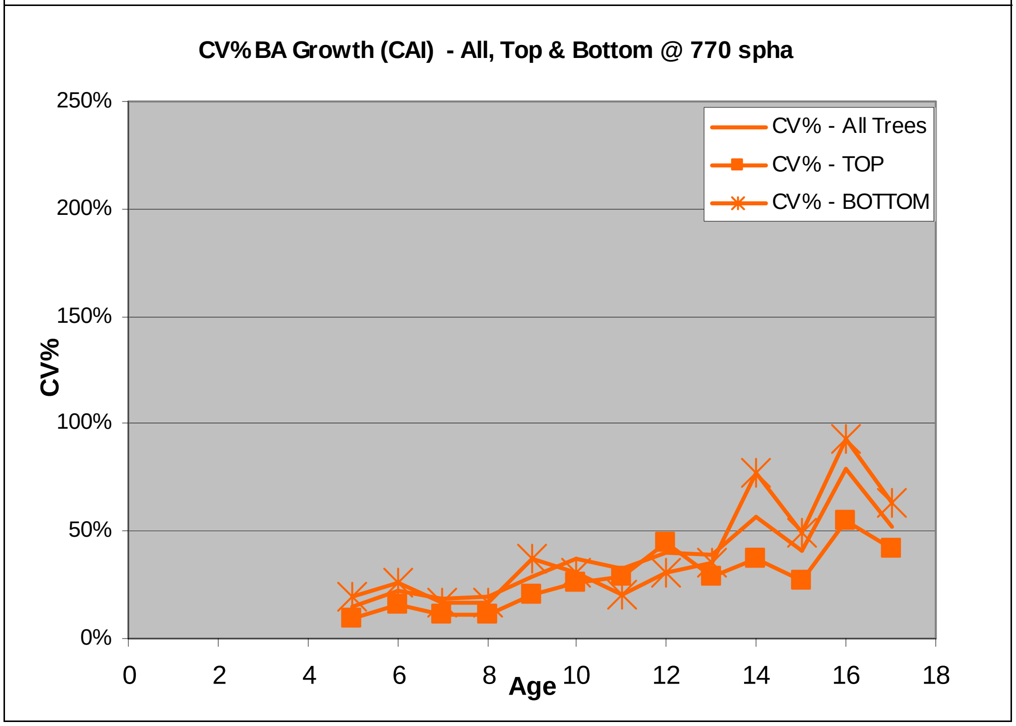




Appendix C – Basal Area growth and CV% of Basal Area growth – Page 5 of 7

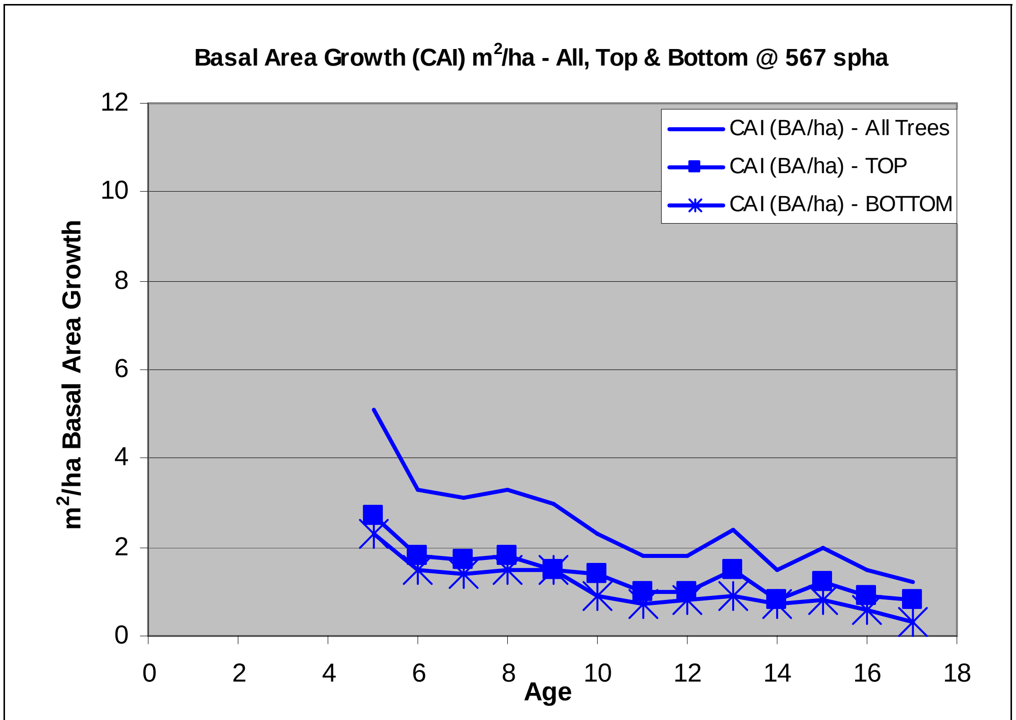
770 spha – 3.6 x 3.6 m spacing (11.8 x 11.8 ft.)

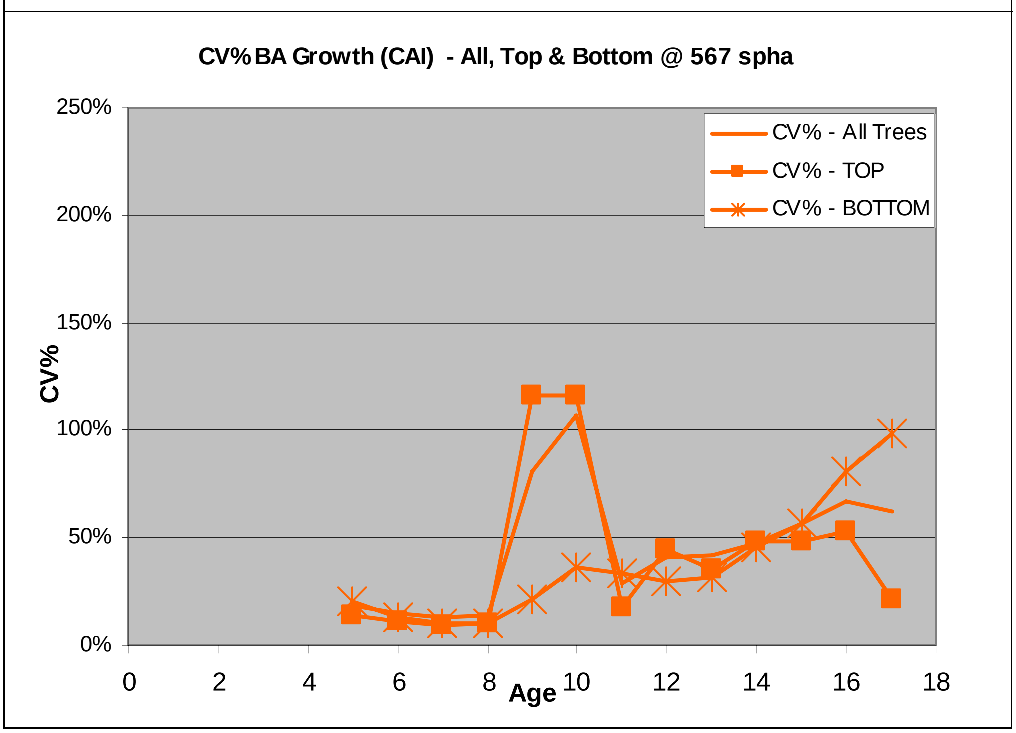




<u>Appendix C</u> – Basal Area growth and CV% of Basal Area growth – Page 6 of 7

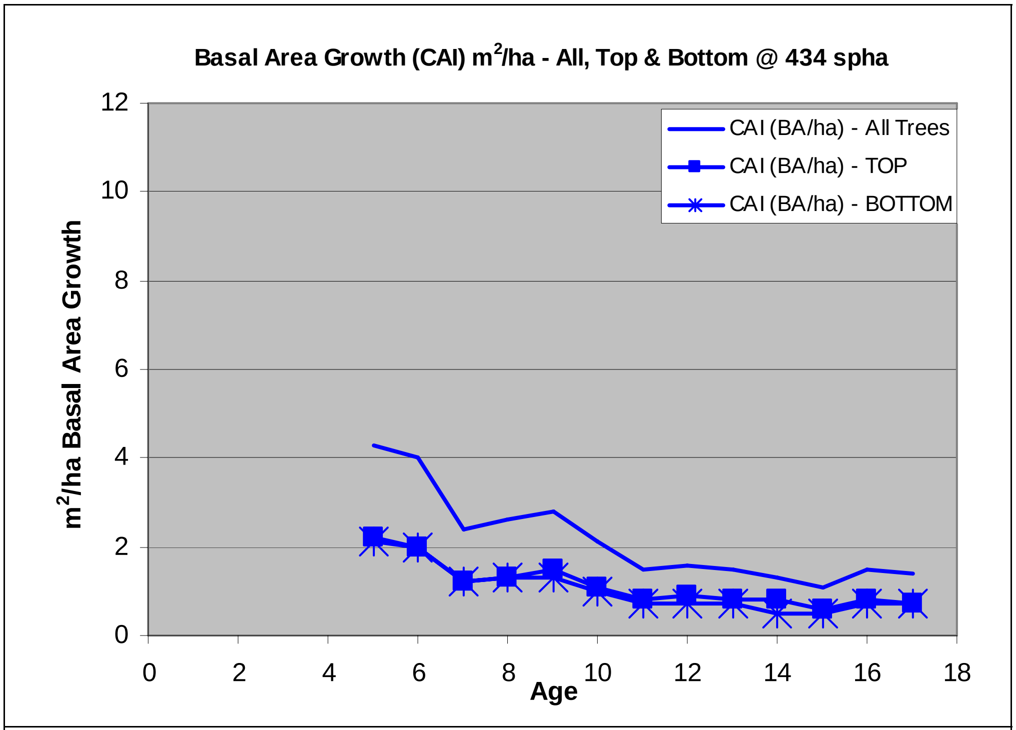
567 spha – 4.2 x 4.2 m spacing (13.8 x 13.8 ft.)

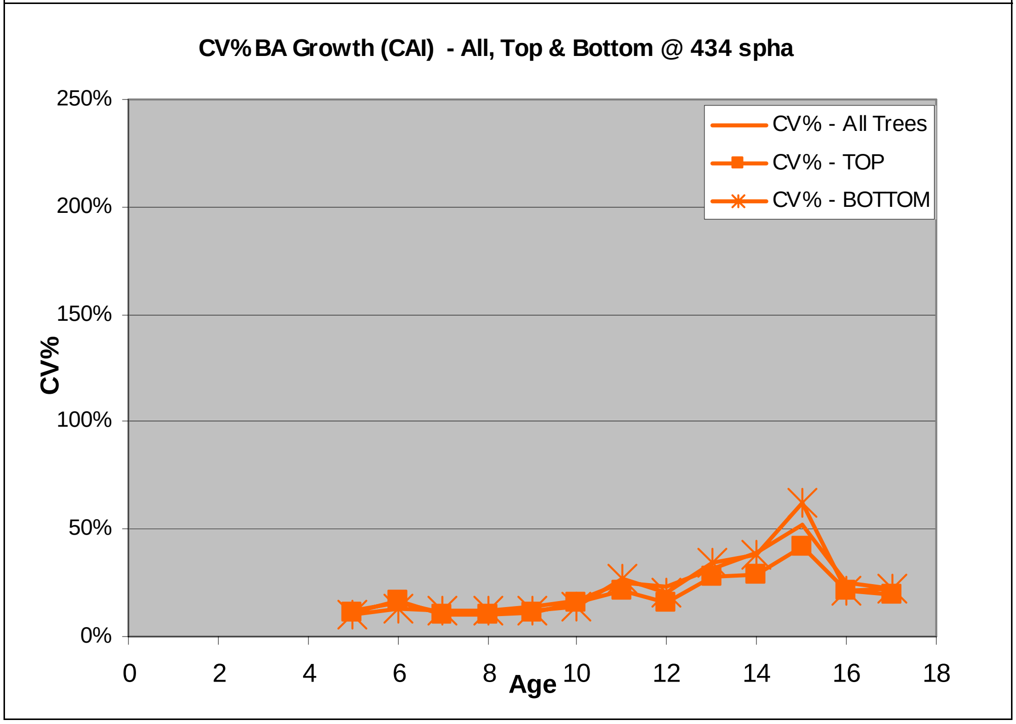




<u>Appendix C</u> – Basal Area growth and CV% of Basal Area growth – Page 7 of 7

434 spha – 4.8 x 4.8 m spacing (15.7 x 15.7 ft.)



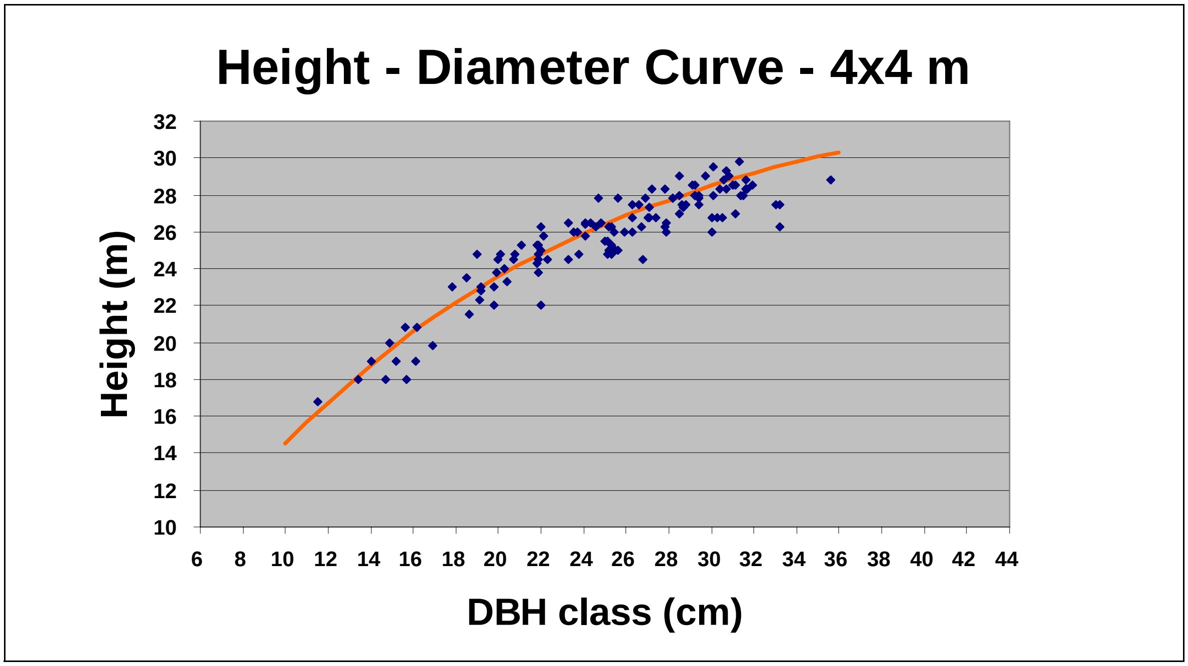


Appendix D – Piece values of 4/4 lumber in US$

Grade 1, Grade 2 and Grade 3 are Optitek grades (Table 8). The piece values were derived from the prices of Table 9 and were provided by the Expert Review Group.

Thickness (in.)	Width (in.)	Length (ft.)	Piece Value, US$/piece		
			Grade 1	Grade 2	Grade 3
1.19	4	6	2.33	1.45	1.08
1.19	4	7	2.72	1.69	1.26
1.19	4	8	3.11	1.94	1.44
1.19	4	9	3.50	2.18	1.62
1.19	4	10	3.89	2.42	1.80
1.19	4	12	4.66	2.90	2.17
1.19	4	14	5.44	3.39	2.53
1.19	4	16	6.22	3.87	2.89
1.19	5	6	2.92	1.81	1.35
1.19	5	7	3.40	2.12	1.58
1.19	5	8	3.89	2.42	1.80
1.19	5	9	4.37	2.72	2.03
1.19	5	10	4.86	3.02	2.26
1.19	5	12	5.83	3.63	2.71
1.19	5	14	6.80	4.23	3.16
1.19	5	16	7.77	4.84	3.61
1.19	6	6	3.50	2.18	1.62
1.19	6	7	4.08	2.54	1.90
1.19	6	8	4.66	2.90	2.17
1.19	6	9	5.25	3.27	2.44
1.19	6	10	5.83	3.63	2.71
1.19	6	12	7.00	4.36	3.25
1.19	6	14	8.16	5.08	3.79
1.19	6	16	9.33	5.81	4.33
1.19	7	6	4.08	2.54	1.90
1.19	7	7	4.76	2.96	2.21
1.19	7	8	5.44	3.39	2.53
1.19	7	9	6.12	3.81	2.84
1.19	7	10	6.80	4.23	3.16
1.19	7	12	8.16	5.08	3.79
1.19	7	14	9.52	5.93	4.42
1.19	7	16	10.88	6.78	5.05
1.19	8	6	4.66	2.90	2.17
1.19	8	7	5.44	3.39	2.53
1.19	8	8	6.22	3.87	2.89
1.19	8	9	7.00	4.36	3.25
1.19	8	10	7.77	4.84	3.61
1.19	8	12	9.33	5.81	4.33
1.19	8	14	10.88	6.78	5.05
1.19	8	16	12.44	7.74	5.78

Appendix E – Height – Diameter (DBH) relationship for a trial planted at 625 spha.



<u>Appendix F</u> – Hybrid Poplar Stem Volume Table (inside bark) – see: Popovich, 1986

These volume tables are valid for crop densities of 400-1000 spha (Popovich, 1986); Samples are based on 555 spha. The formula below was used to generate these values, with height in m, DBH in cm and Volume per tree in m^3.

$$\left\{ 0.41791 - \frac{0.51408}{\text{Height}} - \frac{0.1293 \text{ X Height}}{\text{DBH}} + \frac{0.94392 \text{ X Height}}{(\text{DBH})^2} + \frac{55.5001}{(\text{DBH})^2 \text{ X Height}} \right\} \text{ X Basal Area X Height}$$

Fields highlighted are based on the best data; non-highlighted fields are based on fewer data points.

Diameter at Breast Height (DBH) - cm	Height - m												
	8	9	10	11	12	13	14	15	16	17	18	19	20
10	0.0248	0.0276	0.0304	0.0331	0.0358	0.0384							
11	0.0288	0.0322	0.0354	0.0386	0.0417	0.0448							
12	0.0333	0.0372	0.0410	0.0448	0.0484	0.0519							
13	0.0382	0.0428	0.0472	0.0515	0.0558	0.0599	0.0638						
14	0.0436	0.0488	0.0540	0.0590	0.0638	0.0686	0.0732						
15		0.0554	0.0613	0.0670	0.0726	0.0781	0.0833						
16			0.0692	0.0758	0.0821	0.0883	0.0943	0.1002	0.1058				
17			0.0777	0.0851	0.0923	0.0994	0.1062	0.1128	0.1192				
18				0.0951	0.1032	0.1112	0.1189	0.1263	0.1336	0.1407	0.1475	0.1541	
19				0.1057	0.1149	0.1237	0.1324	0.1408	0.1490	0.1569	0.1646	0.1720	
20				0.1170	0.1272	0.1371	0.1467	0.1561	0.1653	0.1741	0.1827	0.1911	
21					0.1402	0.1512	0.1619	0.1724	0.1825	0.1924	0.2020	0.2113	
22					0.1540	0.1661	0.1780	0.1895	0.2008	0.2117	0.2224	0.2328	
23					0.1684	0.1818	0.1948	0.2076	0.2200	0.2321	0.2439	0.2553	
24					0.1836	0.1982	0.2125	0.2265	0.2402	0.2535	0.2665	0.2791	
25						0.2154	0.2311	0.2464	0.2613	0.2759	0.2901	0.3040	
26						0.2334	0.2505	0.2672	0.2835	0.2994	0.3149	0.3301	
27						0.2522	0.2707	0.2888	0.3066	0.3239	0.3408	0.3573	
28						0.2717	0.2918	0.3114	0.3306	0.3494	0.3678	0.3857	

The formula to calculate these values was applied to diameters and heights in excess of the table values to a DBH as high as 36 cm and a height as high as 30 m for the plot data of the analysis. The values of all DBH and Height combinations used were compared to those generated by a taper and volume equation developed for hybrid poplar on North Vancouver Island, which covers the entire range of DBH and height values (unpublished).

For the lower DBH range (12-20 cm) the volumes using the table and formula above is between 5-7% lower, but for the higher DBH range (30-36 cm) they are 4-10% higher.

Appendix G – Output summary of simulation and data conversion[I]

This summary only applies to stems with a taper of 1 cm per meter (1.25 in. per 10 ft.) and knotty cores of 10 cm (4 in.) and 14 cm (5.5 in.) respectively. Note that lumber value per '000' fbm are in US dollars; Lumber value per hectare are in Can dollars. The exchange rate of US$0.85 per C$1.00 was used.

Volume information	**1077 spha**	**897 spha**	**770 spha**	**657 spha**	**567 spha**	**494 spha**	**434 spha**
Volume/ha (m^3)	351	368	381	372	315	286	273
Saw log - m^3/ha	241	280	312	309	263	239	228
Saw log - %	69%	76%	82%	83%	83%	84%	84%
Pulpwood - m^3/ha	110	88	69	63	53	48	45
Residual chip volume (m^3/ha solid wood equivalent)	84.0	94.0	97.4	92.2	80.0	68.9	63.7
Knotty core of 10 cm (4 in.)							
Lumber value - C$/ha	$43,700	$54,726	$64,589	$66,650	$55,922	$53,116	$52,187
Lumber value - US$ - per (000) fbm	$697	$728	$752	$762	$758	$772	$778
Lumber recovered - (000) fbm	53.3	63.9	73.0	74.4	62.7	58.5	57.0
Lumber value - C$/$m^3$ (total volume)	$124	$149	$169	$179	$177	$185	$191
Lumber value - C$/$m^3$ (saw log volume only)	$181	$195	$207	$216	$213	$222	$229
Knotty core of 14 cm (5.5 in.)							
Lumber value - C$/ha	$37,224	$46,711	$55,368	$58,253	$48,507	$46,879	$46,841
Lumber value - US$ - per (000) fbm	$594	$621	$645	$666	$657	$682	$698
Lumber recovered - (000) fbm	53.3	63.9	73.0	74.4	62.7	58.5	57.0
Lumber value - C$/$m^3$ (total volume)	$106	$127	$145	$157	$154	$164	$172
Lumber value - C$/$m^3$ (saw log volume only)	$154	$167	$177	$189	$185	$196	$206
100% Knotty core No pruning							
Lumber value - C$/ha	$28,531	$34,223	$39,076	$39,808	$33,581	$31,297	$30,530
Lumber value - US$ - per (000) fbm	$455	$455	$455	$455	$455	$455	$455

[I] Note that the 100% Knotty core (no pruning) was not simulated by Forintek. Although the same lumber output was applied by density, the lumber value was assumed to be US$455 per '000' fbm in all cases.

<u>Appendix H</u> – Log prices per m^3 for different densities and knotty cores

This summary only applies to stems with a taper of 1 cm per meter (1.25 in. per 10 ft.) and knotty cores of 10 cm (4 in.), 14 cm (5.5 in.) and 100% knotty core respectively.

The equivalent price of the saw log is set at 50% of the lumber value per m^3. All prices are considered 'at the mill gate'.

Volume information	**1077 spha**	**897 spha**	**770 spha**	**657 spha**	**567 spha**	**494 spha**	**434 spha**
Volume/ha (m^3)	351	368	381	372	315	286	273
Saw log - m^3/ha	241	280	312	309	263	239	228
Pulpwood - m^3/ha	110	88	69	63	53	48	45

Knotty core of 10 cm (4 in.)							
Lumber value - C$/$m^3$ (saw log volume only)	$181	$195	$207	$216	$213	$222	$229
Saw log price (C$/$m^3$)	$91	$98	$104	$108	$107	$112	$115
Pulpwood price (C$/$m^3$)	$30	$30	$30	$30	$30	$30	$30
Saw log value - C$/ha	$21,937	$27,471	$32,423	$33,457	$28,072	$26,663	$26,197
Pulpwood value - C$/ha	$3,293	$2,628	$2,076	$1,891	$1,578	$1,427	$1,349
Total value - C$/ha	**$25,230**	**$30,099**	**$34,499**	**$35,348**	**$29,650**	**$28,090**	**$27,546**

Knotty core of 14 cm (5.5 in.)							
Lumber value - C$/$m^3$ (saw log volume only)	$154	$167	$177	$189	$185	$196	$206
Saw log price (C$/$m^3$)	$77	$84	$89	$95	$93	$99	$103
Pulpwood price (C$/$m^3$)	$30	$30	$30	$30	$30	$30	$30
Saw log value - C$/ha	$18,686	$23,448	$27,794	$29,242	$24,350	$23,533	$23,513
Pulpwood value - C$/ha	$3,293	$2,628	$2,076	$1,891	$1,578	$1,427	$1,349
Total value - C$/ha	**$21,979**	**$26,076**	**$29,870**	**$31,133**	**$25,928**	**$24,960**	**$24,862**

100% Knotty core No pruning							
Lumber value - C$/$m^3$ (saw log volume only)	$118	$122	$125	$129	$128	$131	$134
Saw log price (C$/$m^3$)	$59	$61	$63	$65	$64	$66	$67
Pulpwood price (C$/$m^3$)	$30	$30	$30	$30	$30	$30	$30
Saw log value - C$/ha	$14,322	$17,179	$19,616	$19,983	$16,857	$15,711	$15,325
Pulpwood value - C$/ha	$3,293	$2,628	$2,076	$1,891	$1,578	$1,427	$1,349
Total value - C$/ha	**$17,615**	**$19,807**	**$21,692**	**$21,874**	**$18,435**	**$17,138**	**$16,674**

<u>Appendix I</u> – Discounting table

The tables below can be used in financial analysis to discount values to a present value PV), for instance:

- At a 2% discount rate, one dollar at 10 years is worth today (present) $0.82.
- At a 10% discount rate, one dollar at 10 years is worth today (present) $0.38.

- At a 2% discount rate, one dollar at 30 years is worth today (present) $0.55.
- At a 10% discount rate, one dollar at 30 years is worth today (present) $0.06.

This table uses rounded off values and can cause insignificant rounding errors.

Discounting Table

	Years										
	0	1	2	3	4	5	6	7	8	9	10
2%	1.000	0.980	0.961	0.942	0.924	0.906	0.888	0.871	0.853	0.837	0.820
4%	1.000	0.962	0.925	0.889	0.855	0.822	0.790	0.760	0.731	0.703	0.676
6%	1.000	0.943	0.890	0.840	0.792	0.747	0.705	0.665	0.627	0.592	0.558
8%	1.000	0.926	0.857	0.794	0.735	0.681	0.630	0.583	0.540	0.500	0.463
10%	1.000	0.909	0.826	0.751	0.683	0.621	0.564	0.513	0.467	0.424	0.386

	11	12	13	14	15	16	17	18	19	20
2%	0.804	0.788	0.773	0.758	0.743	0.728	0.714	0.700	0.686	0.673
4%	0.650	0.625	0.601	0.577	0.555	0.534	0.513	0.494	0.475	0.456
6%	0.527	0.497	0.469	0.442	0.417	0.394	0.371	0.350	0.331	0.312
8%	0.429	0.397	0.368	0.340	0.315	0.292	0.270	0.250	0.232	0.215
10%	0.350	0.319	0.290	0.263	0.239	0.218	0.198	0.180	0.164	0.149

	21	22	23	24	25	26	27	28	29	30
2%	0.660	0.647	0.634	0.622	0.610	0.598	0.586	0.574	0.563	0.552
4%	0.439	0.422	0.406	0.390	0.375	0.361	0.347	0.333	0.321	0.308
6%	0.294	0.278	0.262	0.247	0.233	0.220	0.207	0.196	0.185	0.174
8%	0.199	0.184	0.170	0.158	0.146	0.135	0.125	0.116	0.107	0.099
10%	0.135	0.123	0.112	0.102	0.092	0.084	0.076	0.069	0.063	0.057

Appendix J – Real Discount Rate - Page 1 of 2

- Background

To arrive at a net discounted cash flow or net present value (NPV), future costs and revenues must be discounted to the present; in the discounted cash flow analysis this is "year 0". For the discounting we use an interest rate, also referred to as the discount rate. The discount rate consists of the following components[I]:

1. Pure rate,
   The risk free cost of using money over time. This is the return investors or savers expect to receive in a risk- and inflation free environment.
2. Expected inflation rate,
   This is the year-over-year increase in the consumer price index (CPI), as published by Statistics Canada.
3. Risk rate,
   Future uncertainty and risk demand a premium on the pure rate. Canada savings bonds carry a low risk and would therefore have a low premium on the pure rate, whereas junk bonds would carry a high risk rate, demanding a high premium on the pure rate.

When we exclude the inflation component from the discount rate, we refer to it as the real discount rate (RDR). The RDR is used to characterize investments in current (or constant) dollars. The inflation rate can be safely ignored in the calculation of the NPV (or net discounted cash flow) because the inflation factor occurs both in the numerator and the denominator of the present value calculation formulas, thereby effectively cancelling each other out. To illustrate this:

» Present value V_0

$$V_0 = \frac{V_n}{(1+r)^n}$$

where V_n is the future return in <u>today's</u> market prices, or in <u>deflated</u> dollars, n is the time period to be discounted to the present and r is the real discount rate or RDR.

» When future return V^{infl}_n is measured in future <u>inflated</u> dollars, the value of the inflated return is:

$V^{infl}_n = V_n \times (1+infl)^n$, where "infl" is the inflation rate.

[I] From Lawrence S. Davis and K. Norman Johnson - Forest Management – 3rd edition (1986), McGraw-Hill Book Company.

Appendix J – Real Discount Rate - Page 2 of 2

Present value V_0 can therefore be rewritten as:

$$V_0 = \frac{V^{infl}_n}{(1+r)^n \times (1+infl)^n} = \frac{V_n \times (1+infl)^n}{(1+r)^n \times (1+infl)^n} = \frac{V_n}{(1+r)^n}$$

The inflation factor "infl" occurs both in the numerator and the denominator of the present value calculation formulas and thereby cancelling each other out.

"The important implication is that future revenues (referred to this as price) *and costs can be estimated by their current values and do not need to be inflated in an analysis, as long as the discount rate does not include the inflation factor"* [I]

[I] From Lawrence S. Davis and K. Norman Johnson - Forest Management – 3rd edition (1986), McGraw-Hill Book Company.

<u>Appendix K</u> – Incremental Net Present Values per hectare – Page 1 of 2

The **Base Case** of 1077 spha, unpruned. Key values can be found in Appendix H

DCF Analysis

Pruning 10 cm knotty core
Pruning 14 cm knotty core

Just regular number of weed controls
Additional weed control @ lower densities

spha	**1077**	m³/ha	**351**	Pruning		tr/md (275 or blank)		
		1 md:	$250	Knotty core				

	$/unit	PV	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13
Planting stock costs	$0.43			$463												
Planting	$0.22			$237												
Shaping or singling	$0.25				$269											
Weeding cost																
Two-way	$70.00			$70	$140											
Shielded	$60.00			$60	$60	$60										
Pruning cost/tr to 3m; 275-300 tr/md	$0.91															
Pruning cost/tr to 6.7m; 275-300 tr/md	$0.91															
Harvest & transport - $/m³	$18.00															$6,318
Present Value (PV) of incremental cost - $/ha	**2%**	**$6,185**	$0	$830	$469	$60	$979	$979	$0	$0	$0	$0	$0	$0	$0	$6,318
	4%	**$5,073**														
	6%	**$4,218**														
	8%	**$3,561**														
	10%	**$3,022**														
Present Value (PV) of incremental revenue - $/ha	**2%**	**$13,564**	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	**$17,615**
	4%	**$10,569**														
	6%	**$8,279**														
	8%	**$6,518**														
	10%	**$5,108**														

	Present Value (PV) of incremental revenue - $/ha	**Present Value (PV) of incremental cost - $/ha**	**Net present value (NPV) - $/ha – Base Case**
2%	$13,564	$6,185	**$7,378**
4%	$10,569	$5,073	**$5,496**
6%	$8,279	$4,218	**$4,061**
8%	$6,518	$3,561	**$2,957**
10%	$5,108	$3,022	**$2,086**

These present values are for the Base Case unpruned (100% knotty core) of a crop planted at 1077 spha {Present Value (PV) of incremental revenue **minus** Present Value (PV) of incremental cost}. See Page 2 of 2.

Appendix K – Incremental Net Present Values per hectare – Page 2 of 2

The Base Case of 1077 spha, unpruned vs. 1077 spha, pruned to a 14 cm knotty core. Key values can be found in Appendix H

DCF Analysis

Legend	
Pruning 10 cm knotty core	Just regular number of weed controls
Pruning 14 cm knotty core	Additional weed control @ lower densities

spha	**1077**	m³/ha	**351**	Pruning	275 tr/md (275 or blank)
		1 md:	$250	Knotty core	14

	$/unit	PV	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13
Planting stock costs	$0.43			$463												
Planting	$0.22			$237												
Shaping or singling	$0.25				$269											
Weeding cost																
Two-way	$70.00			$70	$140											
Shielded	$60.00			$60	$60	$60										
Pruning cost/tr to 3m; 275-300 tr/md	$0.91						$979									
Pruning cost/tr to 6.7m; 275-300 tr/md	$0.91							$979								
Harvest & transport - $/m³	$18.00															$6,318
Present Value (PV) of incremental cost - $/ha	**2%**	**$7,977**	$0	$830	$469	$60	$979	$979	$0	$0	$0	$0	$0	$0	$0	$6,318
	4%	**$6,708**														
	6%	**$5,726**														
	8%	**$4,951**														
	10%	**$4,295**														
Present Value (PV) of incremental revenue - $/ha	**2%**	**$16,924**	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	**$21,979**
	4%	**$13,187**														
	6%	**$10,330**														
	8%	**$8,132**														
	10%	**$6,374**														

	Net present value (NPV) - $/ha – **Base Case (page 1 of 2)**	Net present value (NPV) - $/ha – **1077 spha, pruned to a 14 cm knotty core**	**Increase/Decrease over Base Case – NPV $/ha**
2%	$7,378	$8,947	**$1,569**
4%	$5,496	$6,480	**$983**
6%	$4,061	$4,605	**$543**
8%	$2,957	$3,181	**$224**
10%	$2,086	$2,079	**$7**

The table on the left compares the NPV of the 'Base Case' from page 1 of 2 to the 1077 spha, pruned to a 14 cm knotty core.

<u>Appendix L</u> – Sensitivity analysis: saw log price (**A**) & Pruning productivity (**B**)

A — 50% of saw log value - Increase or decrease over Base Case
Net Present Value ($/ha) of Incremental Management Activities over base case

Discount Rate	1077 spha	897 spha	770 spha	657 spha	567 spha	494 spha	434 spha
	Base Case Unpruned	Unpruned	Unpruned	Unpruned	Unpruned	Unpruned	Unpruned
2%	$0	$394	$644	$865	$116	$29	$54
4%	$0	$338	$524	$716	$122	$66	$97
6%	$0	$294	$434	$602	$128	$97	$130
8%	$0	$261	$366	$518	$137	$124	$161
10%	$0	$233	$311	$447	$144	$145	$183
	14 cm core	14 cm core	14 cm core	14 cm core	14 cm core	14 cm core	14 cm core
2%	$232	$1,294	$2,484	$3,306	$2,033	$2,192	$2,457
4%	$420	$840	$1,787	$2,472	$1,490	$1,643	$1,873
6%	$556	$499	$1,260	$1,839	$1,080	$1,227	$1,430
8%	$641	$253	$872	$1,368	$780	$921	$1,102
10%	$686	$74	$576	$1,002	$551	$686	$847
	10 cm core	10 cm core	10 cm core	10 cm core	10 cm core	10 cm core	10 cm core
2%	$979	$2,805	$4,229	$4,896	$3,438	$3,374	$3,470
4%	$478	$1,980	$3,114	$3,683	$2,561	$2,542	$2,644
6%	$113	$1,363	$2,276	$2,768	$1,901	$1,916	$2,020
8%	$153	$901	$1,644	$2,075	$1,406	$1,446	$1,551
10%	$346	$546	$1,151	$1,530	$1,019	$1,077	$1,182

B — 54% of pruning productivity (& full price) - Increase or decrease over Base Case
Net Present Value ($/ha) of Incremental Management Activities over base case

	Base Case Unpruned	Unpruned	Unpruned	Unpruned	Unpruned	Unpruned	Unpruned
2%	$0	$1,610	$2,806	$3,170	$1,207	$675	$550
4%	$0	$1,285	$2,209	$2,512	$973	$570	$483
6%	$0	$1,036	$1,753	$2,009	$794	$491	$433
8%	$0	$845	$1,405	$1,625	$662	$435	$399
10%	$0	$691	$1,125	$1,315	$555	$389	$370
	14 cm core	14 cm core	14 cm core	14 cm core	14 cm core	14 cm core	14 cm core
2%	$75	$3,701	$6,754	$8,295	$5,248	$5,191	$5,531
4%	$379	$2,550	$4,972	$6,238	$3,890	$3,888	$4,188
6%	$713	$1,681	$3,621	$4,675	$2,861	$2,899	$3,167
8%	$934	$1,042	$2,609	$3,496	$2,092	$2,160	$2,401
10%	$1,068	$565	$1,829	$2,577	$1,499	$1,587	$1,804
	10 cm core	10 cm core	10 cm core	10 cm core	10 cm core	10 cm core	10 cm core
2%	$2,525	$6,754	$10,280	$11,508	$8,085	$7,576	$7,576
4%	$1,446	$4,859	$7,660	$8,691	$6,057	$5,708	$5,748
6%	$653	$3,437	$5,681	$6,557	$4,525	$4,296	$4,364
8%	$71	$2,366	$4,180	$4,935	$3,365	$3,227	$3,315
10%	$359	$1,538	$3,004	$3,657	$2,456	$2,387	$2,488

<u>Appendix M</u> – Prairie region – Incremental Net Present Values per hectare – Page 1 of 2

The **Base Case** of 1077 spha, unpruned. Key $ values can be found in Appendix H

DCF Analysis

Pruning 10 cm knotty core
Pruning 14 cm knotty core

Just regular number of weed controls
Additional weed control @ lower densities

spha	**1077**	m^3/ha	**351**	Pruning	tr/md (275 or blank)
		1 md:	$250	Knotty core	

	$/unit	PV	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	→	→	Year 25
Planting stock costs	$0.43			$463												
Planting	$0.22			$237												
Shaping or singling	$0.25				$269											
Weeding cost																
Two-way	$70.00			$70	$140											
Shielded	$60.00			$60	$60	$60										
Pruning cost/tr to 3m; 275-300 tr/md	$0.91									979						
Pruning cost/tr to 6.7m; 275-300 tr/md	$0.91												979			
Harvest & transport - $/$m^3$	$18.00															$6,318
Present Value (PV) of incremental cost - $/ha	**2%**	**$5,361**	$0	$830	$469	$60	$979	$979	$0	$0	$0	$0	$0	$0	$0	$6,318
	4%	**$3,858**														
	6%	**$2,866**														
	8%	**$2,326**														
	10%	**$1,904**														
Present Value (PV) of incremental revenue - $/ha	**2%**	**$10,745**	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	**$17,615**
	4%	**$6,694**														
	6%	**$4,051**														
	8%	**$2,642**														
	10%	**$1,585**														

	Present Value (PV) of incremental revenue - $/ha	**Present Value (PV) of incremental cost - $/ha**	**Net present value (NPV) - $/ha – Base Case**
2%	$10,745	$5,361	**$5,384**
4%	$6,694	$3,858	**$2,835**
6%	$4,051	$2,866	**$1,185**
8%	$2,642	$2,326	**$317**
10%	$1,585	$1,904	**$319**

These present values are for the Base Case unpruned (100% knotty core) of a crop planted at 1077 spha {Present Value (PV) of incremental revenue **minus** Present Value (PV) of incremental cost}. See Page 2 of 2.

Appendix M – Prairie region – Incremental Net Present Values per hectare – Page 2 of 2

The Base Case of 1077 spha, unpruned vs. 1077 spha, pruned to a 14 cm knotty core. Key values can be found in Appendix H

DCF Analysis

Legend: Pruning 10 cm knotty core; Pruning 14 cm knotty core; Just regular number of weed controls; Additional weed control @ lower densities

spha	1077	
m³/ha	351	
1 md:	$250	
Pruning	275	tr/md (275 or blank)
Knotty core	14	

	$/unit	PV	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	→	→	Year 25
Planting stock costs	$0.43			$463												
Planting	$0.22			$237												
Shaping or singling	$0.25				$269											
Weeding cost																
Two-way	$70.00			$70	$140											
Shielded	$60.00			$60	$60	$60										
Pruning cost/tr to 3m; 275-300 tr/md	$0.91									$979						
Pruning cost/tr to 6.7m; 275-300 tr/md	$0.91												$979			
Harvest & transport - $/m³	$18.00															$6,318
Present Value (PV) of incremental cost - $/ha	**2%**	**$7,016**	$0	$830	$469	$60	$979	$979	$0	$979	$0	$0	$979	$0	$0	$6,318
	4%	**$5,268**														
	6%	**$4,071**														
	8%	**$3,344**														
	10%	**$2,785**														
Present Value (PV) of incremental revenue - $/ha	**2%**	**$13,407**	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	**$21,979**
	4%	**$8,352**														
	6%	**$5,055**														
	8%	**$3,297**														
	10%	**$1,978**														

	Net present value (NPV) - $/ha – Base Case (page 1 of 2)	Net present value (NPV) - $/ha – **1077 spha, pruned to a 14 cm knotty core**	**Net present value (NPV) - $/ha – Base Case**
2%	$5,384	$6,391	**$1,007**
4%	$2,835	$3,084	**$248**
6%	$1,185	$984	**$201**
8%	$317	$47	**$364**
10%	$319	$807	**$488**

The table on the left compares the NPV of the 'Base Case' from page 1 of 2 to the 1077 spha, pruned to a 14 cm knotty core.

Appendix N – Sensitivity analysis: saw log price (**A**) & Pruning productivity (**B**) Page 1

A	**50% of saw log value - Increase or decrease over Base Case – Prairie region Net Present Value ($/ha) of Incremental Management Activities over base case**						
Discount Rate	**1077 spha**	**897 spha**	**770 spha**	**657 spha**	**567 spha**	**494 spha**	**434 spha**
	Base Case Unpruned	**Unpruned**	**Unpruned**	**Unpruned**	**Unpruned**	**Unpruned**	**Unpruned**
2%	**$0**	$345	$531	$727	$114	$58	$89
4%	**$0**	$270	$371	$528	$125	$112	$150
6%	**$0**	**$221**	**$268**	**$399**	**$134**	**$150**	**$192**
8%	**$0**	**$194**	**$217**	**$333**	**$148**	**$178**	**$222**
10%	**$0**	**$171**	**$179**	**$283**	**$159**	**$200**	**$245**
	14 cm core	**14 cm core**	**14 cm core**	**14 cm core**	**14 cm core**	**14 cm core**	**14 cm core**
2%	$419	$862	$1,820	$2,517	$1,509	$1,664	$1,898
4%	$640	$277	$903	$1,412	$794	$939	$1,124
6%	$739	$68	**$339**	$720	**$354**	$489	$640
8%	$715	$188	**$96**	**$400**	**$169**	**$293**	**$421**
10%	$699	$283	$87	**$159**	**$30**	**$145**	**$255**
	10 cm core	**10 cm core**	**10 cm core**	**10 cm core**	**10 cm core**	**10 cm core**	**10 cm core**
2%	$495	$2,022	$3,170	$3,749	$2,598	$2,579	$2,682
4%	$136	$945	$1,698	$2,140	$1,438	$1,479	$1,586
6%	$515	**$269**	$762	$1,110	$701	$779	$887
8%	$649	$36	**$315**	**$606**	**$353**	**$445**	**$549**
10%	$740	$258	$13	**$233**	**$98**	**$199**	**$300**

B	**54% of pruning productivity (& full price) - Increase or decrease over Base Case – Prairie region Net Present Value ($/ha) of Incremental Management Activities over base case**						
	Base Case Unpruned	**Unpruned**	**Unpruned**	**Unpruned**	**Unpruned**	**Unpruned**	**Unpruned**
2%	**$0**	$1,308	$2,243	$2,552	$979	$570	$482
4%	**$0**	$870	$1,438	$1,665	$663	$431	$395
6%	**$0**	$584	$914	$1,087	$460	$343	$340
8%	**$0**	$430	$638	$782	$361	$304	$319
10%	**$0**	**$314**	$431	$552	**$287**	**$275**	**$303**
	14 cm core	**14 cm core**	**14 cm core**	**14 cm core**	**14 cm core**	**14 cm core**	**14 cm core**
2%	$372	$2,606	$5,063	$6,350	$3,952	$3,950	$4,254
4%	$926	$1,100	$2,698	$3,607	$2,150	$2,218	$2,465
6%	$1,204	$187	$1,216	$1,870	$1,021	$1,129	$1,333
8%	$1,212	$184	$530	$1,032	$502	$621	$795
10%	$1,223	$468	**$12**	$400	**$111**	**$238**	$389
	10 cm core	**10 cm core**	**10 cm core**	**10 cm core**	**10 cm core**	**10 cm core**	**10 cm core**
2%	$1,486	$4,955	$7,797	$8,844	$6,157	$5,801	$5,841
4%	$111	$2,464	$4,316	$5,088	$3,460	$3,316	$3,405
6%	$726	$888	$2,088	$2,675	$1,735	$1,725	$1,842
8%	$1,048	$150	$993	$1,467	$890	$943	$1,067
10%	$1,271	$390	**$185**	$572	**$266**	$364	$493

<u>Appendix N</u> – Sensitivity analysis: saw log price (**A**) & Pruning productivity (**B**) Page 2

For all scenarios at all densities, the positive values in **blue font** in the table of Appendix N Page 1, are not sufficiently high to compensate for the negative net present values of the respective 'Base Case' at the various discount rates. It indicates that these scenarios have an internal rate of return that is lower than then associated discount rates.

Literature Listing – Density

The fields highlighted in light grey are key articles for this report

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