MOISTURE CONTENT VARIATION IN KILN-DRIED LUMBER FROM PLANTATIONS OF *VOCHYSIA GUATEMALENSIS*

Róger Moya†

Professor
Escuela de Ingeniería Forestal
Instituto Tecnológico de Costa Rica
Apartado 159-7050
Cartago, Costa Rica

Diana Aguilar Tovar

Student
Facultad de Ingeniería Forestal
Universidad del Tolima
B. Santa Helena A.A. 546
Ibagué, Colombia

Carolina Tenorio

Research Scientist
Escuela de Ingeniería Forestal
Instituto Tecnológico de Costa Rica
Apartado 159-7050
Cartago, Costa Rica

Brian Bond†

Professor
Department of Wood Science and Forest Products
Virginia Tech
Blacksburg, VA

(Received September 2010)

Abstract. *Vochysia guatemalensis* is planted across large areas of Latin America; however, a major problem with its use is the large variation in final moisture content (MC_f) after drying. This research studied the causes for high moisture content variation. Variables included the climate in which the tree was grown, the amount of heartwood, grain pattern within the piece, sample distance from the pith, and height of the log. The results showed that the initial moisture content (MC_i) ranged 110-280% and MC_f 10-17%. The variation in MC_i was attributed to climatic conditions, heartwood presence, grain pattern, and height of the log. Boards with a radial surface in width produced the highest MC_f. The MC_f of lumber tended to increase with distance from the pith, and sapwood had lower MC_f than heartwood. *V. guatemalensis* produced wet pockets in 42% of the dried boards.

Keywords: Fast-growth plantations, tropical species, wood quality, wet pockets.

INTRODUCTION

Vochysia guatemalensis Donn Sm. (Vochysiaceae), with the common name of cebo, mayo blanco, and guaruba in Spanish, and yemeri in English, is the most important native species in fast-growing plantations in Latin America, particularly Costa Rica. The wood has a low specific gravity (SG) of 0.35-0.45 with white sapwood and light reddish heartwood. It is used to make veneer for plywood and handicrafts (Solis and Moya 2004). *V. guatemalensis*

* Corresponding author: rmoya@itcr.ac.cr
† SWST member

© 2011 by the Society of Wood Science and Technology

plantations have high productivity; the species has the ability to grow in abandoned areas and contributes to agroforestry and silvopastoral systems, which assists in the current promotion of this species for reforestation of native species in Costa Rica (Calvo-Alvarado et al 2007). However, lumber from thinnings and clear-cuts of fast-growth plantations have been found to have severe drying defects and a large variation in final moisture content (MC_f) (Moya et al 2008).

This study examined the variation of moisture content in relation to climatic conditions of tree growth, position of the log in the tree, distance of the board from the pith, grain pattern (tangential and radial), and proportions of heartwood and sapwood.

BACKGROUND

Following proper drying procedures typically decreases drying defects and ensures MC_f uniformity (FPL 1999). Boone et al (1988) recommended a T2-D4 kiln schedule (Table 1) for approximately 28-mm-thick lumber in drying *V. guatemalensis* from native trees, and Moya et al (2008) have applied it to lumber from fast-growth trees. This schedule starts with a low temperature (38°C) and moderate RH (77%), and the initial humidity set point is reached using water evaporating from the wood rather than injecting steam. The problem associated with using the recommended schedule is the high variability of MC_f commonly found in dried lumber, which contributes to dimensional instability. This increases drying defects and thus decreases lumber value (Cai and Hayashi 2007). Literature suggests that the variation in MC_f in dried lumber may be related to different initial moisture content (MC_i) (Ofori and Brentuo 2005), drying schedules (Gu et al 2004), physical and chemical properties (Möttönen 2006), wood anatomy (Moya and Muñoz 2008), radial/longitudinal position of lumber in the trees (Ofori and Brentuo 2005), wetwood presence (Ward and Pang 1980), or harvest season (Möttönen 2006).

Information explaining the causes for MC_i variations in plantation-grown wood and of MC_f of *V. guatemalensis* lumber after kiln drying is limited. For example, Llach (1971) reported MC_i averages of 180 and 140% for trees from natural forests. Moya et al (2009) and Moya and Muñoz (2010) found MC_i averages of 150 and 180% for 8- and 10-yr-old trees from plantations, respectively. Other tropical species with similar SG (*V. guatemalensis* SG = 0.35) growing in plantation conditions also reported high values and high variability of MC_i. For example, species such as *Gmelina arborea* (SG = 0.40) and *Bombacopsis quinata* (SG = 0.32) reported an average 170% MC_i (140-180% range) and 160% (100-220% range), respectively (Moya et al 2009; Moya and Muñoz 2010). A large variation of MC_f in dried lumber of *V. guatemalensis* was found in previous studies (Moya et al 2008). The lack of uniformity in MC_f for dried lumber has also been found in wood from other tropical

Table 1. Characteristics of the fast-growth plantations of *V. guatemalensis* sampled for this study.

Characteristics	Parameters	Climatic conditions	
		Dry tropical	Wet tropical
Environmental conditions	Average temperature (°C)	21-31	20-25
	Average precipitation (mm/yr)	1620	2950
	Dry season	November-May	February-March
Plantation characteristics[a]	Tree age (yr)	8	8
	Plantation density (number/ha)	464	486
	Diameter at breast height (cm)	26 (4.7)[b]	26 (4.7)
	Basal area (m^2/ha)	26 (3.1)	26 (1.9)
	Tree height (m)	19 (1.2)	18 (2.8)
	Commercial height (m)	13 (2.5)	11 (3.8)
	Volume (m^3/ha)	215 (18)	212 (20)

[a] Obtained from two temporal trials established in sampled plantations.
[b] Standard deviation.

plantation species such as *Gmelina arborea* (Muñoz and Moya 2008).

MATERIALS AND METHODS

Plantations and Sampled Trees

Twenty *V. guatemalensis* trees were harvested from two 8-yr-old fast-growth tropical plantations. One plantation was located in the northern region of Costa Rica having a dry climate; the second was located in a wet climate. Detailed plantation characteristics and climatic conditions are shown in Table 1. Ten representative trees (each having an average diameter at breast height equal to the average for the plantation) were harvested as a second thinning in each plantation. The harvested trees had straight boles with normal branching. The north orientation was marked on each tree. From each tree, two 2.5-m logs were obtained, one from the tree base to 2.5-m height (lower log) and the other from 2.5- to 5.0-m height (upper log). The log ends were coated with paint to decrease moisture content loss and were quickly transported to a sawmill.

Sawing Pattern

Logs were sawn using a pattern to produce 25-mm-thick boards with the different orthotropic directions commonly used in Costa Rica for the furniture industry (Fig 1a) and edged.

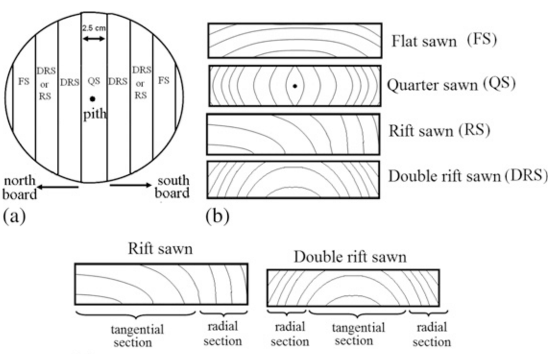

Figure 1. (a) Sawing pattern used to obtain lumber, (b) resulting grain patterns, and (c) radial and tangential sections in rift and double rift-sawn boards.

A description of this sawing pattern is given in Moya and Muñoz (2008). Each board was identified by the climatic condition, position of the log in the tree, radial distance from the pith, and tree number. A total of 112 boards from the north side of each log were used.

Moisture Content, Grain Pattern, and Heartwood Determination

The moisture content of all boards was determined before and after drying. Two 5-mm-thick samples with a cross-section of 20 mm were cut 0.3 m from the lower end of the boards; one was used to determine the MC_i and the other to classify the lumber according to the grain pattern. Thus, the boards to be kiln-dried were 2.15 m long. After drying, cross-sections were cut from the ends of boards for MC_f determination on an oven-dry weight basis using ASTM D4442-92, Method A (ASTM 2003).

The grain patterns for each sample were classified as flat sawn (FS), quarter sawn (QS), rift sawn (RS), and double rift-sawn (DRS) based on the cross-section (Fig 1b). The amount of heartwood was determined by scanning the 5-mm cross-sections, measuring the area of heartwood, and expressing it as a percentage of total area.

Drying Process and Moisture Content Control

Before each board was stacked for drying, a 10- to 15-mm-thick section was cut from the ends to eliminate end coating. The T2-D4 schedule (Boone et al 1988) for wood from natural forest was used (Table 2). Kiln samples were cut from the centers of six representative boards. These were placed at different heights in the package (1.0 m wide, 1.5 m high, and 2.5 m long) in a Nardi dry kiln (San Bonifacio, Italy). Moisture probes (pairs of 19-mm pins) were embedded in the remaining portions of the six boards located at different heights and values read with a resistance moisture meter. A computerized Leonardo system provided the control, using the probes as input for changing temperature and RH, while

Table 2. Kiln schedule used for drying *Vochysia guatemalensis* (Boone et al 1988).

Step	Dry-bulb temperature (°C)	Equilibrium moisture content (%)	Moisture content in wood (%)
Heating	35	14.8	— (2)[a]
Drying	38	14.3	50 (2)
	38	11.9	45 (2)
	38	11.2	35 (2)
	43	10.5	30 (2)
	44	7.6	30 (2)
	49	5.5	25 (1)
	55	4.0	20 (1)
	66	3.2	15 (1)
	66	3.2	12 (1)
Equalization	66	3.2	12 (2)
Conditioning	60	3.5	—
Cooling	30	3.5	—

[a] Number in parenthesis is time (h) that climate conditions were maintained in the kiln after the moisture content in the schedule was reached and before the next stage.

the kiln samples were used to determine schedule steps. Kiln samples were weighed twice per day, and the values from the probes were continuously recorded. The target moisture content was 12% based on the anticipated equilibrium moisture content (EMC) in the main zone of Costa Rica (Meseta Central), which is 10-14% (Tuk 2007). Air velocity was 2.5 m/s and air reversal was done every 2h.

Wet Pocket Determination

After drying, each board was evaluated for the presence of wet pockets (WP) by cutting a 1.5-2.0 mm-thick cross-section 0.3 m from the end of each board that was originally located near the butt of the tree. This end was used for observation because it was closest to where MCi was measured. Thin cross-sections were inspected against light for the presence or absence of WP according to methodology suggested by Coutts and Rishbeth (1977). When a WP was present in dried boards, it was outlined and its location identified as from the tangential or radial section (Fig 1c). A digital photograph was taken before oven-drying and WP area was determined using Image Tool Software® (San Antonio, TX) (Health Science Center 2009).

Statistical Analysis

Before the data were analyzed using analysis of variance or regression analysis, it was necessary to verify normality and homogeneity of variance. The UNIVARIATE procedure of the SAS System (SAS Institute Inc, Cary, NC) was used to test assumptions for the analysis of variance. It was determined that data transformations were necessary because of the existence of outliers in the data and a positive skewness test ($\alpha < 0.05$). $X^{1.5}$ and X^{-2} transformations were applied for MC_i and MC_f, respectively. A mixed linear model was used in the analysis of variance for MC_i, and split-plot design was used in MC_f. The model included the following sources of variation: part of tree (lower log/upper log), climate type, grain pattern, distance from pith, and heartwood percentage for MC_i. In addition to these variables, the percentage of WP area and schedule were included in MC_f analysis and part of tree, climate type, and grain pattern were randomly assigned to split plots within each drying schedule (random effects). Second-order interactions were included in the model. The statistical difference between two means was established by Tukey's test. The GLM procedure of SAS was used to estimate the significance of sources of variation for MC_i, and PROC Mix was used to estimate the significance in MC_f. SAS (Statsoft Inc, Tulsa, OK) programs were used for the statistical computations.

RESULTS AND DISCUSSION

The actual kiln temperatures and EMC are shown in Fig 2. EMC values were determined by the average of the six moisture probes.

Initial Moisture Content

Table 3 shows the average MC_i for all variables, which was 160%, with a large variation (120-180%). Analysis of variance showed that MC_i was significantly affected by log height, climatic conditions, heartwood presence, and sawing pattern (Table 4), but interactions among different

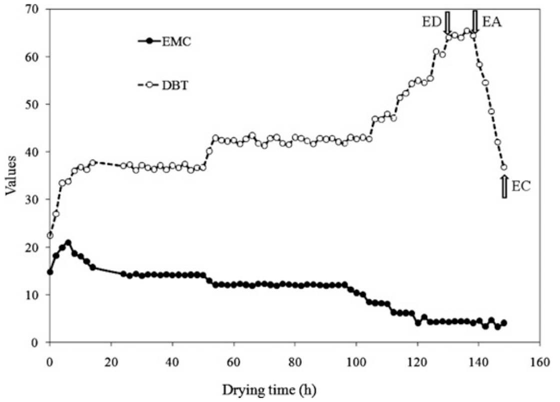

Figure 2. Variation of dry bulb temperature (DBT, °C) and equilibrium moisture content (EMC, %) for the T2-D4 schedule used in drying *V. guatemalensis*. ED, end of drying; EA, end of conditioning; EC, end of cooling.

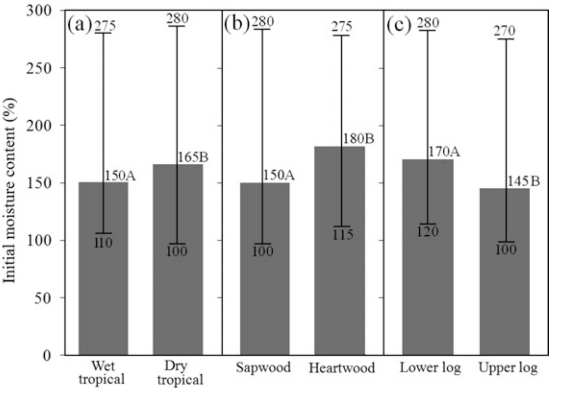

Figure 3. Variation of initial moisture content relative to (a) climatic condition, (b) sapwood and heartwood, and (c) position in the tree.

Table 3. Initial (average and range) and final (average and range) moisture content of *V. guatemalensis* lumber.

Condition	Initial moisture content (%)	Final moisture content (%)
All boards	160	12
	120-180 (41)[b]	10-17 (3)
Kiln samples[a]	150	12
	130-170 (17)	10-14 (2)

[a] Moisture content monitored with six kiln samples at different locations.
[b] Standard deviation.

Table 4. Analysis of variance for initial moisture content (MC_i) and split-plot design of final moisture content (MC_f) in *V. guatemalensis* kiln-dried lumber (N = 112).

Source	DF	MC_i	MC_f
Log location	1	23.42**	0.33
Climate	1	12.53**	0.48
Heartwood presence	1	6.70*	0.41
Sawing pattern	3	0.04*	3.41*
Distance from pith	1	0.38	21.38**
Wet pockets	1	—	7.60*
Climate × grain pattern	2	3.02	1.35
Climate × heartwood presence	1	0.85	0.49
Log location × heartwood presence	1	1.14	1.61
Log location × grain pattern	2	0.19	2.01
Log location × climate	1	0.00	0.71
Grain pattern × heartwood presence	2	0.01	0.26

* Statistically significant at $\alpha = 0.05$.
** Statistically significant at $\alpha = 0.01$. df, degrees of freedom.

factors were not statistically significant. The MC_i results were similar to other studies using natural forest and plantation trees (Llach 1971; Moya et al 2009; Moya and Muñoz 2010.

Log height had a statistically significant effect on MC_i (Table 4). Lumber from lower or basal logs had higher MC_i than lumber from logs located 2.5-5.0 m high for different climatic conditions (Fig 3c). The difference of MC_i with the log height (lower or upper) is caused by water requirements for physiological processes at different heights (Zobel and Van Buijtenen 1989).

Although MC_i of lumber from a dry climate was greater than that of wood from a wet climate, a large variation was found in both climatic conditions (Fig 3a). The climatic difference can be attributed to anatomical features caused by different ecological or soil conditions (Zobel and Van Buijtenen 1989; González and Fisher 1998). High vessel frequency produced in trees growing in the dry condition produces more void space than does the wet condition, permitting more water to be contained in green wood.

MC_i was not significantly related to radial distance from the pith (Table 4; Figs 4a and 4b). However, values greater than 200% were found for samples that were 20-60% of the distance from pith to bark (Fig 4a). At these distances, the majority of the sample was heartwood. Higher values of MC_i with heartwood content confirm the hypothesis that MC_i increases with increasing heartwood area in cross-section for any climatic condition. Therefore, the average MC_i of boards containing all heartwood was

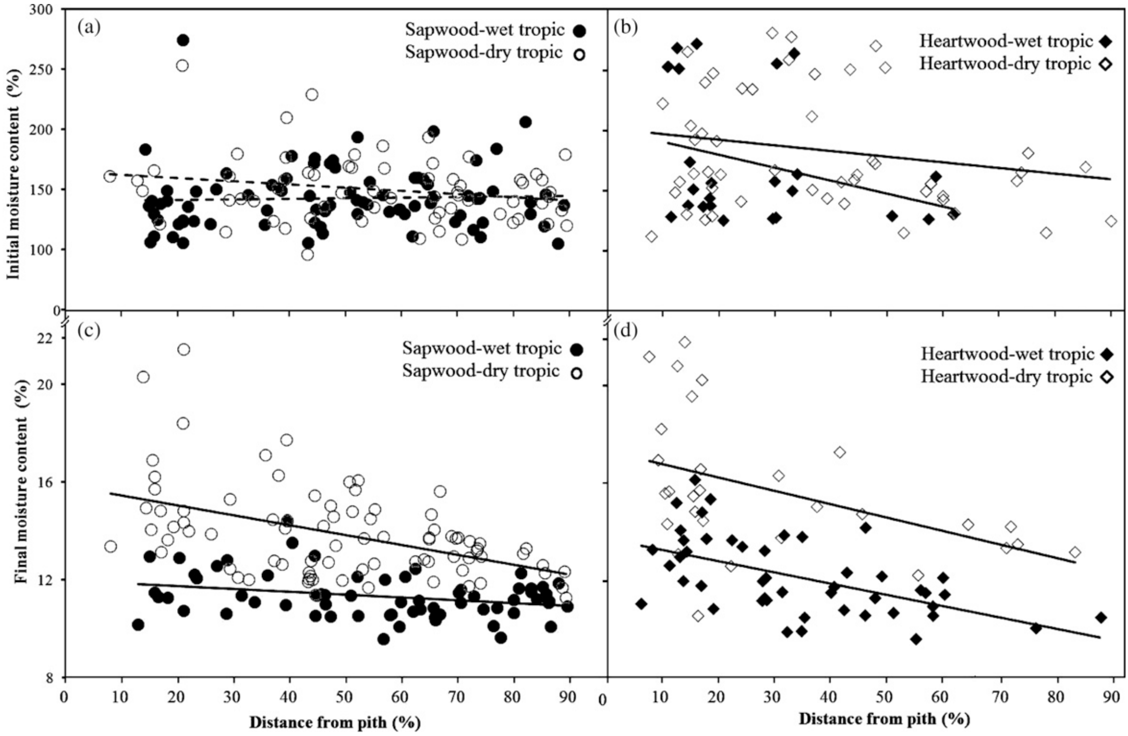

Figure 4. Variation of (a) initial moisture content (MC) and (b) final MC relative to pith distance for sapwood and heartwood.

statistically greater than the average MC_i of boards containing all sapwood (Figs 3b and 4b).

Higher MC_i values in heartwood than sapwood of *V. guatemalensis* is less common in many other species, although it also occurs in *Gmelina arborea*, *Cedrela odorata*, *Acacia mangium*, and *Acacia auriculiformis* (Yamamoto et al 2003; Ofori and Brentuo 2005; Moya and Muñoz 2008). However, for temperate species, MC_i of sapwood is usually higher than in heartwood, especially in species with lower SG and in softwoods (Skaar 1972). However, some other factors can affect this relationship. For example, WP presence can produce higher moisture content in heartwood than in sapwood.

Another characteristic of *V. guatemalensis* that led to increased high MC_i was the amount of juvenile wood in the samples. Juvenile wood, with thinner cell walls and larger lumens (Zobel and Sprague 1998), leads to higher MC_i, which is not affected by distance from pith, because the same void spaces exist across the section. This was shown by Butterfield et al (1993) who studied the anatomical features of *V. guatemalensis* and determined that wood density, diameter of vessels, and pore frequency were stable across the distance from the pith and in heartwood and sapwood.

Final Moisture Content

Total drying time was 150 h and the average MC_f was 12% for all boards with a range of 10-17% (Table 3). The variation agrees with previous studies on this species (Moya et al 2008) and other tropical plantation species (Muñoz and Moya 2008) and is considered acceptable (FPL 1999). Analysis of variance showed that MC_f was significantly affected by grain pattern, radial distance from the pith, drying schedule, and WP area (Table 4). However, there were no significant differences in climatic conditions, log height, or heartwood presence for average MC_f. There was not a large difference in average MC_f between kiln samples and all boards.

MC_f in boards originating close to the pith was higher than boards near the bark (Figs 4c and 4d), therefore boards produced near the pith will have a high MC_f if they are dried in the same batch as those from outer wood. These results are similar to that of other tropical plantation species such as *Gmelina arborea*, *Cedrela odorata*, *Acacia mangium,* and *Acacia auriculiformis* in which it was found that higher values of MC_f were found in boards near the pith and that the moisture content decreased with distance from the pith (Yamamoto et al 2003; Ofori and Brentuo 2005; Moya and Muñoz 2008). The tendency of sapwood to reach a lower MC_f than heartwood regardless of the distance from the pith is explained by water movement rates. The presence of extractives or other substances in the lumens of vessels or fibers of heartwood limits vapor flow or water diffusion during drying (Skaar 1972). However, if uniform MC_f is the goal, the kiln should be set to a predetermined EMC level and left long enough for heartwood and sapwood to equalize regardless of the diffusion rate.

Another important finding was that dried lumber of *V. guatemalensis* included WP, which were found in 42% of the 112 boards and had large variations in area and shape. WP are zones with higher than average moisture content that can extend for a large portion along the width and length of a board (Anon 2001). MC_f of the cross-sections varied 10-17%. Dried boards with DRS, QS, and RS grain patterns had 28, 8, and 6% WP, respectively, but WP were not present in FS pattern boards. It was also found that WP presence was not related to log height, radial distance from pith, or climatic condition. Heartwood or sapwood had no effect on WP presence; 14% of boards with WP had 100% sapwood and 28% of all boards with WP had some portion of heartwood. Figure 5 shows typical WP in a board with both tangential and radial sections. It was possible to observe WP in radial and sapwood sections of a board, but they did not extend into the tangential sections that contained heartwood. The results agree with that reported for *G. arborea* (Moya and Muñoz 2008), in which lumber produced with radial grain patterns (QS, RS, and DRS) had MC_f that varied 15-35%. Moya and Muñoz (2008) mentioned two possible explanations for WP formation: high levels of capillary forces during the initial drying process producing aspiration of pits in radial sections and water movement in areas with radial orientation that occurs mainly through the fiber pits, which are scarce and minute, causing slower diffusion rates.

The impact of grain pattern on MC_f (Table 5) can be explained by anisotropic water movement

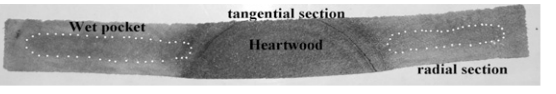

Figure 5. Wet pockets in dried wood of *V. guatemalensis* for double rift-sawn boards.

Table 5. Average and range of final moisture content (MC_f) for different variables in kiln-dried *V. guatemalensis* lumber.

Variable	Subvariable	MC_f
General average		12
		10-17 (1.4)[a]
Climate	Wet tropical	12A[b]
		10-14 (1.0)
	Dry tropical	12A
		10-17 (1.7)
Log position	Lower	12A
		10-14 (1.1)
	Upper	12A
		10-17 (1.6)
Type of wood	Sapwood	12A
		10-17 (1.2)
	Heartwood	12A
		10-16 (1.6)
Grain pattern	QS	13B
		11-15 (1.0)
	DRS	12A
		10-17 (1.4)
	RS	14B
		12-15 (1.7)
	FS	11A
		10-12 (0.7)

[a] Standard deviation.
[b] Means with the same letter within each column and variable are not significantly different at $p = 0.05$ according to Tukey's test.
QS, quarter sawn; DRS, double rift-sawn; RS, rift sawn; FS, flat sawn.

caused by different orientations of wood cells. In the tangential direction, from center to surface, vapor or water diffuses through rays, whereas in the radial direction, the movement occurs through fiber pits, which are generally on the radial face. Water movement in this direction results in FS boards drying faster than QS boards (Anon 2001) if all boards are dried in the same batch. Therefore, FS boards reach lower MC_f than QS, RS, or DRS boards. On average, MC_f in QS and DRS boards was statistically higher than that of FS or RS boards.

One recommendation to decrease the variation in MC_f for different grain patterns and heartwood is to separate boards with tangential grain (FS) from radial (QS, RS, or DRS) and heartwood from sapwood. With appropriate board separation, we can probably also decrease energy consumption, drying time, and labor cost. However, these suggested separations would be expensive and impractical in some sawmills, especially small ones. A practical alternative is to use kiln samples that include the different grain patterns present, but the samples should reflect relative amounts of the QS and FS in a charge. Therefore, the moisture content average for controlling the charge would be determined by the QS boards, which generally dry more slowly than FS boards (Anon 2001).

CONCLUSIONS

Green lumber samples of *V. guatemalensis* from fast-growth tropical plantations were found to have high MC_i (160%) with a large range (120-280%). MC_i of lumber did not vary when sampled from pith to bark but did vary with tree height with lower logs having higher MC_i than upper logs. Wood from dry climates had a higher MC_i than wood from humid climates. Heartwood had a higher MC_i than sapwood. The highest values of MC_f were found in boards that were cut from near the pith, were QS, and contained heartwood.

The high variability of MC_f found for *V. guatemalensis* produced from plantations is an important finding because it is vital for commercial applications to have acceptable drying processes. Results indicated that separating lumber for drying based on the distance from the pith, lumber produced from the lower or upper part of the tree, and heartwood and sapwood should improve MC_f uniformity, thus producing a dried raw material with better quality for both furniture and construction.

ACKNOWLEDGMENTS

We thank the Vicerrectoría de Insvestigación y Extensión of Instituto Tecnológico de Costa Rica, for financial support and Precious Woods of Central America (MACORI), and the Escuela de Agricultura de Trópico Húmedo (EARTH) for providing the raw materials and facilities for this study.

REFERENCES

Anon (2001) Dry kiln operator's manual handbook. Ag Handb 188. USDA For Serv Forest Prod Lab, Madison, WI.

ASTM (2003) D 4442-92. Standard test methods for direct moisture content measurements of wood and wood-based materials. American Society for Testing and Materials, West Conshohocken, PA.

Boone RS, Kozlik CJ, Bois PJ, Wengert EM (1988) Dry kiln schedules for commercial woods—Temperate and tropical. Gen Tech Rep FPL-GTR-57 USDA For Serv Forest Prod Lab, Madison, WI. 158 pp.

Butterfield RP, Crook RP, Adams R, Morris R (1993) Radial variation in wood specific gravity, fiber lengths and vessel area for two Central American hardwoods: *Hyeronima alchornoides* and *Vochysia guatemalensis* natural and plantation-grown trees. IAWA J 14:153-162.

Cai Y, Hayashi K (2007) New monitoring concept of moisture content distribution in wood during RF/vacuum drying. J Wood Sci 53:1-4.

Calvo-Alvarado JC, Arias D, Ritcher DD (2007) Early growth performance of native and introduced fast growing tree species in wet to sub-humid climates of the southern region of Costa Rica. For Ecol Mgmt 242:227-235.

Coutts MP, Rishbeth J (1977) The formation of wetwood in grand fir. Eur J Forest Pathol 7:13-22.

FPL (1999) Wood handbook: Wood as an engineering material. Gen Tech Rep FPL-GTR-113. USDA For Serv Forest Prod Lab, Madison, WI. 463 pp.

González D, Fisher R (1998) Variation in selected wood properties of *Vochysia guatemalensis* from four sites in Costa Rica. Forest Sci 44:185-191.

Gu H, Young TM, Moschler WW, Bond BH (2004) Potential sources of variation that influence the final moisture content of kiln-dried hardwood lumber. Forest Prod J 54(11):65-70.

Health Science Center (2009) Image tools. Texas University–San Antonio. http://ddsdx.uthscsa.edu/dig/download.html (15 February 2009).

Llach L (1971) Propiedades físicas y mecánicas de ciento trece especies maderables de Panamá. Parte 3: Laboratorio de Productos Forestales. Universidad de Costa Rica, San José, Costa Rica. 130 pp.

Möttönen V (2006) Variation in drying behavior and final moisture content of wood during conventional low temperature drying and vacuum drying of *Betula pendula* timber. Drying Technol 24:1405-1413.

Moya R, Leandro L, Murillo O (2009) Wood characteristics of *Terminalia amazonia, Vochysia guatemalensis* and *Hyeronima alchornoides* planted in Costa Rica. Revista Bosques 30:78-87.

Moya R, Muñoz F (2008) Wet pockets in kiln-dried *Gmelina arborea* lumber. J Trop For Sci 20:48-56.

Moya R, Muñoz F (2010) Physical and mechanical properties of eight species growing in fast-growth plantations in Costa Rica. J Trop For Sci 22(3):317-328.

Moya R, Urueña E, Muñoz F (2008) Modulation of moisture content in conventional kiln of wood from fast-growing tropical species in plantation. Paper AP-7, 7 pp. *In* Proc 2008 SWST International Annual Convention, November 10-12, 2008, Concepcion, Chile. Society of Wood Science and Technology, Madison, WI. ISBN #978-0-9817876-0-2.

Muñoz F, Moya R (2008) Moisture content variability in kiln-dried *Gmelina arborea* wood: Effect of radial position and anatomical features. J Wood Sci 54:318-322.

Ofori J, Brentuo B (2005) Green moisture content, basic density, shrinkage and drying characteristics of the wood of *Cedrela odorata* grown in Ghana. J Trop For Sci 17:211-223.

Skaar C (1972) Water in wood. 1st ed. Syracuse University Press, Syracuse, NY. 218 pp.

Solis M, Moya R (2004) *Vochysia guatemalensis* en Costa Rica. FONAFIFO. Ministerio de Energía y Minas. Gobierno de Costa Rica, San José, Costa Rica. 107 pp.

Tuk J (2007) Maderas, Diseño y Construcción. 1st ed. Colegio Federado de Ingenieros y de Arquitectos de Costa Rica, San José, Costa Rica. 235 pp.

Ward JC, Pang WY (1980) Wetwood in trees: A timber resource problem. Gen Tech Rep PNW-GTR-112. USDA Pacific Northwest Forest Range Exp Stn, Portland, OR. 87 pp.

Yamamoto K, Sulaiman O, Kitingan C, Choon L, Nhan N (2003) Moisture distribution in stems of *Acacia mangium, A. auriculiformis* and hybrid acacia trees. Jpn Agric Res Q 37(3):207-212.

Zobel BJ, Sprague JR (1998) Juvenile wood in forest trees. Springer-Verlag, Heidelberg, Germany. 300 pp.

Zobel BJ, Van Buijtenen B (1989) Wood variation: Its causes and control. Springer-Verlag, New York, NY. 458 pp.