NATURAL VARIATION IN WOOD PROPERTIES OF *ALNUS ACUMINATA* H.B.K. GROWN IN COLOMBIA

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ABSTRACT

Ninety-nine Andean alder (*Alnus acuminata* H.B.K.) trees were sampled from eleven regions in Colombia and Venezuela to determine the pattern of wood property variation between regions, between altitude within regions, between trees, and within a tree. A 5-mm-diameter increment core was extracted from each tree at breast height. The core was used to evaluate wood density and the dynamic compliance coefficient in the longitudinal direction. Based on mean regional values, wood density varied from 314 kg/m^3 to 409 kg/m^3; and dynamic compliance coefficient varied from 91 $\times$ 10^{-6} MPa^{-1} to 136 $\times$ 10^{-6} MPa^{-1}. Single-tree values ranged from 249 kg/m^3 to 446 kg/m^3 for wood density, and from 81 $\times$ 10^{-6} MPa^{-1} to 187 $\times$ 10^{-6} MPa^{-1} for the compliance coefficient, respectively. The analysis of variance indicated that both wood properties vary considerably between geographic locations, between trees, and within a tree. The wood density tends to increase linearly from pith to bark, although there were differences in the magnitude of increase between regions. Finally, tree characteristics (tree height and diameter at breast height) were not related to wood properties.

Keywords: Wood quality, wood density, compliance coefficient, nondestructive evaluation, alder, *Alnus acuminata.*

INTRODUCTION

Two alder species are present in the highland regions of South and Central America: *Alnus jorullensis* H.B.K. and *Alnus acuminata* H.B.K. Both species have wood suitable for a variety of end products. *Alnus jorullensis* H.B.K. has a limited distribution from northwestern Mexico to southern Guatemala, while *Alnus acuminata* H.B.K. is widely distributed from northwestern Mexico to northwestern Argentina (Furlow 1979). In Colombia, trees of the latter species have a pioneer habit and they are normally distributed between 2,000 m and 3,300 m above sea level, in the Central and Oriental cordilleras (Restrepo 1993). According to the classification system of Holdridge (1967), alder is present in the following types of habitats: dry forest-lower montane (df-LM), moist forest-lower montane (mf-LM), wet forest-lower montane (wf-LM), moist forest-montane (mf-M), and wet forest-montane (wf-M). The species grows on soils from volcanic, organic, and alluvial origins and prefers open forests to closed forests. Principally, it is found associated with *Pennisetum, Holcus, Chusquea, Salvia, Miconia, Tibouchina,* and *Weinmannia* genus. In the Central cordillera, *Alnus acuminata* takes the form of a tree that can grow up to a height of 40 m and a diameter

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TABLE 1. *Geographic locations of eleven hydrographic basins where Andean alder trees were sampled.*

Basin number	Location		Lowest elevation			Intermediate elevation			Highest elevation		
	County	Department	Latitude North	Longitude West	Elevation (m)	Latitude North	Longitude West	Elevation (m)	Latitude North	Longitude West	Elevation (m)
1	Neira	Caldas	5°20′	75°32′	2,260	5°21′	75°32′	2,380	5°23′	75°33′	2,700
2	Manizales	Caldas	5°04′	75°28′	2,270	5°04′	75°26′	2,480	5°02′	75°20′	3,120
3	Salento	Quindío	4°43′	75°34′	2,240	4°45′	75°33′	2,600	4°45′	75°32′	2,880
4	Pijao	Quindío	4°20′	75°36′	2,290	4°20′	75°35′	2,350	4°21′	75°35′	2,640
5	Silvia	Cauca	2°34′	76°22′	2,300	2°36′	76°21′	2,440	2°37′	76°20′	2,650
6	Pasto	Nariño	1°03′	77°05′	2,710	1°01′	77°05′	2,750	1°00′	77°05′	2,820
7	Gigante	Huila	2°23′	75°28′	2,200	2°23′	75°26′	2,520	2°23′	75°25′	2,730
8	Guasca	Cundinamarca	4°52′	73°50′	2,730	4°44′	73°55′	2,880	4°52′	73°48′	3,030
9	Arcabuco	Boyacá	5°46′	73°26′	2,580	5°44′	73°26′	2,790	5°42′	73°26′	2,950
10	Pamplona	Norte Santander	7°20′	72°39′	2,930	7°17′	72°50′	3,100	7°10′	72°50′	3,310
11	Mucuchíes	Mérida[1]	8°38′	71°04′	2,050	8°41′	71°00′	2,500	8°46′	70°52′	3,120

[1] State of Venezuela.

of 70 cm. In the Oriental cordillera, however, the species is more shrublike, and only a few trees in certain habitats exceed 10 m (Restrepo 1993).

Alnus acuminata has a fast juvenile growth rate and good adaptability to a wide range of site conditions, which makes this species an excellent candidate for plantations with short rotations that produce wood for conversion by the forest industry. Aspects of silviculture, including growth and agroforestry, have been widely studied for this species. However, Hunt (1967) outlined the little attention that has been paid to the variation in wood properties for alder. Therefore, the purpose of this paper is to provide information on patterns of wood property variation between eleven natural geographic locations from Colombia and Venezuela, within these locations, between trees, and within individual trees of this species. Wood density and the dynamic compliance coefficient in the longitudinal direction (s_{11}) were investigated. Results presented here were obtained from increment cores sampled at breast height using nondestructive methods.

MATERIALS AND METHODS

Sample collection and preparation

Ninety-nine dominant trees from eleven hydrographic basins were sampled within the natural range of Andean alder in Colombia and Venezuela (Table 1). Three natural stands from three elevations (lowest, intermediate, and highest) from each basin were selected. Three trees from each stand were sampled. The height of each tree was measured with a Blumeleiss, and the diameter was measured with a diameter tape at breast height (1.4 m above ground). An increment core was extracted at this height, using a 5-mm-diameter increment borer from each tree. This core was obtained from the high side of the slope. Only knot-free cores were used, and these were kept frozen until the densities were measured.

Laboratory measurements

The cores were divided into 25-mm segments from the pith with a razor blade. In a few cases where a core did not contain pith, the distance from the pith was estimated by examining the core with a microscope (10×) in order to estimate the point of convergence of the wood rays. This point was assigned as the location of the pith, and from it, distances to each 25-mm segment were calculated. Green volume of each segment was then determined by the water-displacement method (measured to 0.001 g). Moisture content of the segments before immersion varied from 120% to 180%.

Subsequently, the cores were placed in a conditioning room set at 20 C and 65% relative humidity (RH), to provide a nominal equilibrium moisture content (EMC) of 14%. Once equilibrium was reached, measurement of the

TABLE 2. *Mean values and coefficients of variation for wood properties of Andean alder grown in eleven hydrographic basins from Colombia and Venezuela.*

Basin number	Location		Wood density		Dynamic compliance coefficient s_{11}	
	County	Department	Mean (kg/m^3)	C.V. (%)	Mean ($\cdot 10^{-6}$ MPa^{-1})	C.V. (%)
1	Neira	Caldas	319	12.0	121	16.8
2	Manizales	Caldas	333	14.0	120	23.5
3	Salento	Quindío	333	7.0	119	11.5
4	Pijao	Quindío	360	12.5	103	11.6
5	Silvia	Cauca	402	7.5	108	13.8
6	Pasto	Nariño	409	5.2	91	8.7
7	Gigante	Huila	314	12.0	132	11.4
8	Guasca	Cundinamarca	363	8.6	129	13.4
9	Arcabuco	Boyacá	355	3.7	125	4.7
10	Pamplona	Norte Santander	346	6.0	136	11.0
11	Mucuchíes	Mérida[1]	347	7.9	133	9.1

[1] State of Venezuela.

compliance coefficient s_{11} was done using an ultrasonic method described in detail by Bucur (1983) and Herzig (1992). Each segment is placed between two sensors (transmitter and receiver), and a 1 Mhz frequency wave is then propagated through the segment. The time taken by the wave to pass through the segment is measured to 10^{-8} sec. Since the wood density at the time of testing is also required, the volume of the core was determined by a mercury-displacement method, and its weight was obtained to the nearest 0.001 g. These measurements permit calculation of the dynamic compliance coefficient in the axial direction, s_{11}, of the wood. The reciprocal of this parameter is Young's modulus in the axial direction (MOE). Therefore:

$$s_{11} = (\rho v^2)^{-1}$$

where:

ρ = wood density at time of testing (nominal equilibrium moisture content)
v = velocity of wave propagation

It should be noted that the correction to take into account the effect of Poisson's ratio on the segments was not considered. Therefore, compliance coefficients should be considered as apparent as proposed by Bucur (1981).

Finally, all samples were oven-dried at 103 ± 2 C until a nearly constant weight was reached (24 hours). After the samples were cooled to room temperature, their oven-dry weights were measured to the nearest 0.0001

TABLE 3. *Analysis of variance for wood properties of Andean alder.*

Source of variation	Degrees of freedom	Wood density		Compliance coefficient s_{11}	
		Mean square	*F*	Mean square	*F*
Region	10	0.0248	9.0**	5,161	8.4**
Altitude	2	0.0023	0.8 n.s.	505	0.8 n.s.
Region × altitude	20	0.0043	1.5 n.s.	1,218	2.0*
Tree (altitude)	66	0.0028	6.3**	617	4.2**
Segment	2	0.0686	157.6**	12,079	81.4**
Region × segment	20	0.0025	5.7**	564	3.8**
Altitude × segment	4	0.0007	1.5 n.s.	707	4.8**
Region × altitude × segment	40	0.0007	1.7*	260	1.8**
Error	132	0.0004		148	
Total	296				

** Significant at the 1% probability level; * significant at the 5% probability level; n.s. not significant at the 5% probability level.

TABLE 4. *Duncan's multiple-range test of wood density and dynamic compliance coefficient for Andean alder grown in eleven hydrographic basins from Colombia and Venezuela.*

	Wood density										
Basin number	6	5	8	4	9	11	10	2	3	1	7
Density (kg/m^3)	409	402	363	360	355	347	346	333	333	319	314

	Dynamic compliance coefficient s_{11}										
Basin number	10	11	7	8	9	1	2	3	5	4	6
$s_{11}(\cdot 10^{-6}$ MPa$^{-1})$	136	133	132	129	125	121	120	119	108	103	91

g. The increment core wood density is reported on an oven-dry weight to green volume ratio.

Data analysis

A three-way analysis of variance (ANOVA) was carried out to identify the sources of variation in density and dynamic compliance coefficient, s_{11}. A mixed model was used with trees nested within altitude to determine the hydrographic basin (region), the altitude, the tree, and the distance from the pith (segment) effects. Three values in the radial direction were compared to evaluate this last source of variation. These values were taken from 25-mm segments from near the pith and the bark and were compared to the overall mean values calculated from all segments from an intermediate position. This was done in order to account for variation in tree diameter. Trees were considered as replicates. Duncan's multiple-range tests were used to further analyze within-tree and geographic variation. Finally, simple correlation coefficients were computed to assess the relationships between the wood density, the compliance coefficient s_{11}, and the tree characteristics.

RESULTS AND DISCUSSION

Wood density

The wood from the 99 trees sampled in this study had a mean basic density of 353 kg/m^3 with a coefficient of variation of 11.9% at breast height. Means for individual trees ranged from 249 kg/m^3 to 446 kg/m^3, while those for geographical regions ranged from 314 kg/m^3 to 409 kg/m^3 (Table 2). Wood density values of 360 kg/m^3 (González and van der Slooten 1975), 370 kg/m^3 (Pérez and Corral 1980), and 410 kg/m^3 (Acosta 1967) have been reported for alder coming from other Latin American countries (Mexico and Costa Rica). These values reported in the literature are within the range obtained for the geographical regions studied here. Previous studies reported values of 306 kg/m^3 (Lastra 1986) and 330 kg/m^3 (Barghoorn 1965) for the Manizales region in Colombia. Mean wood density for this region (333 kg/m^3) is within a 95% confidence interval.

The model used for the analysis of variance presented in Table 3 explained 93% of the total variation in wood density. There was a significant difference between the means of wood density obtained for the eleven hydrographic basins (regions). Disregarding the interaction component, the region effect accounted for 31% of the total variation present (estimated from the type III sum of squares). A Duncan's multiple-range test was applied to determine which of the means differ at the 95% probability level. The results are presented in Table 4. The practical implication of this test for foresters is that it should be possible to select a basin whose trees will have a high density or low density, depending of the end use of wood. This study indicates that alder trees coming from Pasto (409 kg/m^3) and Silvia (402 kg/m^3) regions would be preferred to trees coming from remaining regions if denser wood was desired. Trees coming from Guasca, Pijao, and Arcabuco regions show intermediate values of wood density (from 355 to 363 kg/m^3). The six remaining regions are not statistically differen-

TABLE 5. *Correlation coefficients for the relationships between wood properties, tree height, and diameter at breast height (dbh) for Andean alder.*

Correlating variables	Correlation coefficient
Height vs. dbh	0.65**
Height vs. wood density	−0.36*
Height vs. compliance coefficient	−0.15 n.s.
dbh vs. wood density	0.06 n.s.
dbh vs. compliance coefficient	−0.11 n.s.
Compliance coefficient vs. wood density	−0.72**

** Significant at the 1% probability level; * significant at the 5% probability level; n.s. not significant at the 5% probability level.

tiated from each other and contain trees producing a light wood, namely between 314 and 347 kg/m^3 (Mucuchíes, Pamplona, Manizales, Salento, Neira, and Gigante). Three of these regions were considered by Valle and González (1988) to be among those showing the highest growth rates in Colombia (Manizales, Salento, and Neira). These locations seem to facilitate the growth of alder, which would lead to a reduction in wood density. However, a correlation between the growth rate (tree height) and wood density at breast height showed a weak ($r = -0.36$) but significant negative relationship between these two variables (Table 5).

The effect due to the altitude was nonsignificant for wood density (Table 3). Although there was a significant region × altitude × segment interaction, this participation can be considered as negligible. This means that trees coming from different altitudes within a given hydrographic basin would produce equivalent wood densities. Similar results were obtained by Foster and Thor (1979) when comparing upland and bottomland trees of American sycamore in Tennessee.

Between-tree variation.—The variation of wood density was significant between trees within the same region and accounted for about 23% of the total variation (interaction terms not considered). The variation in wood density explained by this factor (between trees) is lower than that explained by the region effect. It is therefore confirmed that selection of this property between different regions is practical. This analysis also indicates that it should be possible to select specific trees within regions in order to increase or decrease the density, depending on the end use of wood. Zobel and van Buijtenen (1989) outline the importance of the tree to tree differences and indicate that this variability is often not appreciated or is even ignored, resulting in some major errors in the use of wood.

Within-tree variation.—The analysis of variance in Table 3 reveals that radial position (segment) affects wood density, i.e., this property increases linearly from pith to bark as already reported for other tropical pioneer species (Whitmore 1973; Wiemann and Williamson 1988, 1989a; Butterfield et al. 1993; Fimbel and Sjaastad 1994). The radial position effect accounted for at least 17% of the total variation in wood density (interaction terms not considered). This analysis also shows a significant geographical region × segment interaction. This means that the degree of variation in wood density in the radial direction is a function of the location considered. Figure 1 shows different slopes of variation in wood density for some representative geographical sites as a function of three radial positions at breast height. The geographical regions having trees with lower wood densities show greater radial changes than those from locations having trees with higher densities. This is clearly noticed when the mean wood density near the pith is considered. Similar results, but between species, were reported by Wiemann and Williamson (1989b) for trees growing in wet tropical forests. This indicates that alder could have a mechanism to control the natural variation in its wood density. At earlier growth stages (position 1), trees producing low wood density will tend to increase in density more sharply than trees having initial high wood densities. This trend will lead to a reduction in the overall variation of wood density as the tree ages.

Dynamic compliance coefficient

The wood from the 99 trees studied had a mean dynamic compliance coefficient s_{11} of

120×10^{-6} MPa^{-1} with a coefficient of variation of 16.7% at breast height. Means for individual trees ranged from 81×10^{-6} MPa^{-1} to 187×10^{-6} MPa^{-1} and from 91×10^{-6} MPa^{-1} to 136×10^{-6} MPa^{-1} for geographical regions (Table 2). The mean dynamic compliance coefficient for the Manizales county is comparable to the static compliance coefficient of 123×10^{-6} MPa^{-1} for this same region reported by Lastra (1986).

The model used for the analysis of variance presented in Table 3 explained 89% of the total variation in the dynamic compliance coefficient. As expected, the relationship between this property and the wood density was highly significant ($r = -0.72$, Table 5). For this reason the results of the analysis of variance for the compliance coefficient were somewhat similar to those obtained for wood density. The differences of means between regions, between trees, and within individual trees were statistically significant. However, all interaction terms, including those related to the altitude, were also statistically significant. This means that there were not general relationships between the principal sources of variation, which makes the discussion difficult. Thus, the variation in compliance coefficient between altitudes within a region will vary with the region considered (region × altitude interaction), whereas the radial variation within a tree will vary with the altitude (altitude × segment interaction) and with the region considered (region × segment interaction).

A Duncan's multiple-range test was applied to determine which of the means may differ at the 95% probability level. The results shown in Table 4 indicate various overlaps between the mean values. This can be partially explained by the relatively high coefficients of variation for each region presented in Table 2. Nevertheless, trees from the Oriental cordillera regions (Pamplona, Mucuchíes, Gigante, Guasca, and Arcabuco) would be preferred to trees coming from Silvia, Pijao, and Pasto regions if more flexible wood was desired. Trees growing in Pasto region would produce wood having the lowest compliance. As expected, this same region gave the densest wood of all regions studied. Finally, the remaining regions (Neira, Manizales, and Salento) were not statistically differentiated, producing wood with intermediate compliance coefficient values.

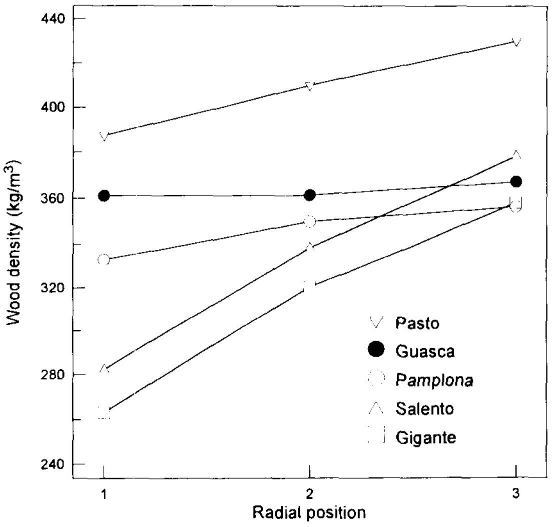

FIG. 1. Wood density variation as a function of the radial position at breast height for some hydrographic basins where alder trees were sampled (1: segment near to the pith; 2: mean of all intermediate segments; 3: segment near to the bark).

It is of interest to note that a cordillera effect appears to be present since the higher compliance coefficients correspond to the Oriental cordillera while the lower correspond to the Central cordillera (Neira, Manizales, Salento, Silvia, and Pijao regions). A trend in the opposite direction and not so evident can be seen in wood density. In an associated study, Restrepo (1993) reported that trees coming from the Oriental cordillera have a shrub form, whereas most of the trees coming from the Central cordillera have a more arborescent form. These morphological differences indicate the probable presence of two taxa of *Alnus acuminata* H.B.K. In addition, we found that the mean compliance coefficient tends to decrease from north to south for each one of the cordilleras. Additional work, however, is required to validate these trends.

Correlations between wood properties and tree characteristics

In general, alder has a rapid growing rate, so it is important to know the influence of this growth rate on wood properties. According to our study, wood density is moderately correlated to the tree height but not to the tree diameter at breast height (Table 5). However, these tree characteristics were not related to the compliance coefficient s_{11}. This indicates that estimations of wood properties from the tree characteristics are not possible.

CONCLUSIONS

This research indicates that wood density and dynamic compliance coefficient s_{11} for Andean alder vary considerably between geographic locations, between trees, and within a tree. This offers excellent opportunities for yield improvements through selection of regions or individual trees for both wood properties. In addition, this study could give useful information to the wood industry in order to obtain alder trees having reasonable uniformity in wood properties among supplies coming from different locations.

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