

WOOD DENSITY AND FIBER LENGTH IN YOUNG *POPULUS* STEMS: RELATION TO CLONE, AGE, GROWTH RATE, AND PRUNING

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ABSTRACT

Cross-sectional disks were cut at two stem heights (1.5 m and 3.0 m) from 9-year-old trees of three *Populus* clones grown in an intensively-cultured plantation in western Washington. At age 1.5 years, when the trees averaged 3.4 m tall, half of the trees were pruned by removing all branches below 1.8 m. Ring width, wood density, and fiber length were measured for each ring. Pruning had no effect on mean ring width or wood properties, averaged over the entire disk or on rings produced during the 2nd through the 4th years. Averaged over all trees, wood density of the 1.5-m sample was 0.37 g cm⁻³ during the first 3 years, decreased somewhat at age 4 or 5, and then increased to an average of 0.45 g cm⁻³ at age 9. Fiber length increased from 0.57 mm at age 1 to nearly 1.0 mm at age 9. Averaged over all disks at 1.5 m, clones differed significantly in ring width, wood density, and fiber length. Mean values for the two wood properties at 3.0 m were slightly lower than those at 1.5 m and did not differ significantly among clones. Within clone correlations between ring width and wood density or fiber length or between wood properties were low, and generally nonsignificant or inconsistent.

Keywords: *Populus*, wood density, fiber length, ring width, clones, sampling height, pruning.

INTRODUCTION

Thousands of hectares of clonal plantations of poplar hybrids have been established by in-

dustrial firms during the past decade. Initially, the primary purpose of these plantations was fiber for pulp and paper, but objectives have expanded to include solid (Eaton 2000) and composite wood products and, in some cases,

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biomass for energy, carbon sequestration, and phytoremediation of environmental problems (Kuhn and Nuss 2000). Silviculture is intensive and rotations are short: 5 to 8 years for fiber alone and up to 15 years for solid wood products. Thus, a large portion if not all of the wood produced will be in the juvenile core. Wood properties in the juvenile core differ from those of mature wood of most tree species in several ways. Fibers are shorter, wood densities are lower, and microfibril angle and spiral grain are commonly greater in rings near the pith than in rings near the bark in mature trees. Although such differences between juvenile core and mature wood in diffuse-porous hardwoods such as *Populus* are less than differences in conifers and ring-porous hardwoods (Zobel and Sprague 1998), they can affect feedstock quality and uniformity and thereby influence processing operations and product quality. Mature wood of *Populus* has been reported to have wood density values of 0.35 to 0.43 g cm⁻³ and mean fiber lengths from 1.3 to 1.4 mm (cf. various tables in Forest Products Laboratory 1999; Haygreen and Bowyer 1996; Panshin and deZeeuw 1980; Zobel and Sprague 1998).

Information on basic wood properties of *Populus* grown in short-rotation plantations and on opportunities to alter such properties through silvicultural practices and management decisions is limited. Previous research demonstrated that fiber length in species or clones increases with age or distance from the pith (Yanchuk et al. 1984; Bendtsen and Senft 1986; Koubaa et al. 1998). Within a ring at any common age, fiber length seems little affected by growth rate (Bendtsen and Senft 1986; DeBell et al. 1998) though Koubaa et al. (1998) did find a slight negative correlation between fiber length and growth rate at age 6 and 8 in samples collected at 1.5 m but not at lower or greater tree heights. Reports on the relation of wood density or specific gravity to age (or distance from the pith) and growth rate are inconsistent. Some workers have found that density increases with age or distance from pith (Boyce and Kaiser 1961; Curro

1960; Farmer and Wilcox 1966), whereas others suggest a decrease or a decrease followed by an increase (Einspahr et al. 1972; Yanchuk et al. 1983). Reports on the relation of wood density to growth rate are even less conclusive. Peszlen (1998) found no effect of growth on specific gravity or mechanical wood properties of three *Populus* clones growing on two sites in Hungary; Beaudoin et al. (1992) found a slight negative correlation between weighted wood density and stem diameter at breast height but did not examine such relationships within rings of the same age. Moreover, recent studies by Peszlen (1998) and Hernández et al. (1998) showed that mechanical properties of young *Populus* stems are only moderately or weakly correlated with wood density; this is in contrast to the generally strong relationship that exists in mature wood of both conifer and hardwood species. Some of the variance in findings regarding wood density may be associated with differences in species and growing conditions as well as objectives and methods of the researchers. There is a clear need for additional basic information applicable to the clones and regimes now used or under consideration in short-rotation poplar plantings.

Because of increased interest in longer rotations of *Populus* plantations and associated solid wood products, incentives may exist for more extensive pruning to produce additional clear wood. Studies of pruning in young *Populus* stems are few: Keller (1979) showed that pruning of clone I-214 at age 7 did not affect height growth and reduced stem taper; circumference growth, however, was decreased in the more severe treatments (i.e., where pruning was done to 60% or more of the tree height); Polge (1985) showed that pruning of the same clone had no influence on tension wood but increased percentage of heartwood in the more severely pruned trees.

Some evidence suggests for conifers that pruning of branches may accelerate the transition from juvenile wood to mature wood (Polge 1969; Megraw 1985, 1986; Jozsa 1995). Very little work has been done on ef-

TABLE 1. Characteristics of 9-year-old *Populus* trees analyzed for wood properties.

Clone	Treatment	n	Height (m)		Diameter (cm) ¹	
			Mean	Range	Mean	Range
Capitol Lake	Unpruned	4	15.2	12.8–16.6	8.7	6.5–11.4
	Pruned	4	14.3	11.4–15.6	7.4	5.6–9.0
11-11	Unpruned	3	17.9	17.4–18.8	9.5	8.9–10.6
	Pruned	5	17.5	16.1–19.1	9.1	8.0–9.6
47-174	Unpruned	10	18.9	14.7–21.2	10.2	6.3–14.7
	Pruned	9	18.0	14.2–21.1	9.4	7.2–12.5

¹ Diameter inside bark calculated by doubling the sum of radial increments from pith to bark at 1.5 m above ground.

fects of pruning on wood anatomy of hardwoods and on *Populus* in particular. Pruning is reported to have no effect on wood density of *Eucalyptus*, even though timing and rate of wood formation are altered (Schonau 1973). Because of the rapid growth rate of poplar, young stems offer an opportunity to see if such accelerated maturation might also occur in this diffuse-porous hardwood species. If it does, managers might achieve unexpected benefits if they prune lower branches in young plantations to make cuttings for additional plantings. Trees remaining after plantations are thinned for pulpwood are commonly destined for solid or laminated wood products where mature characteristics may be more important and valuable than in wood used for pulp or bioenergy.

This paper provides information on the characteristics of stem wood produced in short-rotation *Populus* plantings and how they vary by clone, age, and growth rate. The influence of pruning on the transition from juvenile to mature wood is also examined. Implications of this information in decisions about cultural practices and rotation length are discussed.

MATERIALS AND METHODS

Wood samples

Cross-sectional disks were collected from 9-year-old *Populus* stems grown in a silvicultural research plantation in western Washington. Details on establishment and culture of the entire plantation are given in DeBell and Harrington (1997). In brief, unrooted cuttings

of several clones were planted in a thoroughly disked, weed-free area; lime and a mixture of nitrogen, phosphorus, and potassium fertilizer were applied to the soil prior to planting and additional nitrogen was applied after the second growing season; plots were irrigated by a drip system and maintained in a nearly weed-free condition. Work reported in this paper is based on sampling dominant and codominant trees of three clones grown in monoclonal plots planted at 1.5 m by 1.5 m. Two of the clones, 11-11 and 47-174, were hybrids of *P. trichocarpa* Torr. & Gray × *P. deltoides* Bartr. ex Marsh, developed in the University of Washington–Washington State University poplar breeding program (Heilman and Stettler 1985), and had been planted extensively in commercial plantations in western Oregon and Washington. The third clone, Capitol Lake (CL), was a native clone of *P. trichocarpa* collected near Olympia, Washington, and had been planted in research trials only. Characteristics of these trees at time of sampling are shown in Table 1. The two hybrid clones averaged 18 m tall and about 10 cm in diameter (*inside* bark). The native clone (CL) was about 3 m shorter and 1.5 cm smaller in diameter (*inside* bark). Thus, the trees were approaching the size (i.e., 15-cm diameter *outside* bark) generally sought in short-rotation plantations.

We initially sampled 18 to 24 trees of each clone. Half of the trees of each clone were unpruned and half had been pruned to a height of 1.8 m at age 1.5 years (July of the 2nd growing season). Prior to pruning, trees averaged 3.4 m tall and there were no size differ-

ences among clones or between trees assigned individually to the pruned and control treatments. Disks were collected at two stem heights—1.5 m (i.e., 0.3 m below the pruned height) and at 3.0 m. The disks were placed in plastic bags and transported to the Oregon State University's Forest Products Laboratory at Corvallis, Oregon. A pith-to-bark strip about 1 cm wide and 1.5 cm thick was sawed along an average radius from each disk; this strip was subsequently separated into two strips: one strip (about 1 cm wide and 1 cm thick) was used to measure fiber length; the remaining portion was reduced to a strip 7 mm wide and 1.5 mm thick that was used to assess wood density and ring width.

Many of the samples were excluded from subsequent measurements of wood properties because they had been damaged by holes and tunnels created by the poplar-and-willow borer (*Chryptorhyncus lapathi*) while the trees were alive. Although this created some imbalance in the design and analyses, the number of intact samples was sufficient to evaluate differences among clones, determine patterns of change in wood properties with age, and test effects of the pruning treatment on clone 47-174.

Wood density and ring width measurement

The 7-mm by 1.5-mm samples were X-rayed using a system developed at Oregon State University's Forest Products Laboratory to determine relative wood density within and between growth rings. The X-ray system was run with a step size of 100 μm , thus providing the greatest resolution possible with this system.

The relative density values of the X-rayed samples were converted to actual oven-dry density by calculating bulk density of each sample based on oven-dry weight and oven-dry volume measurements (the latter determined by immersion in mercury). These data were used to set a baseline density for use in Dendro-Scan (Varem-Sanders and Campbell 1996), a software package that automates sum-

mary and analysis of the X-ray data and affords manual manipulation of some variables, such as location of ring boundaries. Because the poplar sections did not show strong differences in X-ray pattern at ring boundaries, we measured growth rings based on visual appearances coupled with knowledge of number of rings present on the section and past diameter measurements. These ring width data were used to set ring boundaries on the X-ray data, and thereby determine average wood density for individual rings. Given the difficulty of determining the annual boundaries with X-ray data alone, we did not attempt to distinguish between earlywood and latewood within each ring.

Fiber length measurements

Growth rings were identified visually on the 1-cm wide by 1-cm thick pith-to-bark strips designated for fiber length measurement, and then separated with a razor blade. Each ring was placed into an individual test tube and submerged by addition of a hydrogen peroxide solution (20% by volume). The test tubes were then placed in a drying oven at 63°C to hasten the chemical maceration process. After several hours, the samples were rinsed three times with de-ionized water and stained with an aqueous solution of safranin-o to improve contrast for microscopic viewing. The stained macerated material from each growth ring was placed on three microscopic slides and mounted in glycerine.

Fiber lengths were measured with a Macintosh-based image analysis system; this system employed a black and white, charge coupled device camera, a dissecting microscope with 0–6.3 magnification, and NIH Image 1.60 software (Rasband 1996). The system was calibrated at the beginning of each measurement session. With a slide's image on the computer monitor, we selected unbroken libriform fibers and used a mouse to locate the two ends of each fiber; the software calculated fiber length. A minimum of 36 fibers were measured on each slide, resulting in at least 108 fibers mea-

sured for each growth ring. From these data, an average fiber length was calculated for each ring.

Data analysis

Basic measurements of ring width, wood density, and fiber length were used to determine the mean, maximum, and minimum of these traits for rings of the same age and for various combinations of clone, sample height, and pruning treatment. Values were plotted over ring age to determine changes in traits over time. In addition, we calculated weighted values for wood density and fiber length based on the cross-sectional area of each ring; this value is equivalent to mean values for the disk and approximates relative mean tree values.

Differences among clones and pruning treatments were evaluated by analyses of variance, followed by separation of means by least significant difference. Although the two stem height samples were derived from many of the same trees, some of the samples for each height came from trees only represented at one height; all analyses were therefore done independently for each stem height rather than considering each height as a subplot within an individual tree.

Effects of the pruning treatment were evaluated only for clone 47-174 because it was the only clone with an adequate number of usable (undamaged by the poplar-and-willow borer) samples from pruned and unpruned trees. Fortunately, the branching habit of clone 47-174 made it the most likely clone to be affected by branch removal; i.e., typically it produces very few sylleptic branches, and after pruning it had fewer remaining branches to compensate for removal of the lower branches. We assessed the influence of pruning the lower crown on transition from juvenile to mature wood by comparing values for fiber length and wood density over the entire cross-sectional disk and for age 2 through 4 years—the period most likely to be affected by the pruning treatment; beyond age 4, natural pruning had lifted the crown above the height of the pruning

treatment, and thus would have masked any treatment-related differences in live crown characteristics.

Following the above analysis in which effects of pruning were found to be insignificant (discussed below) and exploratory analyses that demonstrated clone by treatment interactions to be negligible, we combined samples from pruned and unpruned trees for analyses of clonal differences in ring width and wood properties and for examining correlations among ring width, wood density, and fiber length *within clone* for each sample height. Combining the treatments increased the sample size for the additional analysis, which should make them more sensitive. Correlations among variables were calculated for the entire cross-section and within rings of the same age. Differences among clones or pruning treatments and correlations among growth and wood property traits were considered significant if $P \leq 0.10$.

RESULTS AND DISCUSSION

Influence of pruning on ring width and wood anatomy

Averaged over the disk cross-section, mean ring width, wood density, and fiber length at either stem height of clone 47-174 were not affected significantly by pruning (Table 2). Because pruning effects on current wood anatomy might last only as long as treatment-related differences in crown length were maintained and subsequently diminish or disappear, we also analyzed effects on rings laid down during the 2nd through the 4th growing seasons. Even for this presumably more sensitive time period, pruning had no significant effect on ring width or the two wood properties (Table 2). Mean ring width for clone 47-174 was about 10% lower in pruned trees than in unpruned trees but the difference was nonsignificant. Two-year growth data from a larger sample of trees in the same study area (data not shown) also showed no effect of pruning ($P = 0.70$, $n = 88$) so it appears that this level of pruning has no detrimental effects on tree

