Within-Tree Variation of Wood Specific Gravity in Ocote Pine[1]

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ABSTRACT

Wood specific gravity (S.G.) was examined in 15 ocote pine (*Pinus oocarpa* Schiede) trees from the central Honduran highlands. The mean tree S.G., determined from unextracted increment core samples taken at 1.5 m height, was 0.517 ± 0.022 with 95% confidence. No significant relationship was found between growth rate or percent latewood and whole core density. A definite pattern of within-tree variation in stemwood S.G. was observed. Below 10.5 m, S.G. was greatest at the pith. S.G. decreased rapidly moving out from the pith to ring five and then began a gradual increase to ring 18, where it stablized. Corewood S.G. decreased up the stem, but this decrease was less significant in the mature wood zone. The earlywood-latewood transition was mild, suggesting a uniform overall quality. Mean branches S.G. was 0.618 and was not related to stemwood S.G.

COMPENDIO

El presente trabajo resume los resultados de un estudio de peso específico en 15 árboles de *Pinus oocarpa* Schiede, de las montañas centrales de Honduras. Las muestras se tomaron con barreno a 1.5 m de altura. El valor promedio fue de 9.52 ± 0.02 g/cm³, con una confianza de 95%. La relación significativa entre la tasa de crecimiento y el porcentaje de madera de verano. Se observó una variación en el peso específico de adentro hacia fuera de la médula.

INTRODUCTION

Ocote pine (*Pinus oocarpa*) is an important component of the coniferious forest of Mexico and Central America. In Honduras, it is the primary source of raw material for forest industry. Of possibly greater significant is the potential use of this species in exotic plantations throughout the tropical zones of the world. Despite the apparent utility of ocote pine, little attention has been given to the quality of its wood.

Wood specific gravity (S.G.) is an easily determinable trait often used to express wood quality. The specific gravity of wood is commonly defined as the ratio of the weight of the oven-dry wood to the weight of a volume of water equivalent to the overall volume of the wood (5). Elliott (3) reviewed S.G. variation in conifers and found that it shows much variation among species, among trees within a species and within trees. The high degree of variability of S.G. is believed to be a major problem confronting the wood utilization industry (13). Furthermore, because S.G. varies greatly within a single tree, extrapolation of breast height increment core value to whole tree estimates is difficult.

Published results of S.G. surveys of unextracted breast height increment core samples of ocote pine from Honduras have included a broad range of sites, age classes and sample sizes (6, 9, 10, 20). Notwithsstanding, an overall estimate of the average S.G. can be but at around 0.509 for mature trees (i.e. 40-45 years old). Where pine is grown as an exotic, S.G. has generally been found to be considerably lower (1, 4, 7, 19), presumably due to the accelerated growth rates and younger ages of the material. A comparison of S.G. of six geographic seed sources from throughout Central America in a replicated provenance trial in the Ivory Coast showed no significant differences among seed sources at age eight (1).

Comparisons of S.G. among ocote pine populations within Honduras have demostrated considerable variation (10, 20). When comparing 11 disjunct populations, the variation found was not related to either geographic location or evaluation (10). Guevara (6) did, however, find a significant decrease in S.G. with increasing evaluation after examining two natural stands in Honduras.

Studies of within-tree variation in S.G. of ocote pine (1, 6, 7, 18, 19) indicate that S.G. increase with age or distance from the pith and decrease with

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height up the stem. Palmer and Gibbs (15) found that variation was greater within a single stem than among trees when examining a small population from Belize. Earlywood-latewood differences in S.G. are small and ocote pine wood is considered rather even-textured (7). Plumtre *et al* (17) concluded that the low density central core is less pronounced in ocote pine than in either *Pinus caribaea* or *Pinus kesiya* from Nigeria

This paper examines several aspects of among-tree and within-tree variation in ocote pine from Honduras.

MATERIALS AND METHODS

In October 1981, 15 ocote pine trees were selected from an uneven-aged natural stand occupying a homogeneous site surrounding Siguatepegue, Honduras (14.50°N and 87.80°W; altitude 1 000-1 100 m). Individual trees were separated by at least 0.5 km and possessed good stem and crown form. In order to insure equal repetition of internal stem measurements, trees in the 28-32 year age class (determined by ring count at 1.5 m height) were selected.

Once selected, trees were felled at ground level. A 5 cm thick disc was removed from the base of the stem and every 1.5 m thereafter to the stem apex. From three to five branchwood samples were collected per tree at various heights by removing a 5 cm thick disc 10 cm up the branch from the main stem. In the laboratory, a pie-shaped wedge including the pith was cut from each disc. At this time, a 12 mm diameter increment core sample was extracted from the wedge sampled at 1.5 m height. In all instances, care was taken to avoid inclusion of reaction wood.

A series of subsamples was then separated from the stemwood wedges. Variation in the radial direction was examined by sampling all rings at the 1.5 m height. Initially, total width and width of the latewood were measured to the nearest 0.1 mm for each ring. Rings were then carefully separated with a wood chisel. Longitudinal stem variation from a fixed annual ring number from the pith was examined by removing rings 2 and 3 (juvenile wood) and rings 14 and 15 (mature wood) from each height. Longitudinal variation in a continuous annual growth sheath was also examined. In this case, rings 24 and 25 from the pith were designated in the basal stem section and the number of rings from ring 25 to the secondary cambium noted. At subsequent heights, rings 24 and 25 were identified by counting the determined number of rings in from the cambium and were then removed. Variation between early wood and latewood in the stem was examined by removing rings 2 and 4 (juvenile wood) and rings 8, 15 and 22 (mature wood) from the 1.5 m wedge. Earlywood and latewood subsamples were then separated with a wood chisel. Branchwood variation was examined by dividing samples into radially equal inner (i.e. adjacent to the pith) and outer sections.

In a previous study (10), the alcohol-benzene extractable constitutents of the mature wood of ocote pine were found to be less than 3% of the extracted dry weight. Therefore, S.G. determinations in this study were made on unextracted samples. Due to the small volume of many of the samples, Smith's (21) maximum moisture content method was used to determine S.G. Prior to measurement, samples were submersed in water and subjected to an oscillating vacuum until fully saturated. The saturated weight of each sample was measured on an analytical balance to the nearest microgram. Samples were then oven-dried at 105°C to a steady state and re-weighed. The formula used to calculate S.G. as described by Smith is;

$$\text{Specific Gravity} = \frac{1}{\dfrac{W_s - W^d}{W_d} + \dfrac{1}{1.53}}$$

where W_d = dry weight (g)
W_s = saturated weight (g)
1.53 = the specific gravity of the solid wood fraction

RESULTS

Among-Tree Variation

Data of whole increment cores collected at 1.5 m height for individual trees are presented in Table 1. The mean S.G. is 0.517 ± 0.022 with 95% confidence which concurs with previous information for ocote pine from Honduras (10).

A large portion of the tree-to-tree variation in S.G in conifers has been associated with differences in percent latewood and/or growth rate (12, 22). The mean latewood percent for the trees is 25.5 ± 0.9% with 95% confidence and is fairly consistent. Furthermore, simple linear correlation analysis of individual tree whole core S.G. with percent latewood was insignificant (r = 0.32 with N = 15). Growth rate, expressed as core length/age, was subjected to the same analysis, revealing an insignificant relationship (r = 0.45 with N = 15). This apparent lack of

Table 1. Increment core data at 1.5 m.

Tree No.	Age (Years)	Core Length (cm) (inside-bark)	S.G.	Latewood (%)
1	29	12.5	0.538	24
2	30	9.5	0.545	29
3	30	11.0	0.562	26
4	29	12.6	0.495	27
5	30	14.1	0.581	28
6	30	13.7	0.438	27
7	30	13.9	0.534	28
8	29	13.0	0.538	28
9	30	15.0	0.526	26
10	28	14.8	0.482	20
11	29	14.4	0.467	25
12	32	14.3	0.551	25
13	31	17.0	0.487	26
14	29	14.7	0.500	19
15	29	15.9	0.514	24

association of S.G. to either percent latewood or growth rate needs critical evaluation. Guevara (6) concluded that variation in percent latewood accounted for a sizeable proportion of the S.G. variation among 48 ocote pines from Honduras. The 15 tree sample in this study is too small to make any confident evaluation of the association of these characters. Furthermore, Spurr and Hsuing (22) pointed out that changes in growth rate effect changes in many other characters which directly or indirectly influence S.G., greatly confounding its interpretation.

Radial Variation

Population mean S.G. values and their coefficients of variability (CV) for annual rings at 1.5 m height are presented in Table 2. Whole ring density is greatest in ring 1, followed by a rapid decrease to ring 5. S.G. gradually increases from ring 5 to ring 19, where it levels off. Among-tree variability is greatest in rings near the pith and is considerably less in the remaining rings. The greater S.G., and greater variability in S.G. formed in rings near the pith, are probably associated with variable levels of deposition of extractives in this corewood zone. Accumulation of chemicals such as fatty acids, resin acids and essential oils is usually greatest near the pith in pines (23).

In an effort to more accurately describe the radial variation pattern and to develop a method of predicting the S.G. of individual rings, regression analysis was performed on the mean values shown in Table 2 (including only means based on ⩾ 14 observations). Because the pattern found near the pith is so divergent from that found closer to the bark, separate equations were developed. Fig. 1 illustrates the plotted actual means, calculated regression curves and their equations. Surprisingly, the curve developed for rings 5 through 29 shows a definite downward slope after ring 22. Normally, S.G. in pines does not begin to decrease in the mature wood portion of the stem until the pines are relatively old and growth rates have declined (12). In Fig. 1, the downward slope of the regression line beyond ring 20 may be an artifact resulting from the variability of S.G. of rings nearer to the bark.

Longitudinal Variation

Longitudinal variation in S.G. up the stem for rings 2, 3, 14 and 15 from the pith and in a continuous growth sheath (rings 24 and 25 as determined at the base) is shown in Table 3. Values are means of all 15 trees and their corresponding coefficients of variability (CV). In the juvenile wood zone (rings 2 and 3), S.G. is greatest at the base of the stem and decreases rapidly to 1.5 m. Thereafter a gradual decline is noted to around 16.5 m. In the mature wood zone (rings and 14 and 15), S.G. gradually decreases from the base upwards. Rings 24 and 25 show a similar pattern. Guevara (6) found a decrease in S.G. with increasing stem height for both unextracted samples of ocote pine from Honduras. Although he found that absolute S.G. values were significantly reduced following extraction, the degree

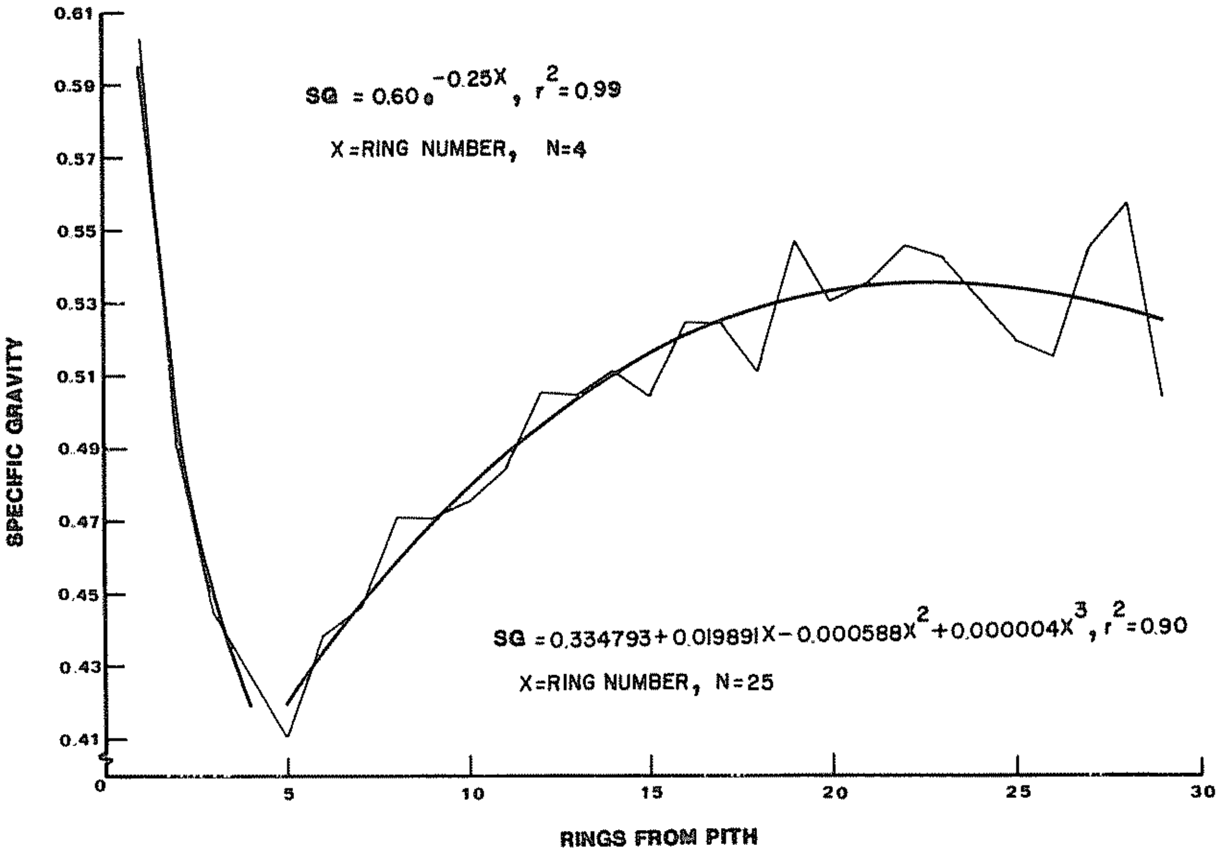

Fig. 1. Regression curves of radial variation in S.G. at 1.5 m.

Table 2. Radial variation of S.G. at 1.5 m.

Ring No. from pith	S.G.	CV	Ring No. from pith	S.G.	CV
1	0.602	33	17	0.524	9
2	0.491	36	18	0.51	11
3	0.445	31	19	0.547	11
4	0.427	19	20	0.530	13
5	0.411	13	21	0.535	12
6	0.439	11	22	0.546	5
7	0.446	12	23	0.542	14
8	0.471	8	24	0.530	14
9	0.470	10	25	0.518	13
10	0.475	8	26	0.516	13
11	0.483	8	27(14)	0.545	13
12	0.505	9	28	0.557	11
13	0.504	9	29(14)	0.503	20
14	0.511	7	30(12)	0.560	15
15(14)*	0.503	9	31(2)	0.470	22
16	0.524	10	32(1)	0.516	–

* Indicates number of observation if less than 15.

of change in S.G. with increasing height up the stem coincides with results reported here. It is likely that the increased density in the juvenile wood zone at the base of the stem is related to increased extractive deposition as suggested by Taras and Saucier (23) for a number of pines.

Regression analyses of pooled data combining rings 2 and 3, rings 14 and 15 and ring 24 and 25 were performed to produce predictive equations (Fig. 2). Linear regressions adequately described variation patterns for rings 14 and 15 and rings 24 and 25, but a polynomial gave the best fit for the curvilinear function of rings 2 and 3. In all three cases, height accounted for a significant portion of the variation in S.G.

Earlywood – Latewood Variation

Mean earlywood and latewood S.G. values for rings 2, 4, 8, 15 and 22 at 1.5 m height for the 15 trees along with their standard deviation(s) are shown in Table 4. Paired t-tests comparing mean earlywood and latewood values within each ring showed highly significant differences for rings 4, 8, 15 and 22. Simple linear regression analysis demonstrated that latewood S.G. significantly increased with increasing ring number while earlywood S.G remained rather constant, which is normal for pines.

The ratio of latewood to earlywood S.G. can be used to evaluate wood quality and, when large enough, can predict serious problems in utilization (11). For ocote pine, pooling of all the individual latewood and earlywood estimates produced a ratio of 1.2 to 1. This figure is lower than those reported for seven other pine species by Kollman and Côté (12) and concurs with Harris' (7) observation that the wood of ocote pine is even-textured in terms of the latewood – earlywood transition.

Branchwood Variation

Mean branchwood S.G. values for individual trees are presented in Table 5. The overall mean branchwood S.G., calculated from tree means, is 0.618 ± 0.028 with 95% confidence. A paired t-test showed this mean to be significantly different from the mean increment core density of 0.517. This finding is contrary to that of Phillips *et al.* (16), where the branchwood of four southern pines was significantly less dense than the stemwood. Table 5 shows that inner samples of branchwood have lower S.G. values than outer samples of branchwood. This implies that smaller diameter branches would have a lower S.G. than large diameter branches and agrees with previous observations (16).

Comparison of mean branchwood and stem S.G. as measured by increment core samples at 1.5 m height produced an insignificant correlation coefficient (r = 0.14, N = 15). However, our sample was small and our estimate on mean branchwood S.G. is not

Table 3. Longitudinal variation of S.G.

	Ring 2		Ring 3		Ring 14		Ring 15		Ring 24		Ring 25	
Hgt. (m)	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
0.0	0.600	26	0.503	25	0.518	16	0.544	10	0.550	11	0.555	9
1.5	0.491	36	0.445	31	0.511	7	0.505	9	0.551	10	0.539	14
3.0	0.485	19	0.415	20	0.505	10	0.518	10	0.530	14	0.533	13
4.5	0.498	29	0.422	29	0.478	12	0.496	7	0.506	12	0.525	11
6.0	0.445	28	0.409	23	0.471	8	0.488	8	0.489	11	0.494	11
7.5	0.437	34	0.387	32	0.460	10	0.462	7	0.483	9	0.489	13
9.0	0.401	20	0.363	10	0.508(11)	21	0.500(11)	15	0.478	12	0.484	10
10.5	0.378	20	0.384	10	0.507(4)	10	0.526(4)	10	0.487	14	0.487	13
12.0	0.363	16	0.377	12	0.611(1)	–	0.635(1)	–	0.477	12	0.491	12
13.5	0.370	16	0.373	10	0.564(1)	–	0.534(1)	–	0.466	9	0.466	10
15.0	0.371	22	0.392	14	0.510(1)	–	0.509(1)	–	0.467	10	0.454	12
16.5	0.363(9)*	10	0.387(9)	8	–	–	–	–	0.434(9)	9	0.462(9)	11
18.0	0.366(1)	–	0.456(1)	–	–	–	–	–	0.489(1)	–	0.507(1)	–
19.5	0.443(1)	–	0.421(1)	–	–	–	–	–	0.476(1)	–	0.496(1)	–
21.0	0.437(1)	–	0.416(1)	–	–	–	–	–	–	–	–	–
22.5	0.519(1)	–	0.561(1)	–	–	–	–	–	–	–	–	–

* Indicates number of observations if fewer than 15

precise since we made no attempt to estimate S.G. of the total branch. In any case, since even the inner branchwood S.G. is greater than stemwood S.G., it is concluded that branchwood is more dense than stemwood.

Discussion and Conclusions

This study examined the variation of unextracted wood S.G. in 15 ocote pine trees from Honduras. The mean tree density, as determined from increment core samples, is 0.517. This value compares favourably with estimates for other economically important pine species (8, 22, 24). Of possibly greater importance is how this density varies within the sample population. Larson (13) considers variation in wood character to be major problem for the wood industry.

The first level of variation to be considered here is that found among trees. The small population of this study was selected for homogeneity of age and form and originated from a uniform macro-environment. Under such conditions, among-tree S.G. values would be expected to be relatively consistent. S.G. ranged from 0.438 to 0.581, with the mean having a standard deviation of 0.039. Comparisons with findings for other pines are difficult; however, a broad review of the literature indicates that tree-to-tree variation in ocote pine is within normal limits.

Within-tree variation in S.G. has been found in many species, but only recently have researchers such as Echols (2) and Olson and Arganbright (14) attempted to quantify it. These authors have proposed the creation of uniformity factors to assess the internal homogeneity of S.G. for individual trees or species. An attempt was made to apply this method to ocote pine by Resch and Bastendorff (19). Their findings showed ocote pine to be slightly superior to *Pinus caribaea* Morelet, but they did not make an

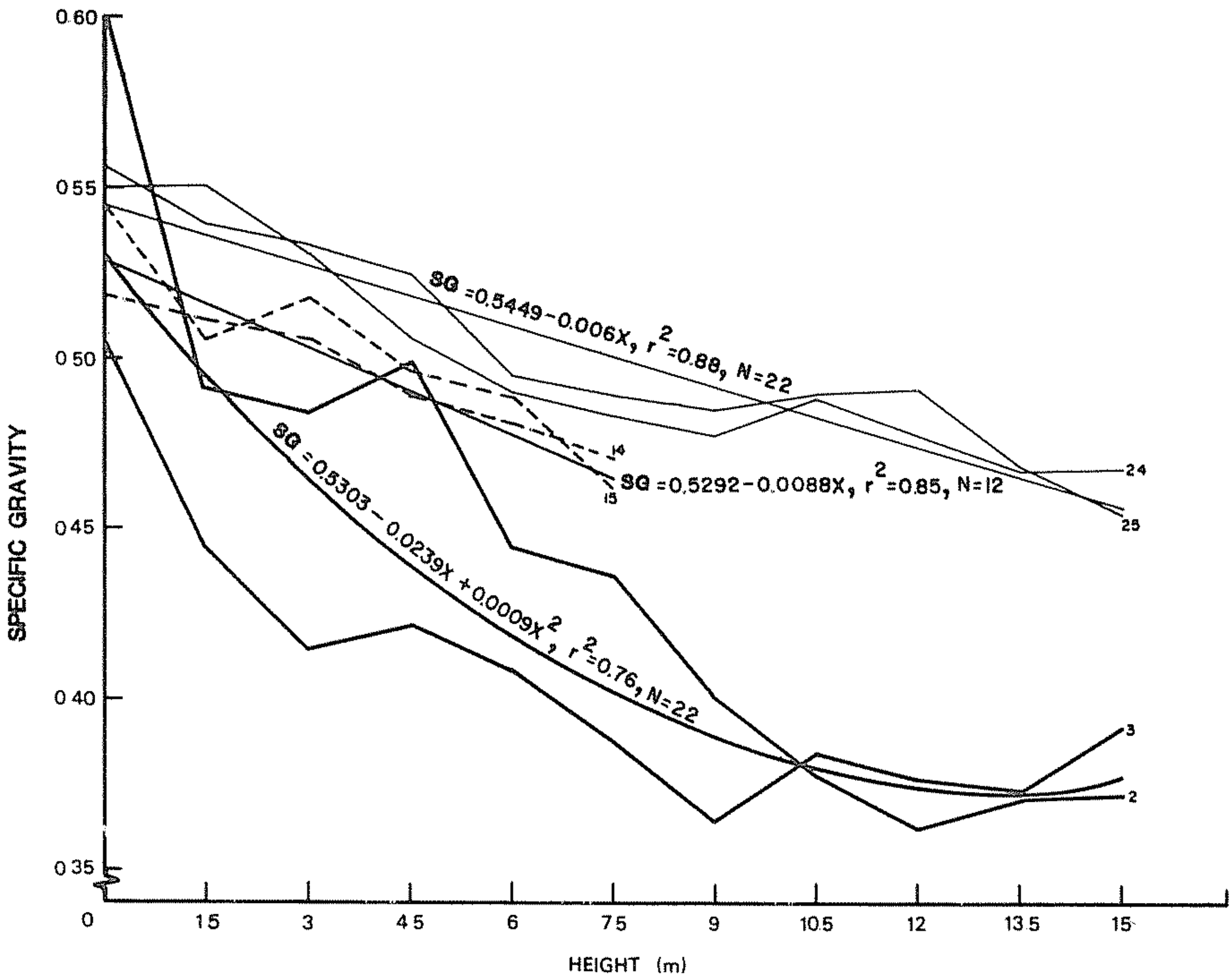

Fig. 2 Regression curves of longitudinal variation in S.G. for various ring pairs.

overall statement on qualitative wood uniformity. The present study did not directly measure intra-tree uniformity of S.G., but the latewood-earlywood transition indicates little variation within annual rings.

The overall pattern of variation in stem S.G. is similar to that described for other pines (3). It is concluded that the wood quality of ocote pine as determined from the analysis of wood S.G. is comparable to that of many other commercial pine species.

Table 4. Earlywood and latewood S.G. of various rings at 1.5 m height

Ring No.	Earlywood Mean	s	Latewood Mean	s	t-value
2	0.477	0.170	0.486	0.160	0.286
4	0.401	0.054	0.495	0.108	3.550**
8	0.425	0.070	0.562	0.086	5.875**
15	0.435	0.066	0.598	0.089	5.065**
22	0.450	0.080	0.583	0.077	10.221**

Tabular $T_{(0.01)}$, N = 15 is 2.977

Table 5. Branchwood S.G.

Tree No.	No. of samples	Inner mean	Outer mean	Overall mean
1	4	0.505	0.660	0.662
2	3	0.528	0.701	0.658
3	3	0.419	0.578	0.538
4	4	0.424	0.585	0.545
5	4	0.470	0.668	0.618
6	5	0.433	0.642	0.589
7	5	0.706	0.625	0.645
8	5	0.653	0.716	0.700
9	5	0.510	0.651	0.616
10	4	0.525	0.641	0.612
11	5	0.393	0.579	0.532
12	5	0.507	0.700	0.651
13	5	0.799	0.668	0.701
14	5	0.436	0.692	0.628
15	5	0.491	0.655	0.641

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