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Influence of Pruning on Wood Characters in Hybrid Aspen

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Fast-growing hybrid aspens (*Populus tremula* L. × *P. tremuloides* Michx.) are currently of great interest in Sweden since they can produce biomass at high rates and, at the same time, can be used to produce higher value wood products. This study focuses on the effects of pruning hybrid aspen to improve its wood quality. About 50% of the trees in the experimental stand were pruned by removing twigs, at heights up to 4 m, when they were 7–8 years old. Ten years later, 20 pruned and 20 unpruned trees, representing four clones, were randomly selected. Ten knots or twig/stem junctions, respectively, per tree were exposed for inspection using a chain saw and examined. The results revealed that pruned trees cicatrised the knots within about three years and thereafter produced substantial amounts of faultless wood. In contrast, unpruned trees (which had retained almost 80% of their twigs, often as dry twigs with bark pockets) had produced small uneven amounts of quality wood. Removal of twigs with acute angles and/or large diameters resulted in greater colour defects and rot in annual rings outside the pruning position, but the time of cicatrisation was not significantly affected. The results show that pruning can be used to enhance the wood quality of hybrid aspen over a short time period, and that pruning should be performed early during the rotation period when branches are small, in order to minimize discolouration and rot in the new annual rings.

Keywords *Populus tremula* × *P. tremuloides*, cicatrisation, faultless wood, twig angle, twig diameter
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1 Introduction

Pruning is a means of improving wood quality by removing quality-reducing branches and twigs. According to Mayer-Wegelin (1952), interest in tree pruning can be traced back to the 18th century when Hans Carl von Carlowitz published articles on management of ”wild trees” (*Sylvicultura Oeconomica* 1713). The first pruning efforts in Sweden were carried out at the end of the 19th century, and were more widely initiated in the 1920's (Nylinder 1952).

Natural losses of twigs and branches occur due to competition for light between trees. However, the more sparsely the trees are growing, the longer this process takes. At the same time, trees grow more rapidly (dimensionally) if they are far apart. Hence, it may be possible to use pruning to combine high dimensional growth with high quality of stems. In addition, the stem form will be improved with pruning, since the stem grows more cylindrically (Nylinder 1952).

Pruning has mostly been applied to oak and Scots pine in Sweden (Walfridsson 1978, Ståål 1986, Josefsson 1995, Svensson 1995), principally due to the low risk of stem rot in these species. Calculations have shown that pruning of oak and pine is profitable, because more valuable tree assortments can be obtained from pruned oak and pine trees (Nylinder 1952, Walfridsson 1978, Josefsson 1995, Svensson 1995, Vadla 1999). The cost of pruning compared with the increased wood value is of course the key-determinant of its cost-effectiveness, but the latter is an uncertain factor since we do not know future wood prices. However, information on pruning of other tree species indicates that pruning is generally a positive and profitable measure. For instance, Nylinder (1952) concluded that pruning of aspen and birch had a positive economic potential, if value was added to wood by lathing, and Vadla (1999) showed high internal rates of interest for pruning of birch.

Hybrid aspen (*Populus tremula* L. × *P. tremuloides* Michx.) is a fast-growing tree (Rytter 2004, Rytter and Stener 2005) that has received much attention recently. It is regarded as a possible future producer of large amounts of biomass. However, the wood can also be used for other purposes, for example panels, which require high-quality logs. The fast growth of hybrid aspen also means that pruning may lead to fast cicatrisation (scar formation) and the production of large amounts of knot-free wood in a short time. Accordingly, it may be possible to produce high quality wood rapidly.

Pruning implies removal of both dead and living twigs (which here refers, for convenience, to both twigs and branches, although some of the material removed would normally be regarded as branches due to their thickness, and the term knot refers to twig or branch parts at their junctions within the stem). Removal of dead twigs resembles the natural process when twigs die and fall off, but the process is accelerated by cutting off dead stumps, thereby preventing them from remaining in future annual rings. Green pruning means removal of living twigs and may be regarded as an artificial operation. In the green pruning procedure, dead twigs are also removed from the stem segment being treated. Heiskanen (1958) showed that green pruning of birch in Finland resulted in larger wood defects than pruning of dead twigs. The cicatrisation, on the other hand, will proceed more rapidly after green pruning than pruning of dead twigs, if other conditions are otherwise similar (Nylinder 1952). There are also differences between tree species; birch, for example, is considered to have slower cicatrisation than aspen and alder (Nylinder 1952).

Pruning should be applied to trees that are to be left until final harvest. The most important operation is to remove twigs and branches from the butt log, which means that at least a 3 m section should be cleaned. The general recommendation found in the literature is to prune between 5 and 7 m of the stem (Nicolescu 1999, St. John 2001). Another important issue is the size of branches that can be successfully removed. The literature suggests an upper limit of 3–5 cm for the twig diameter (Nicolescu 1999), and that pruning should be done before the trees reach 15 cm in diameter at breast height. If branches are thicker, there is a clear risk of rot development and the cicatrisation will take a long time (Heiskanen 1958).

An important finding noted by Heiskanen (1958) was that no rot was recorded in the wood outside the annual ring where the pruning was executed. Similar observations have been made in other studies (Nylinder 1952, Schatz et al.

2008). However, in aspen discolouration is often found outside the pruned twig (Nylinder 1952), which is interpreted as being due to leaching of pigments from the bark that are then deposited in the wood.

The aim of this study was to evaluate the possibility of using pruning of hybrid aspen to improve the volumes of high-quality wood assortment, and thereby increase the profitability and flexibility of hybrid aspen cultivation. Our hypothesis was that the fast growth of hybrid aspen is a character that should favour the advantageous effects of pruning, i.e. cicatrisation and production of knot-free wood. In this study, the effects of twig diameter and twig angle on cicatrisation rot development and wood quality were analyzed and compared in pruned and unpruned trees representing four different clones of hybrid aspen.

2 Material and Methods

2.1 Material

The sample trees were located in an experimental plantation growing close to the southern research station of the Forestry Research Institute of Sweden in north-western Scania (lat. 55°57´; long. 13°07´; alt. 80 m a.s.l.). The stand was planted in 1990 with one-year-old plants of hybrid aspen (*Populus tremula* L. × *P. tremuloides* Michx.) at a spacing of 2.5 m × 2.5 m, i.e. 1600 stems ha^{-1}. It was thinned in the year 2000 (aged 11 years) to about 800 ha^{-1}.

The stand was divided into four parts, each planted with a different clone. Pruning was performed at the end of June 1996, up to 2.5 m height in every second tree row in the stand, then in June 1997 the same trees were further pruned leaving the bottom 4 m of their stems twig-free. An ordinary pruning saw was used for this purpose and the twigs were removed by first applying a few strokes on the lower side of the twig and then sawing from above to avoid bark splitting. Early summer was chosen for pruning, in accordance with the majority of recommendations in the literature (Nylinder 1952, Barnéoud et al. 1982, Delannoy and Poliantre 1990, Jarny 1996, DeBell et al. 2006).

Twenty pruned and 20 unpruned trees were randomly selected from amongst the trees of all four clones (Nos. 844008, 844010, 884036, 884051). Each clone was represented by 4–13 trees with about the same number of pruned and unpruned trees within clone (the unbalanced number of sampled trees among clones could be handled by the selected statistical model, see below). Average values for the height and diameter of the four clones are given in Table 1. During the winter 2006/07, at 18 years of age, the sample trees were cut in connection with a late thinning operation.

2.2 Sampling, Visualization and Measurements

The 4 m butt log was collected from all sample trees for further measurements. Ten twigs or knots were identified on each log. Five of them were situated as close as possible to 2 m height, and the other five as near as possible to 3.25 m height, in

Table 1. Arithmetic mean tree height (H_A) and diameter at breast height of the stem of mean basal area (D_G) of the clones included in the study, measured at 9 and 17 years of age, i.e. one year after completed pruning and one year before harvesting sample trees. N = number of sampled trees per clone in the pruning study.

Character	Year	Age (yr)	Clone 844008	844010	884036	884051	Overall mean
H_A, m	1997/98	9	10.7	9.1	9.6	11.3	10.2
D_G, cm	1997/98	9	11.0	9.8	10.4	11.7	10.7
H_A, m	2005/06	17	21.0	18.8	19.7	21.7	20.3
D_G, cm	2005/06	17	22.1	20.2	22.9	21.6	21.7
N, no	2006/07	18	12	4	11	13	40

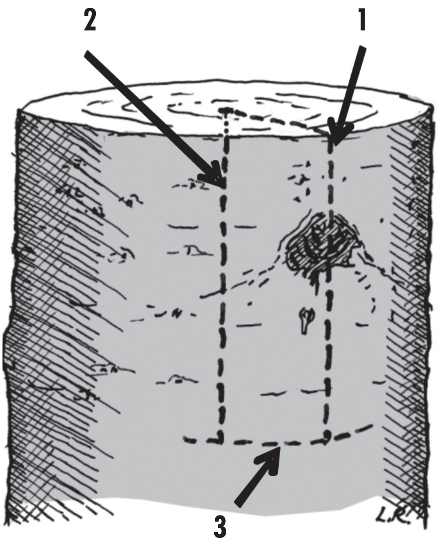

Fig. 1. Visualization of a knot. 1) A vertical cut by a chain saw was directed through the centre of the twig/knot towards the pith; 2) A second vertical cut was made a few cm away from the first and also directed towards the pith; 3) A third cut released the cake-shaped sample.

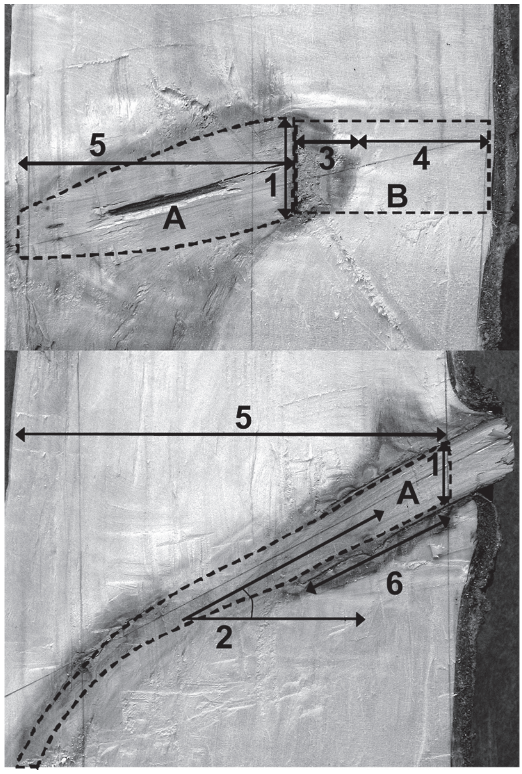

Fig. 2. Measurements from the sawn knot area: 1 = twig thickness in the vertical direction; 2 = twig angle; 3 = discoloured wood and wood with rot in the horizontal direction; 4 = faultless wood outside the knot, horizontal extent; 5 = distance from pith to twig end; 6) the longest length of ingrown bark; A = area within the twig/knot from which % areas affected by discolouration and rot were estimated; B = area between the knot end and the outside of the trunk from which the % areas affected by discolouration and rot were estimated. More explanations are given in the text.

order to examine the same number of knots (and/or corresponding twig-stem junctions) from both pruning occasions.

Each selected knot and junction was exposed for inspection using a chain saw, as follows. First, the top of the log was removed 5–10 cm above the specific knot/junction. Then, a cake-shaped part of the stem was cut out, as illustrated in Fig. 1, one side of which was cut perpendicularly through the knot/junction. The sawn area including the knot or junction was then trimmed by knife to make the surface smoother. Every sample was photographed and identified by tree number, twig number, level above ground and cardinal direction, then the following features and parameters were observed and recorded.

The condition of the knot/junction was recorded from the sawn area (Fig. 2), as dry or green. The thickness of the knot/junction in the vertical direction (1) was measured from where it ended in the wood or passed through an imaginary line along the inner limit of the bark. The twig angle (2) was assessed, on a scale from 0°, indicating horizontal orientation, to 90°, indicating vertical direction. The lengths of discoloured wood and wood with rot (3) horizontally extending from the knot/junction were estimated as well as the percentages of the areas discoloured and with rot within (A) and beyond (B) the knot/junction. Discoloured wood in aspen is called brown heartwood and only has a different colour from ordinary wood, while rot is structurally altered wood, i.e. the wood that has started breaking down. Areas with discoloured wood and rot were separated in this study. The length of faultless wood outside the knot (4) and the horizontal distance from pith to knot/junction end (5) were also recorded, as well as the length of ingrown bark (6) on the side with the most bark. The faultless wood was measured as the distance from the end of the knot/discoloured wood to the imaginary vertical bark line along the stem (Fig. 2), so the common swelling outside the knot was not included. This was motivated since the swelling cannot be used after sawing the log.

In addition, the number of annual rings needed for cicatrisation and the number of annual rings thereafter were also recorded.

2.3 Statistics

The measured variables (Fig. 2) were: twig angle; twig/knot type; twig diameter; rot and discoloured areal percentage within and outside the knot; length of ingrown bark; length of twig/knot; length of defective wood; length of faultless wood; stem radius; cicatrisation time; and time after cicatrisation. Mean value for each tree was calculated and analysed by the model:

$$y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + e_{ijk}, \tag{1}$$

where y_{ijk} = observation on tree *ijk*, μ = mean value, α_i = fix effect of treatment, β_j = fix effect of clone, and e_{ijk} = random error term for tree *ijk*. The SAS-procedure GLM was used (SAS Institute 1999) and least square means (LSMEANS) were calculated. When significant differences were found, pairwise comparisons were carried out using the Tukey-test.

The effects of twig/knot position on the stem, i.e. cardinal point was tested, but did not show any significant effect and was therefore omitted from further analysis. In a second step the effects of height above ground, twig angle and diameter on the variables above were tested where each individual measurement of the twig/knot was included in the analysis:

$$y_{ijkl} = \mu + b_1 x_{ijkl} + \alpha_i + \beta_j + b_{2i} x_{ijkl} + b_{3j} x_{ijkl} + (\alpha\beta)_{ij} + t_{ijk} + e_{ijkl} \tag{2}$$

where y_{ijkl} = value of observation *ijkl*, μ = mean value, α_i = fixed effect of treatment, β_j = fixed effect of clone, t_{ijk} = random effect of tree individual *k* in treatment *i* and clone *j*, and e_{ijkl} = random error term for twig/knot *l* on tree *ijk*. x_{ijk} is the height of the twig/knot *ijkl* on tree *ijk* and the *b*-values are regression coefficients (b_1 overall slope for the covariable i.e. height, b_{2i} = different slope for different treatments *i*, b_{3j} = different slope for different clones *j*). These analyses were performed because the individual twig was the base. The height position, thickness and angle of the twig are continuous variables which means that the test for these variables act in the same way as a linear regression. The analysis was performed with the procedure MIXED in SAS (SAS Institute 1999).

The null hypothesis of no differences between mean values was rejected when the significance (p) was ≤ 0.05.

3 Results

3.1 Effects of Twig/Knot Position and Twig Characters

The analysis of the influence of twig characters on discolouration and rot showed that increases in twig angle and twig diameter generally resulted in increased discolouration and rot outside the knot (Table 2). However, neither angle nor diameter significantly affected cicatrisation time.

The statistical analysis detected no significant effect of the cardinal point of the twigs on the measured variables (data not shown). However, the height of the twig or knot along the stem influenced several characters. As expected, the stem thickness (expressed by the radius) decreased significantly with height of the sampled stem section ($p = 0.0014$), which in turn resulted in reductions in the length of faultless wood with height ($p < 0.0001$). The twig angle and thickness also increased with height ($p < 0.0001$ for both). Since there were no significant differences in twig height/knot position among treatments and clones (Tables 3 and 4), the remaining analyses focused on comparisons between treatment and clones.

Table 2. Effects of twig angle and twig diameter on cicatrisation time, and the extents of discolouration and rot in the twig and the radial area outside the twig.

Character	Affecting property	
	Twig angle p-value	Twig diameter p-value
Discolouration in the twig	0.010	0.48
Discolouration in the radial area outside the twig	0.034	0.066
Rot in the twig	0.19	0.30
Rot in the radial area outside the twig	0.0006	0.0012
Cicatrisation time	0.83	0.53

Table 3. Mean values of characters of the pruned and unpruned hybrid aspen trees expressed by the procedure LSMEANS of SAS (SAS Institute 1999). Every tree value is based on 10 knots/junctions per tree. S.E. = standard error. More details of the measurements can be found in the text and the legend of Fig. 2.

Character	Pruned trees		Not pruned trees		p-value [a)]
	Mean	S.E.	Mean	S.E.	
Twig height (cm above stump)	245	5.8	246	7.6	0.87
Twig angle (°)	27.9	1.3	26.3	1.7	0.52
Twig diameter (mm)	19.5	1.2	21.2	1.5	0.32
Proportion of living twigs (%)	81.0	4.4	24.4	5.7	<0.0001
Discoloured wood					
In twigs (% of visible area A)	26.7	6.5	30.5	8.5	0.57
Outside twigs (% of visible area B)	22.9	2.1	9.0	2.8	0.0005
Rot					
In twigs (% of visible area A)	2.0	0.7	2.8	0.9	0.91
Outside twigs (% of visible area B)	13.3	1.5	4.1	1.9	0.0006
Ingrown bark (mm along the twig)	7.7	2.7	22.9	3.5	<0.0001
Stem radius (mm) [b)]	90.7	2.3	97.7	3.0	0.0121
Pith to twig end (mm)	49.6	1.8	94.4	2.4	<0.0001
Twig end to faultless wood (mm)	8.9	0.4	1.4	0.5	<0.0001
Faultless wood to bark (mm)	32.5	1.7	3.4	2.2	<0.0001
Cicatrisation time (years)	3.0	0.2	5.6	0.3	<0.0001
Time after cicatrisation (years)	7.1	0.2	0.8	0.2	<0.0001

a) p-value for the difference between treatments
b) The stem radius differs somewhat from the sum of the parts from the pith to the bark because a few values for the distance between pith and twig end are lacking.

3.2 Effects of Treatment and Clone

The results from the analyses of the effects of treatment and clones are presented in Tables 3 and 4. No interaction effects between treatment and clones were found for any of the variables ($p = 0.08$–0.95), except for the time (years) after cicatrisation ($p = 0.010$).

A comparison of pruned and unpruned trees revealed no differences between them in twig angle, twig thickness, or the relative areas of discolouration and rot in twigs and knots (Table 3). However, the proportion of twigs that were green when removed (by pruning or naturally) were lower, and the ingrown bark was substantially longer, in trees that had not been pruned (Table 3, Fig. 3). Since the distance from pith to twig or knot end was longer when no pruning was carried out, the distance between knot end and bark was accordingly shorter, as was the length of faultless wood.

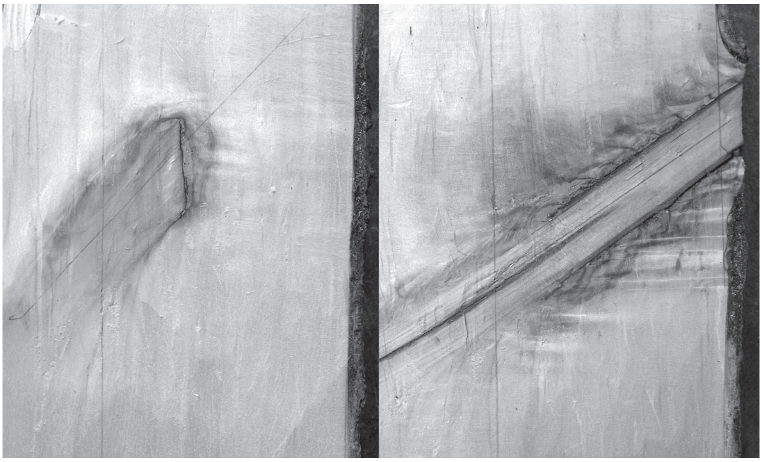

Fig. 3. Example of a pruned twig (to the left) and twig left untouched (to the right). Faultless wood can be formed rapidly after pruning and in-growth of bark, which is often connected to dry twigs, can be avoided.

Table 4. Mean values as LSMEANS of characters of the representatives of the four hybrid aspen clones. The analysis is based on 40 average tree values where every tree value in turn is based on 10 knots/junctions per tree. Different lowercase letters mean significant differences between the clones for a specific character. S.E. = standard error. More details of the measurements are found in the text and in the legend of Fig. 2.

Character	Clone								p-value[a]
	844008		844010		884036		884051		
	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	
Twig height (cm above stump)	231	7.2	248	14.4	254	7.5	248	6.9	0.18
Twig angle (°)	32.0bc	1.6	22.8ab	3.3	37.2c	1.7	16.4a	1.6	<0.0001
Twig diameter (mm)	20.7b	1.5	24.2ab	2.9	23.1b	1.5	13.3a	1.4	<0.0001
Proportion of living twigs (%)	57.5	5.4	56.7	10.9	43.7	5.7	53.0	5.2	0.29
Discoloured wood									
In twigs (% of visible area A)	29.6	8.1	27.2	16.1	34.6	8.5	23.0	7.8	0.77
Outside twigs (% of visible area B)	15.9	2.6	15.2	5.3	14.8	2.8	17.8	2.5	0.76
Rot									
In twigs (% of visible area A)	1.9	0.9	4.2	1.8	0.8	0.9	2.7	0.9	0.91
Outside twigs (% of visible area B)	9.5	1.8	8.7	3.6	8.5	1.9	7.9	1.7	0.83
Ingrown bark (mm along the twig)	11.6a	3.3	4.9a	6.6	33.1b	3.5	11.5a	3.2	<0.0001
Stem radius (mm)[b]	94.1ab	2.8	83.0a	5.7	101.7b	3.0	98.1ab	2.7	0.015
Pith to twig end (mm)	72.8	2.3	65.9	4.5	74.8	2.4	74.5	2.2	0.33
Twig end to faultless wood (mm)	5.2	0.5	4.8	1.0	5.4	0.5	5.2	0.5	0.87
Faultless wood to bark (mm)	16.3	2.1	14.4	4.2	22.4	2.2	18.7	2.0	0.088
Cicatrisation time (years)	4.4	0.3	4.4	0.4	3.9	0.3	4.4	0.2	0.75
Time after cicatrisation (years)	3.8	0.2	4.0	0.4	3.8	0.2	4.2	0.2	0.61

[a] p-value for the difference between clones
[b] The stem radius differs somewhat from the sum of the parts from the pith to the bark because a few values for the distance between pith and twig end are lacking.

This was not affected by the somewhat larger stem diameter of the trees that had not been pruned. In unpruned trees, green twigs or dead twig stumps were still almost 80% of the analysed twigs/knots. The cicatrisation time of pruned trees was estimated to be around 3 years on average, thus there were about seven annual rings outside the knots. In the trees that had not been pruned few knots were cicatrised, and the cicatrisation time of those that had cicatrised was 5–6 years on average, hence there were only a few rings outside them.

The results from the analyses of differences between clones (Table 4) indicate that some characters are genetically based. Twig angle and twig diameter differed significantly between clones, as did the length of ingrown bark. Apart for these variables, only stem diameter differed somewhat among clones.

4 Discussion

The study showed, as hypothesized, that pruning hybrid aspen can promote the production of significantly amounts of wood without rot or discolouration in a short time. At the age of 18 years, knots were cicatrised and, on average, at least 3 cm of faultless wood had been produced (Table 3, Fig. 3). The cicatrisation was completed within about three years, considerably faster than in some other tree species (see, for example, Heiskanen 1958). The time of cicatrisation was also little affected by the knot thickness, in contrast to previous findings (Heiskanen 1958). However, the cicatrisation of thick knots resulted in more rot in the area outside them than that of thinner knots (Table 2). This response was also reported by Heiskanen (1958), but in the cited study no rot spread into the newly formed wood after pruning. In our study, discolouration and rot were found in this zone, but the areas were small compared with the faultless area formed afterwards. On average, it was 9 mm, compared with the faultless wood length of 33 mm (Table 3). Later studies (Schatz et al. 2008) have shown that some rot may also form outside the knots in birch, although only small amounts compared with those in the annual rings found before the pruning occasion. In conclusion, some discolouration will be found in the newly formed wood, and its proportion increases with increases in knot thickness and acuteness of the twig angle. However, this defective area is restricted and does not hamper the production of faultless wood a few annual rings further out. Since pruning small twigs results in small zones of discoloured wood, pruning ought to be carried out early during the rotation, when twigs are small.

Another positive effect of pruning is that it can largely avoid formation of bark pockets; i.e. ingrowth of bark created by the formation of new annual rings outside twigs, and their bark, that die but do not break off (Fig. 3). Ingrown bark is a quality-reducing character, which lowers the value of the log that is ultimately produced. Ingrown bark can be reduced by removing dry twigs immediately after their death, which requires an annual management effort, or by pruning green twigs twice during a rotation period. Significant differences in amounts of ingrown bark between pruned and unpruned trees were detected in this study (Table 3). The length of ingrown bark averaged 8 mm for pruned trees and more than 26 mm for unpruned trees. Further, the ingrown bark in the pruned trees was mainly associated with the twigs that were dry at the time of pruning. Ingrown bark seldom develops in association with green twigs, and if it does develop it is only around part of the twigs' circumference.

Some other important wood properties seem to be little affected by pruning. DeBell et al. (2002) found no significant effects of pruning on wood density or fibre length in poplar.

Pruned trees cicatrized knots faster than unpruned trees (Table 3). An important reason for this is that naturally broken twigs are seldom broken evenly, and the breaks are extended in the radial direction, which prolongs the cicatrisation time. When twigs are pruned, all twigs on the stem section are removed simultaneously and cicatrisation with the following production of knot-free wood start at the same time. Under natural trimming, twigs fall at different times and break at varying places. Hence, it is difficult to predict if and when production of knot-free wood will begin. Pruned stands should therefore be registered, because they will deliver logs with higher and more even quality in the future, which should result in higher profits.

The analysis of differences between characters among the clones was not favoured by blocked clone planting, so the clones lacked regular replication. It should be noted that the effects of clone and differences in soil conditions cannot be separated, but the soil was visually even. Analysis showed that twig angle and twig diameter varied between clones. Clone 884051 had thinner twigs with less acute angles than the others. Twig angle is a character normally registered in genetic tests, where it exhibits a significant genetic component (Stener and Karlsson 2004, Stener and Jansson 2005). Accordingly, it is also included among the criteria used when selecting planting material. Clone 833010 showed a smaller stem radius and less ingrown bark than the other clones, but since it was only represented by four individuals compared with 11–13 for the other clones, these results must be considered with care.

In forthcoming hybrid aspen generations, established from dense root suckering (Rytter 2004, 2006), the possibilities to prune will be even more advantageous than presented here. Future stem populations selected for pruning will have some competition from neighbouring trees, which is not the initial situation for the first planted generation. This means they will have fewer and thinner twigs with less risk for discolouration and rot, compared with the first generation.

In conclusion, this experiment showed that pruning hybrid aspen is followed by fast cicatrisation and growth of faultless wood, with possibilities for the production of high quality logs. Acute twig angles and thick twigs result in increased discolouration and rot formation in the wood outside the knot. Pruning of green twigs results in less ingrown bark than removal of dry twigs. Artificial pruning also gives even wound surfaces that cicatrize rapidly. Twig characters are genetically based, so a proper selection of clones with thin and horizontally oriented twigs is recommended when aiming to produce high-quality wood.

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