Wood Density and Growth Rate of European and Hybrid Aspen in Southern Finland

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Abstract
Aspen species are mainly used for paper production in Finland. In order to increase the cutting potential, hybrid aspen has lately been planted in southern Finland. In this study we compared the rotation-time-long growth rate and within-stem density distribution of mature European and hybrid aspen. The material consisted of 30 naturally born European aspen trees and 45 planted hybrid aspen trees from southern Finland. From those trees, altogether 225 discs were measured for the ring-width data and 5109 specimens for the basic density data. The results showed that after an initiation phase of 5–10 years, European aspen grows relatively steadily ca. 5–8 mm/a in diameter, until the tree age exceeds ca. 50 years. Thereafter the diameter growth decreases. Hybrid aspen attains the average diameter growth of 10–14 mm/a, at the age of 10–20 years. At the age of 25, the diameter growth has already decreased down to the level of 5–6 mm/a. The within-stem density distribution was more uniform in hybrid aspen. The average basic densities of European and hybrid aspen wood material were 376 and 363 kg/m³, respectively.

Key words: basic density, European aspen, growth rate, hybrid aspen, Populus tremula, Populus tremula x tremuloides

Introduction
European aspen (Populus tremula L.) is the fifth common tree species in Finland after Scot pine (Pinus sylvestris L.), Norway spruce (Picea abies Karst.), European white birch (Betula pubescens Ehrh.) and silver birch (Betula pendula Roth.). In the entire country, aspen species are dominant on an area representing 0.3% of the total forest area, whereas in southern Finland the respective proportion is 0.5%. Aspen species make up ca. 1.5% (30 Mill. m³) of the total volume of Finland’s growing stock of 2000 Mill. m³ (Peltola 2004). There are ca. 54,000 hectares of aspen-dominated forests in southern Finland. Volumetrically, however, most of the aspen growers in stands dominated by conifers or birch. Lots of aspen growers also in fragmented small stands along the agricultural lands and roads, for instance. Therefore, harvesting is difficult and expensive compared to harvesting stands with a larger uniform area.

Tree breeding trials of European aspen and North American aspen (P. tremuloides Michx.) during the 1950’s led up to finding an exceptionally fast growing tree for boreal conditions, i.e., hybrid aspen (P. tremula x tremuloides). It can yield as much as 20 m³/ha/a in southern-Finnish fertile soils. In former agricultural lands in southern Sweden, even 30 m³/ha/a average yields have been recorded (Karacic et al. 2003). It is basically the only species that can be grown in a manner of agroforestry in boreal conditions.

The faster growth of P. tremula x tremuloides in comparison to P. tremula is at least partially due to the differences in their phenology. P. tremula x tremuloides grows its leaves earlier in spring, and continues its growth later in autumn (Yu et al. 2001). On the other hand, this makes it more susceptible to frost damages. Also two peaks of fast growth have been noticed during one growing season for hybrid aspen: one in the middle of July and another in the middle of August. P. tremula grows most rapidly in the middle of June (Yu et al. 2001). Still, no studies have been made to compare the Populus species life-long growth rhythms.

Most of the annual aspen wood consumption, i.e., ca. 1.2 Mill. m³, goes for production of high-quality papers in Finland. In fact, the domestic cuttings do not nearly fulfill the industries needs; the majority of aspen pulpwood must, thus, be imported. Finnish wood product industries use some 3000–5000 m³ of
aspen logs annually. The statistics are not exact since most of the sawing and veneering is done according to customer orders, and therefore the annual variations are extensive.

In timber purchase, the most severe problem has been that the aspen supply is so fragmented and the harvesting removals per hectare are, subsequently, small. Only seldom pure aspen stands are harvested, mostly timber is obtained in small amounts as a secondary assortment of harvesting spruce or birch dominated stands (see: Heräjärvi and Junkkonen 2004). There is a countrywide buyer for aspen pulpwood, but only adventurous buyers for aspen logs. Thus, the small amounts of sawable or veneerable logs often end up to the paper mills.

Due to a company-driven campaign started at the end of the 1990’s, ca. 1000 hectares of *P. tremula* x *tremuloides* has been planted in Finland (Holm 2004). Their principal aim is to fulfill the needs of paper industries, but it can be supposed that after two decades also some timber will be available for the wood product industries.

The wood technological properties of *Populus* species have been studied in some Finnish (e.g., Jalava 1945, Tikka 1955, Kärkkäinen and Salmi 1978, Kärki 2001, Pérez 2002) and North American (e.g., Yanchuk et al. 1983, Beaudoin et al. 1992, Matyas and Peszlen 1997, DeBell et al. 1998, Hernández et al. 1998, Koubaa et al. 1998, Semen et al. 2001, DeBell et al. 2002, Peters et al. 2002) studies. In addition to the external quality factors, such as size, stem form and branchiness, wood density can be considered as the most important single property describing the usefulness of timber. According to Kärkkäinen and Salmi (1978), the basic density (dry mass per green volume) of *P. tremula* wood material in saw logs varies from 390 kg/m³ (upper logs) to 410 kg/m³ (butt logs). Yanchuk et al. (1983) found that in Canadian *P. tremuloides* wood density decreases from the pith towards the surface until the borderline of heartwood and sapwood, and then increases again towards the surface of the stem. The wood density of *P. tremula* and *P. tremula* x *tremuloides* hasn’t been studied using comparable Finnish materials.

The objective of this study was to determine the differences between the rotation-time-long growth rhythms of *P. tremula* and *P. tremula* x *tremuloides* grown in southern Finland (ca. 61–63° N.L.) by the annual ring width analysis. In addition, the basic density of wood material was compared between the species and within individual stems in order to facilitate end use oriented planning of industrial woodworking processes for aspen logs.

### Materials and Methods

The material comprised of 12 stands located in southern and central Finland. Criteria were set for the area and soil fertility of the stand, as well as for the size and quality of the trees. Five of the stands were *P. tremula* stands; two of them mixed stands of aspen and conifers. One of the *P. tremula* stands was planted and four of them were of natural origin. The rest of the stands, 7 of them, were cultivated single-species *P. tremula* x *tremuloides* stands. One of those represented “second generation”, i.e., it was regenerated by root suckers. All the stands were located on medium-fertile to fertile mineral soils, either on forestland or on former agricultural land. The average age of the *P. tremula* stands was 44 years and that of *P. tremula* x *tremuloides* stands was 32 years.

Altogether 6 to 7 circular sample plots with an area of one hundred square metres were measured from each stand to determine the average growing conditions and tree characteristics (Table 1). The tree in the centre of each sample plot was selected as a sample tree. After measuring certain characteristics of that stem and drawing a line showing towards north on the stem, the stem was felled, and cut into two-metre-long logs until the diameter of ca. 5 cm. A sample disc of ca. 5 cm was sawn from cutting heights of 0, 2, 4, 8, 12, 16 and 24 metres for the annual ring width and wood density analyses. A sign positioning

<table>
<thead>
<tr>
<th>Stand (basal area, m²/ha)</th>
<th>Age year</th>
<th>Dbh mm</th>
<th>Length m</th>
<th>Lowest dead branch, m</th>
<th>Lowest living branch, m</th>
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<td>1³ (32)</td>
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<td>3 (23)</td>
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<td>4⁵ (25)</td>
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<td>5³ (31)</td>
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<td>1.4</td>
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<td><em>P. tremula</em> x <em>tremuloides</em></td>
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<td>Naturally-born stands</td>
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<td>Entire material</td>
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<td>272</td>
<td>26.2</td>
<td>1.8⁸</td>
<td>12.4</td>
</tr>
</tbody>
</table>

1) Mixed stand of conifers, birch and aspen.
2) Cultivated *P. tremula* stands.
3) Pruned up to a height of 4 metres in 1986.
4) 2nd generation stand, regenerated by the root suckers.
5) Calculated without the pruned stand nr. 8.
north was drawn in every disc. The discs were delivered to freezer within 24 hours after felling the tree.

Discs were further processed in laboratory conditions. A 5-cm-wide diagonal was sawn from every disc in south-north direction. For the heights 0 m, 2 m, as well as the uppermost disc in each tree, the diagonals were further split into two pieces, one intended to density measurements and the other intended to annual ring measurements (Fig. 1). The annual ring widths were measured separately for south and north sides of the diagonals, using a microscope. The basic density specimens were manufactured by splitting the diagonals from the pith towards the surface for ca. 20-mm-wide samples so that the innermost sample included the pith (Fig. 1). The densities in single annual rings were, thus, not measured. The specimens from the north and south side of the diagonal were numbered increasingly from zero upwards towards the cambium. Then, the ca. 20 x 20 x 30 mm specimens were sunk into water for at least two days, after which their moisture content was supposed to be above the fibre saturation point, i.e., they were fully swollen.

Figure 1. Manufacturing principle for specimens for annual ring width measurements (1) and basic density measurements (2). N shows to the north

The intention was to study the basic density variations from the point of view of woodworking processes. Therefore, the density specimens were measured and analysed as a function of location parameters only, no attention was paid on the growth rate or the ring number in this analysis. The results show how the wood density changes from the butt to the top of the tree and from the pith to the surface of the tree. This information can be utilised, for instance, in planning the sawing patterns for aspen logs.

Volume of each specimen was measured using the hydrostatic method (e.g., Kärkkäinen 2003), after which they were dried at 103° C as long as their mass did not change anymore. Then the specimens were weighed, and basic density was calculated on the basis of dry mass and green volume. Altogether 5097 basic density specimens were measured. The statistical differences in wood densities between the two aspen species were analysed using Mann-Whitney U-test.

Results

The average height growth of *P. tremula* trees was ca. 0.7 metres per year, whereas that of *P. tremula x tremuloides* trees was ca. 1.0 metres per year for the first twenty years. Calculated for the entire life span, the annual height growth of *P. tremula x tremuloides* was 0.81 m/a and that of *P. tremula* was 0.56 m/a. Height growth was especially fast for the “second generation” *P. tremula x tremuloides* trees, ca. 1.5 metres per year. It appears, thus, that the root suckers can utilise effectively the existing root system. *P. tremula* trees grown in mixed stands of aspen and conifers represented the slowest height growth.

The growth rhythms of the aspen species differed distinctively from each other. *P. tremula* appears to grow rather steadily, 2–4 mm per year until mature phase at the age of 55 to 60 years. *P. tremula x tremuloides*, on the other hand, grows more rapidly for a period of ca. 15 years, after which its growth decreases considerably (Fig. 2). The diameter growth of *P. tremula x tremuloides* was, at its highest, two times faster than that of *P. tremula*.

The average basic density of *P. tremula* wood was 376 kg/m³, and that of *P. tremula x tremuloides* wood was 362 kg/m³. According to the Mann-Whitney U-test, the difference was significant (*p* < 0.001). Thus, the average basic density of *P. tremula x tremuloides* wood was ca. 15 kg/m³ lower than that of *P. tremula* wood. Densities measured from the south and north sides of the stems did not differ significantly (Mann-Whitney U-test: *p* = 0.480). Furthermore, densities of slightly discoloured and defect free wood on av-
Wood density varied considerably between different stands and also, between different stems in one stand. The fastest grown trees had the lowest average wood density.

**Discussion and Conclusions**

The material of this study represented southern and central Finnish aspen stands. According to the author’s experience, the material’s validity and the extent of generalization are relatively good for this kind of study, under the restriction of geographic area and site types.

There are no previous studies available concerning the rotation-time-long growth rhythms of aspens in Finland. It is evident that *P. tremula x tremuloides* can very efficiently utilise the resources available for a certain time, after which some physiological factors reduce the growth. It is unlikely that the reduction of growth would be caused by increased competition, since the same phenomenon was also observed in stands that had grown in relatively wide spacing. The fast growth of *P. tremula x tremuloides* does not last more than ca. twenty years. During this period, the trees attain their final cutting size, whereas *P. tremula* requires 40–50 years of growth to reach the same dimensions. Therefore, the timings of different silvicultural management practices, such as cleaning of young stands, thinnings and final cutting, differ clearly between the two aspen species.

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**Figure 5.** Basic density of hybrid and European aspen wood as a function of vertical position at pith (line 1), 40-mm-distance from the pith (2) and 80-mm-distance from the pith (3).

Wood density varied considerably between different stands and also, between different stems in one stand. The fastest grown trees had the lowest average wood density.
results logically indicated that trees that had grown in more wide spacing at juvenile age represented the fastest diameter growth. In stand wise evaluation, rapid positive responses for thinning operations could be seen in the diameter growth. This was, nevertheless, true only when the thinnings had been done early enough. Postponed thinning no longer enhances the growth.

It is unclear how cultivated _P. tremula_ trees would have grown in comparison to the cultivated _P. tremula x tremuloides_ trees. On the basis of the material of this study, it cannot be said for sure whether the reason for the different growth rhythms was the species or the regeneration method (cultivated / natural) of the stand. In naturally born _P. tremula_ stands the initial spacing of the seedlings has possibly been denser than in cultivated _P. tremula x tremuloides_ stands. This obviously influences the growth rate at young age. However, it could not be taken into consideration in this study, since detailed management history of the _P. tremula_ stands was not available.

The findings of previous studies performed on the basis of smaller data are generally in line with the results concerning the within-stem wood density variation patterns in this study (see: Kärki 2001, Pérez 2002). Wood density correlated negatively with the growth rate of the trees. The differences between individual trees were, however, irrelevant from the point of view of most of the current end uses. Sometimes, for instance in ice hockey stick production, the wood density is a significant factor influencing the usability of wood. In such cases it is necessary to know the within-stem density variations in order to utilise wood with most desirable properties. The dense wood in the living crown is, however, difficult to utilise due to the large living branches and small stem wood dimensions.

In the material of the current study, the average basic density of _P. tremula_ was somewhat lower than that presented in previous studies (see: Kärkkäinen and Salmi 1978, Uusvaara and Pekkala 1979). Basic density was at its lowest near the tree pith in case of both studied species, and increased towards the cambium. Still, the innermost density specimen, thus, produces more dense wood in the upper parts of the stem relative to the cambium. This would partly explain the vertical density variation pattern shown in Figure 3. The cambium, thus, produces more dense wood in the upper parts of the stem with higher hormone content, and lighter wood lower in the stem with lower growth hormone content. The re-increment of the average wood density near the stump height could be explained by the higher proportion of mature wood.

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References


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ПЛОТНОСТЬ ДРЕВЕСИНЫ И СКОРОСТЬ РОСТА ОСИНЫ ОБЫКНОВЕННОЙ И ГИБРИДНОЙ ОСИНЫ (Populus tremula, P. tremula x tremuloides) В ЮЖНОЙ ФИНЛЯНДИИ

Х. Херяйарви, Р. Йункконен

Резюме

В Финляндии древесина различных видов осины используется, главным образом, для производства бумаги. Для увеличения потенциала заготовок в южной Финляндии была посажена гибридная осина. В данном исследовании сравнивается рост зрелой осины обыкновенной (Populus tremula) и гибридной осины (Populus tremula x tremuloides), а также распределение плотности древесины в стволах этих видов. Материалом исследования служили 30 естественно выросших деревьев P. tremula и 45 посаженных P. tremula x tremuloides в южной Финляндии. Ширина годовых колец замерялась на высоте пня, на высоте 2 метров и на конце товарной части ствола (диаметр 5 см). Диски для измерения плотности сухой древесины были отмечены на высоте 0, 2, 4, 8 и 12 метров и выше с интервалами каждые четыре метра до конца товарной части ствола. Образцы для измерения плотности брались от сердцевины диска по направлению к поверхности. Всего было замерено 225 дисков для сбора данных о годовых колцах и 5109 образцов для сбора данных о плотности. Результаты показали, что после начальной фазы в 5-10 лет P. tremula растет относительно равномерно по 5-8 мм в год в диаметре до достижения деревом возраста примерно 50 лет. После этого рост диаметра снижается. Темпы роста P. tremula x tremuloides составляют в среднем 10-14 мм в год в возрасте 10-20 лет. В возрасте 25 лет рост снижается уже до 5-6 мм в год. Распределение плотности внутри ствола более равномерно в гибридной осине. Средняя плотность сухого древесного материала P. tremula и P. tremula x tremuloides составила 376 и 363 кг/м³ соответственно.

Ключевые слова: плотность сухой древесины, осина обыкновенная, темпы роста, гибридная осина, Populus tremula, Populus tremula x tremuloides